MOTT MACDONALD

SSW Synthetic Drought Series

4 October 2018

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Issue and Revision Record

Revision	Date	Originator	Checker	Approver	Description
A	April 2017	Christopher Rhodes	David Ocio	Peter Ede	First issue
B	August 2017	Christopher Rhodes	David Ocio	Peter Ede	Updated report references
C	October 2018	David Ocio	Peter Ede	Peter Ede	Additional section on drought duration

Document reference: 377769 | 02 | C

Information class: Standard

Contents

1 Introduction

1.1 Background

As part of its 2019 Water Resources Management Plan (WRMP), South Staffordshire Water (SSW) need to assess the response of the supply system to more severe droughts than those observed in the historical records. This project aligns closely with similar work undertaken by Mott MacDonald (MM) for Severn Trent Water Ltd (STWL), and benefits from cooperation between the two water companies regarding the data used and methodologies followed.

SSW want to use their Aquator resources model to:

- Check the resilience of their supply system to severe droughts; and
- Estimate the impact of severe droughts on the Deployable Output (DO)

Mott MacDonald's role for this report is to define characteristic extreme droughts with a range of different return periods, and model the simulated flows for input to Aquator.

To define the severe droughts, Mott MacDonald has been provided with 200 stochastic precipitation and potential evapotranspiration time series which are representative of the period from 1918 to 1990. These are used to generate river flows using recently recalibrated HYSIM hydrological models for upstream and downstream of Blithfield reservoir (Mott MacDonald, 2017a). A sub-set of these are selected by defining a 200-year and 500-year drought event using historical data and searching the synthetic scenarios for the closest drought event. The selected scenarios are then to be used as inputs in Aquator, which will be reported on separately.

1.2 Objectives

The objective of the project was to define a selection of droughts to test the resilience of the supply system against more severe droughts than in the historical record. This includes the following tasks:

- To verify the received 200 stochastic precipitation (P) and potential evapotranspiration (PET) time series;
- To undertake HYSIM modelling using the P and PET series for each of the catchments used in the SSW Aquator model;
- To define a library of droughts from the generated flow series with target return periods of 200 and 500 years;
- Select a sub-set of the synthetic droughts for 200 and 500-year return period events (using the historical data as a target); and
- To report on the work undertaken.

1.3 Report structure

The report is structured as follows:

- Section 2: Rainfall and PET verification.
- Section 3: Procedure for modelling using HYSIM.
- Section 4: Methodology and results of the drought selection process.
- Section 5: Summary.

2 Verification of stochastic rainfall and PET

Droughts that are more severe than previously recorded can be developed using a stochastic approach to generate a range of potential weather scenarios, and hence alternative drought patterns, that can be modelled and tested against water supply systems to check their resilience. If a large number of stochastic series are generated it is possible to select severe drought events (including ones more severe than any in the historical record), and to assign estimated return periods to those events using statistical analysis.

For this project, a stochastic weather generator has been used to derive 200 sets of 73-yr (1918-1990) daily and monthly rainfall and PET series; one for each of the Blithfield catchments. This part of the project was undertaken by Atkins for STWL, with the stochastic series provided by Atkins to MM. An agreement between STWL and SSW has allowed SSW to access this data. Details of the weather generator and its use are the subject of a separate report by Atkins; at the time of writing this Atkins report was not available, but the MM team has an understanding of the processes through discussions with Atkins on this and other projects.

Before using the rainfall and PET series to generate river flows, a verification of their suitability was conducted and is reported here. All analyses reported here have been completed with the monthly time series produced by the stochastic weather generator. (The daily series are subsequently produced by selecting the temporal daily distribution of the historical month with the closest monthly rainfall total.)

2.1 Rainfall

The stochastic rainfall series have been combined and analysed for the upstream and downstream Blithfield catchments, labelled in the model as BL-UPS and BL-DWS respectively. The following monthly statistics have been obtained and compared with those derived from the historical record from 1918-1990:

- Mean
- Standard deviation
- Skewness
- Lag-1 autocorrelation

Lag-1 autocorrelation is the correlation of values separated by 1 time step, in this case 1 month. Results for all four of the above measures are shown in Figure 1 and Figure 2.

Figure 1: Blithfield Upstream average monthly rainfall statistics.

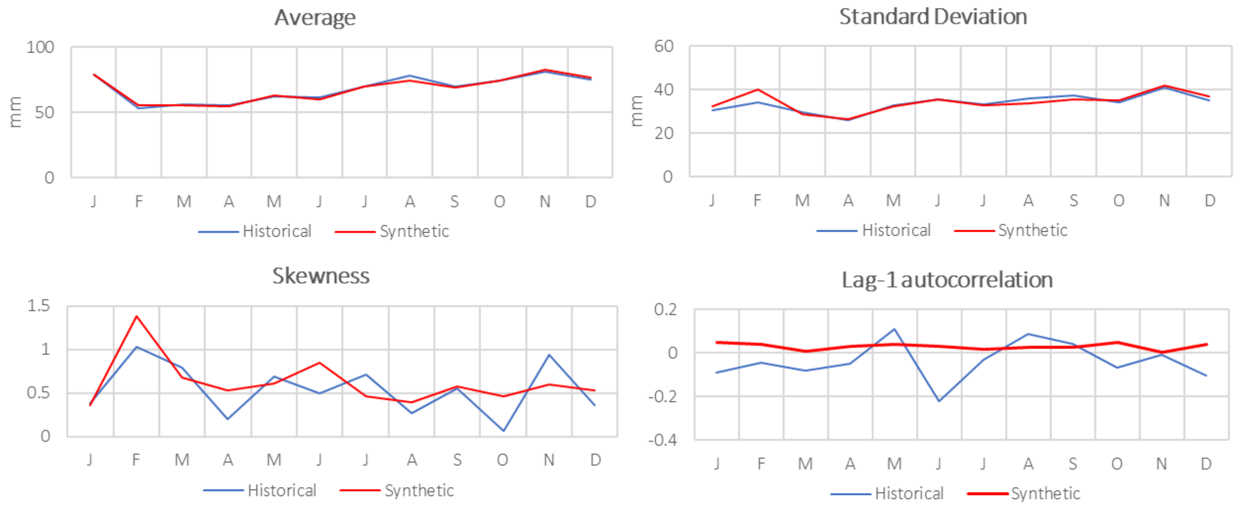
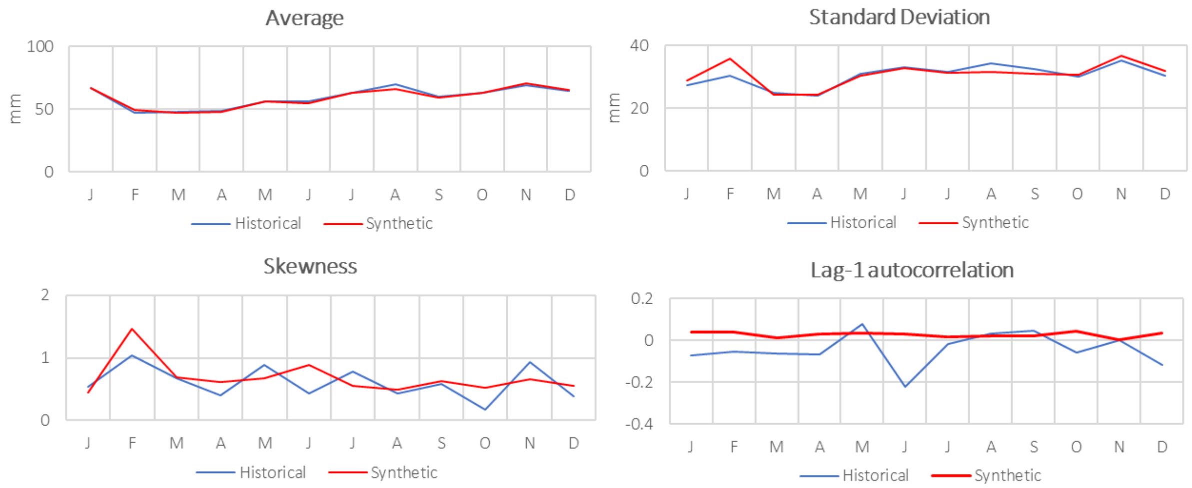


Figure 2: Blithfield Downstream average monthly rainfall statistics.



The analysis shows that there is an excellent match between the stochastic and historical series in terms of monthly average and standard deviation, which is a direct consequence of the stochastic weather generator being fitted to those statistics. There are some discrepancies in the skewness of the stochastic and historical series; the series have a similar annual average (mean of the 12 monthly values), but there is less variation in the stochastic series skewness, which can be attributed to the skewness being averaged across the 200 stochastic scenarios, increasing the chances of smoothing.

The autocorrelation shows a distinctive behaviour in the historical series which is not replicated in the stochastic series. The historical record typically displays higher negative values in June, reflecting the start of the drier season (compared with May), while during the summer and early autumn, monthly values are positively correlated as a reflection of the typical persistence of dry conditions. The autocorrelation values of the stochastic series are less variable and usually slightly greater than 0. This weak positive correlation can be explained by the way the weather generator works. The stochastic model (Autoregressive Moving Average algorithm) that provides the random component of the weather generator is fitted independently to each month of the year, and therefore, rainfall is generated for each month without considering the modelled value during the antecedent months. The deterministic component of the weather generator (regression between rainfall and climatic indices such as the North Atlantic Oscillation, the East Atlantic variability and sea surface temperatures) then introduces some seasonal, albeit weak, autocorrelation, that can account for persistence of wet/dry conditions.

The occurrence of persistent dry conditions in the stochastic series, such as those leading to severe droughts, is therefore dependent on the randomness of the monthly generation with some tendency to replicate past drought durations (e.g. 1975-76). As a result, the weather generator typically produces wetter annual conditions than the observed record because consecutive months are not effectively correlated. Hence, the weather generator finds it difficult to represent the extreme droughts that occur when dry conditions persist over time. To reflect this, a bias correction is introduced (within the weather generator) to regionally reduce rainfall in the driest periods to make them more severe.

The effectiveness of this bias correction can be observed by looking at the number and distribution of wet/dry years in each rainfall sequence. Wet or dry years are defined as those with above or below average rainfall. The following table presents the maximum number of consecutive wet/dry years, as well as the percentage of wet years in the series. In general, there is a good correspondence between the stochastic and historical series, something that can be attributed to the application of the same historical evolution of climate indices in the generation of stochastic rainfall.

Table 1: Dry and wet year characteristics for the Blithfield catchments

Catchment	Series	Proportion of wet years	Max No. of consecutive wet years	Max No. consecutive dry years
BL-UPS	Historical	0.37	6.0	4.0
	Stochastic	0.49	5.8	5.8
BL-DWS	Historical	0.36	12.0	4.0
	Stochastic	0.49	5.8	6.1

The bias correction allows more extreme droughts to be simulated, which provides enough examples for the drought library of extreme droughts (200 and 500-yr return periods) required for SSW to check the resilience of the supply system. However, when considering the whole stochastic data set as representative of long-term weather conditions it must be remembered that the frequency of dry periods in the sequence has been artificially altered.

There is another relevant issue for the interpretation of the results. Because all 200 datasets have been generated with the same historical evolution of climatic indices, they are weakly correlated. Therefore, despite the randomness of the weather generator, there are more chances of experiencing a wet year in 1967 or a dry year in 1921 (for example). This can be seen in Figure 3 and Figure 4 which show the median and 95% confidence intervals of the annual rainfall of the 200 datasets alongside the historical rainfall.

Figure 3: Percentile and historical rainfall series 1918-1990 at Upstream Blithfield.

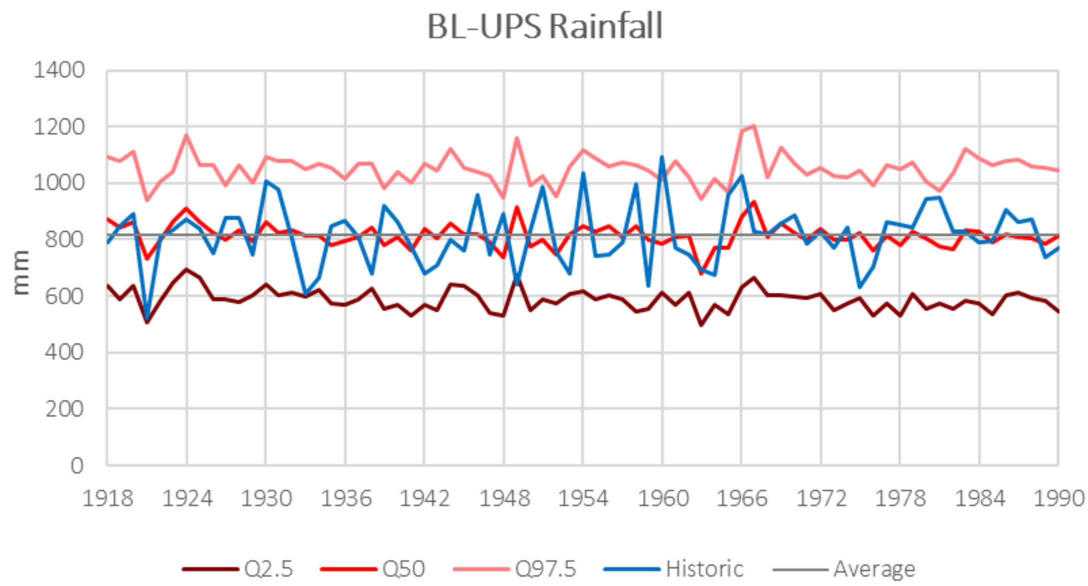
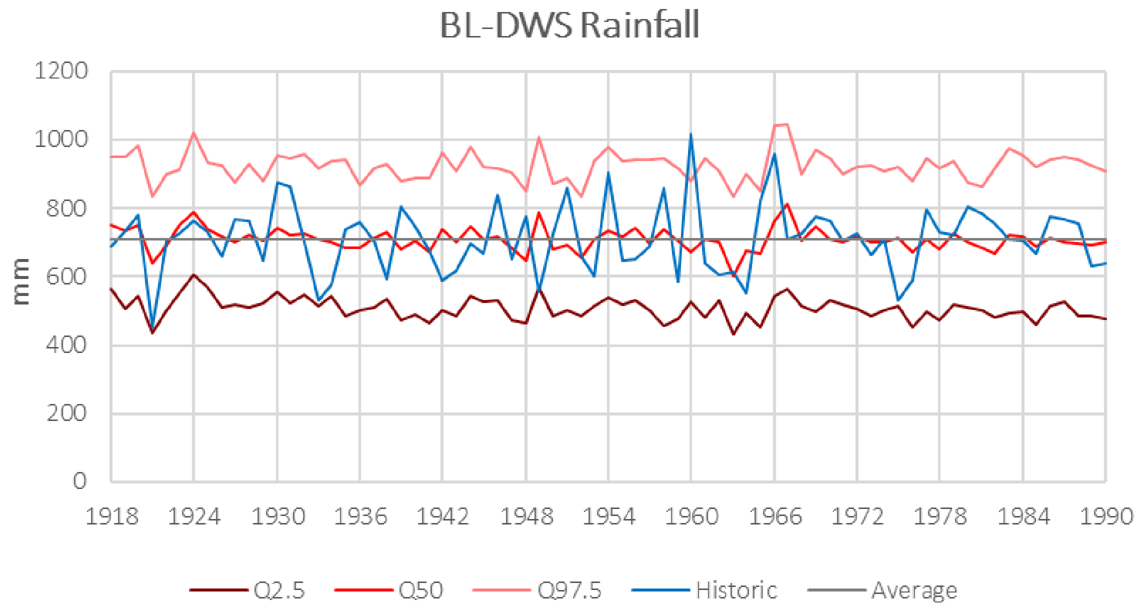


Figure 4: Percentile and historical rainfall series 1918-1990 at Downstream Blithfield.



The use of common climate indices across all 200 stochastic rainfall series mean that each 73-year dataset should be considered as an alternative rainfall scenario during 1918-1990 given the same historical climatic conditions. Consequently, combining all datasets in a single long series for obtaining extreme statistics is not recommended.

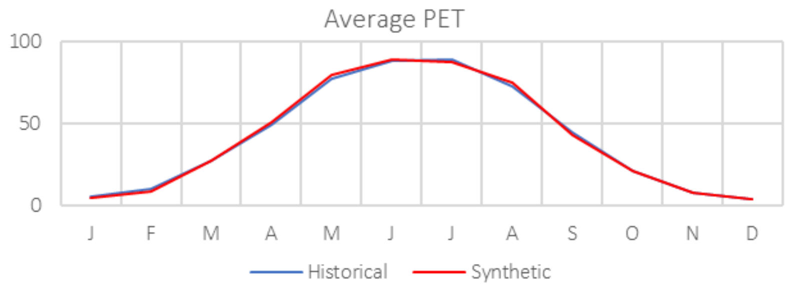
2.2 PET

The stochastic PET series were derived from the historical record by sampling the data from 1961-90 to select the PET with the closest monthly rainfall. The historical PET data covers a shorter period than the rainfall series (1918 – 1990) because the PET data is more reliable after 1961 (due to the introduction of MOSES by the Met Office) than prior to 1961. (However, review of the PET series showed that the characteristics of the full data set were not significantly different from those of the post-1960 data.) This selection process was used to generate 200 PET time series to accompany the rainfall from 1918 to 1990.

The stochastic and historical PET series have been compared as part of this verification process. Average monthly values have been compared satisfactorily for all catchments analysed (Figure 5).

It should be noted that the PET series (unlike the rainfall) have not been generated using a model, but were taken from the historical record. The selection of a PET value based on the monthly rainfall value implies correlation between rainfall and PET, but it should be noted that although there is a tendency for low rainfall to be associated with high PET (in dry summers) the correlation is not particularly strong. Nevertheless, the sampling approach is considered reasonable for use in the stochastic series.

Figure 5: Average monthly PET for BL-UPS and BL-DWS



2.3 Conclusions

The stochastic rainfall and PET series are able to represent the monthly weather of the area of interest, and after a bias correction (due to lack of a strong persistence component) can provide different extreme drought episodes. However, their use and interpretation must consider some limitations in the generation algorithm, as outlined above.

For the purpose of checking the resilience of the system and given the interdependency of each 73-yr run, the synthetic flows should not be used as a whole to build a long record from which statistics can be obtained. The selection of extreme droughts (in relation to the flow during a defined duration) should instead be based on statistical analysis of the historical record of simulated flows (1884-2014) as they provide a much longer record than any synthetic run, enabling a more reliable extrapolation to high return periods. The selection is explained in Section 4.

Although the analysis for the weather generator was limited to data up to 1990 (because of the view that post-1990 data may include some effects of climate change, and 1961-90 is the baseline for climate change scenarios), the full period was used for flows as the Mann-Kendall tests undertaken during the historical extension project indicate that the historical series show no evidence of climate change from pre-1990 levels.

3 HYSIM modelling

The stochastic rainfall and PET series described in Section 2 are the inputs for the HYSIM hydrological models. These two HYSIM models (BL-UPS and BL-DWS) were recalibrated in response to improved hydrology information of the catchment and reported on in the Hydrology Update of the Blithe report (Mott MacDonald, 2017a). In addition, catchments across the Severn and Trent which are relevant to SSW have been modelled (these models were recently updated by MM for STWL, and have been used for SSW under the overall agreement between the two water companies).

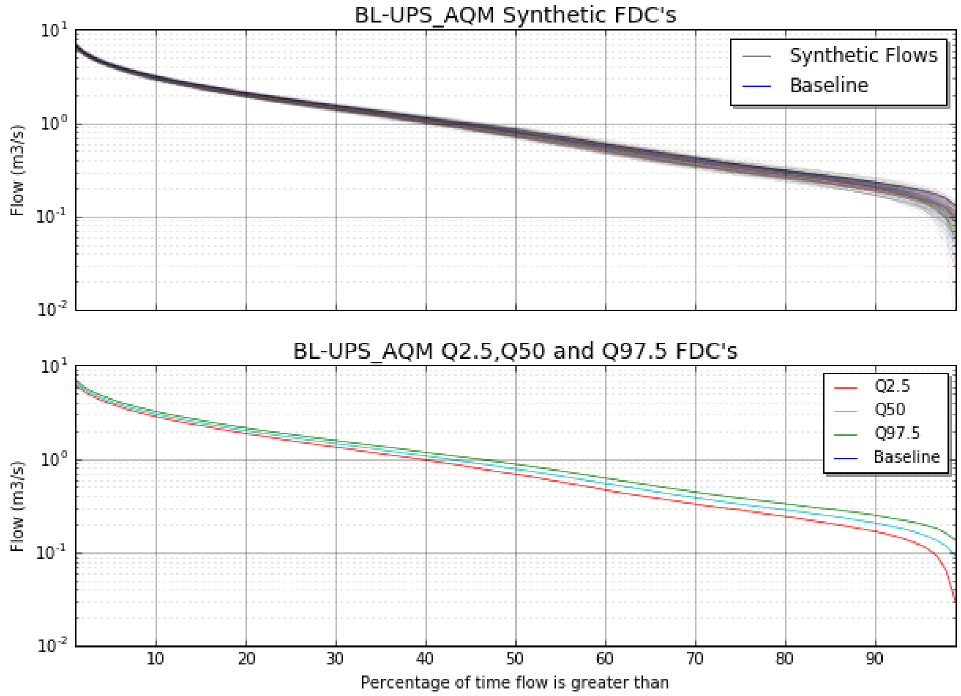
The HYSIM models have been used with the rainfall and PET series to produce river flow series. This section provides an overview of the HYSIM modelling procedure.

The HYSIM modelling procedure undertaken for each one of the 200 scenarios is similar to that in the Water Resources Drought Modelling study (2017a). The full details of the HYSIM procedure, including details of the python scripts developed for this project, are provided in Appendix A.

This modelling produced 200 series of flow data for each of catchments modelled. For the purposes of quality control and error checking several statistics were calculated for the baseline and the synthetic flow series. The mean HYSIM flow, the standard deviation and several percentile flows were obtained and are compared in Table 2 and Table 3 (the baseline value was compared with the median, maximum and minimum value of the 200 scenarios). This shows that the range of the synthetic droughts, compared to the magnitude of the baseline, is greater in the downstream catchment. This could be a result of the calibration incorporating releases from the reservoir, and the fact that when the catchment flows are simulated without the reservoir contribution the flows are more sensitive to variations in rainfall/PET. As each 73-year synthetic flow series can be regarded as an alternative historical scenario, some deviation from the baseline should be expected. Innovative automation for this project allowed time series graphs and flow duration curves for each of the catchments to be efficiently created, providing an additional checking measure.

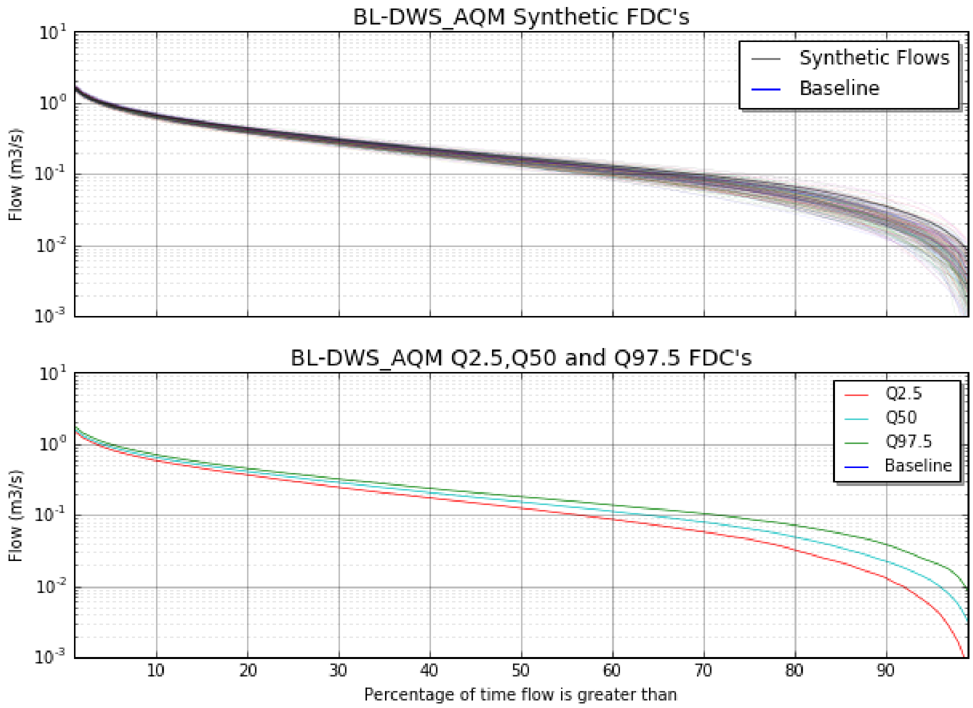
Figure 6 and Figure 7 show the flow duration curves (FDCs) and Figure 8 and Figure 9 show the time series graphs produced for the two catchments of interest.

Figure 6: Flow duration curves of the baseline and synthetic flows at Upstream Blithfield.



Note: Different X-axis minimum values have been selected for Figure 6 and Figure 7.

Figure 7: Flow duration curves of the baseline and synthetic flows for Downstream Blithfield.



Note: Different X-axis minimum values have been selected for Figure 6 and Figure 7.

Figure 8: Annual flow for the Upstream Blithfield (BL-UPS) catchment.

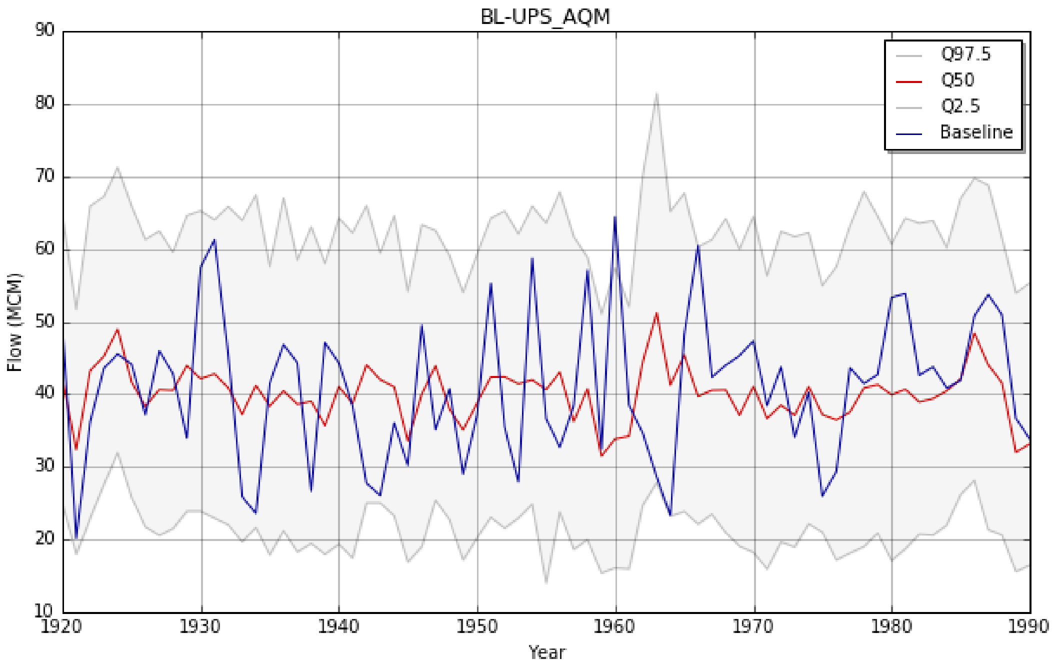


Figure 9: Annual flow for the Downstream Blithfield (BL-DWS) catchment.

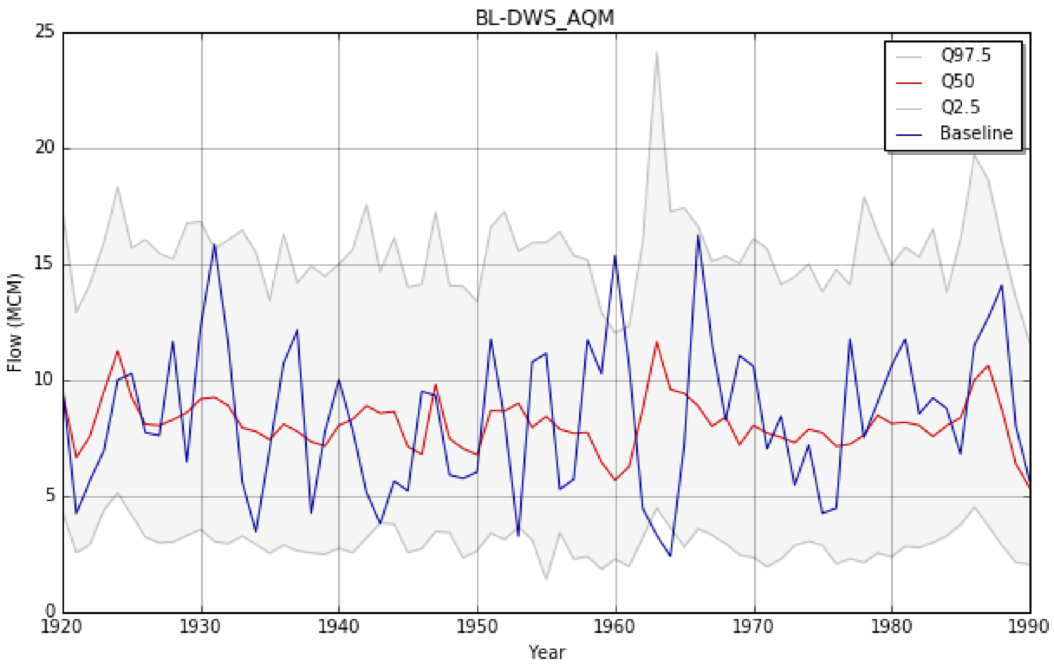


Table 2: Upstream Blithfield catchment (BL-UPS)

(Ml/d)	Baseline	Synthetic Scenario			% of Synthetic Range to Baseline
		Min	Med	Max	
Mean	112	101	111	123	19%
STD	124	115	126	137	18%
Q95	15	9	14	19	66%
Q70	34	27	33	42	44%
Q50	70	57	68	80	33%
Q30	126	113	126	143	24%

Table 3: Downstream Blithfield catchment (BL-DWS)

(Ml/d)	Baseline	Synthetic Scenario			% of Synthetic Range to Baseline
		Min	Med	Max	
Mean	23.1	19.6	23.2	27.7	35%
STD	28.8	26.3	29.6	33.0	23%
Q95	1.1	0.4	1.0	2.8	225%
Q70	7.1	4.3	6.9	10.0	80%
Q50	13.1	9.7	13.2	17.0	56%
Q30	24.6	20.0	24.8	30.8	44%

4 Drought selection

The method of drought selection used the historical flow series to obtain the magnitude of a target drought event (for a given return period and accumulation period) and searched the synthetic flow series for the closest scenario and drought year. The historical series (1884-2014) have been used to set the target event because they produce a longer record than the synthetic time series, enabling a more reliable extrapolation to high return period. This section explains the methodology adopted in greater detail and describes the resulting drought library.

A similar process has been undertaken for STWL in the Severn, Trent and Wye catchments, which had implications on the droughts selected.

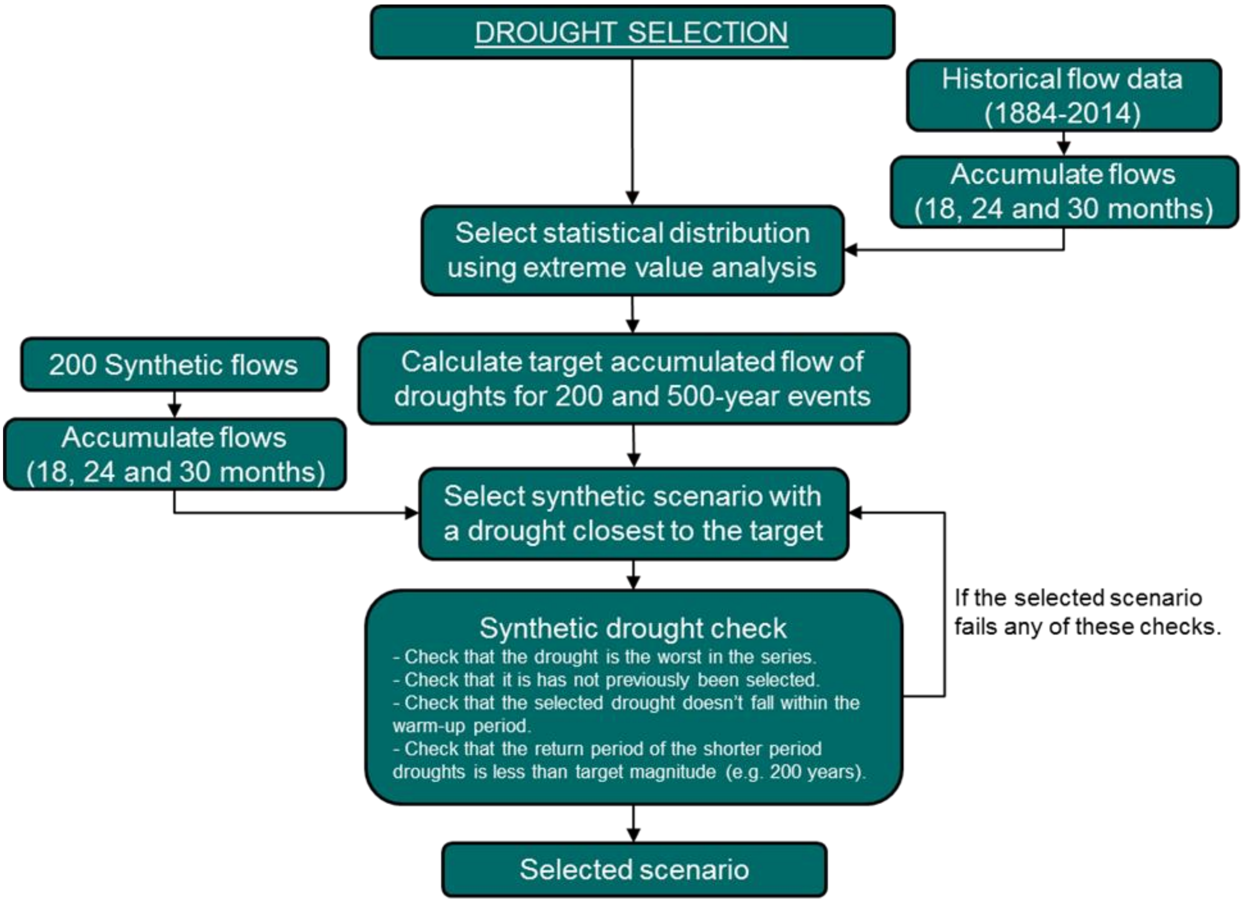
4.1 Methodology

The selection of extreme droughts relies on the following approach:

- Definition of 3 drought durations that can potentially be critical for the supply system.
- Adoption of the Upstream Blithfield (BL-UPS) catchment as a single assessment point representative of the Blithfield hydrology.
- Accumulation of historical flow series (1884-2014) over the 3 drought durations starting in October of each year.
- Extreme Value Analysis of each accumulated flow series by fitting a range of probability distribution functions. The optimum distribution was identified using the Kolmogorov test, Chi-squared test and by visually inspecting the fits.
- Estimation of the 200-year and 500-year magnitude flows for each drought duration and assessment point based on the optimum distribution.
- Identification of the synthetic scenario containing a drought close to each of the target accumulated flows (corresponding to a certain return period and duration). The scenario was chosen so that the target drought was the worst during the simulated record and did not contain a higher return period drought for a shorter drought duration.

Figure 10 provides a flow chart of the drought selection approach. These elements are described further within the next section.

Figure 10: Flow chart of the methodology followed.



4.2 Choice of drought duration and timing

Company experience, together with simulations over the 131-year historic record, indicates that the system is not vulnerable to short-term droughts. If Blithfield reservoir is full in the spring there should be no restrictions needed in the year ahead. Problems may arise if the reservoir is drawn down during the summer and does not refill during the winter, leading to a potential need for restriction events during the second summer. Drought durations of 18, 24 and 30 months are therefore considered suitable.

As a verification, two 6-month synthetic droughts were chosen for each of the 200 and 500 year return periods to allow for temporal variability within the period, and No Restrictions (NR) DO runs were undertaken to identify the demand value that would lead to Hosepipe Bans during the simulation from 1st April to 30th September. Results are shown in **Error! Reference source not found.** and compared with the outcome of a similar analysis for longer drought durations as reported in Appendix X of the dWRMP. As can be seen, the shorter duration is associated with higher NR DO values meaning that they are less critical than longer dry periods. This evidences that the system is not vulnerable to isolated short-term drought events.

Table 4: NR DO for the synthetic drought scenarios

Event	Accumulation period (months)	Scenario	DO (Ml/d)
200-year	6	77	347
		82	352
	18	27	342
	24	99	319
	30	64	313
500-year	6	11	337
		120	336
	18	172	332
	24	124	328
	30	167	311

Source: Mott MacDonald

As regards timing, the critical period for a drought event may vary. The 1975/76 drought broke in late August (and September 1976 was very wet), but in other events the critical date (start of recovery from the maximum drawdown) may be in September or October, or possibly later. The exact duration of a critical event may also vary (a "two summers, one winter" drought might be between around 16 and 20 months), and there is no reason why it would correspond to calendar months. Selecting an appropriate start or end date is not straightforward, but the start of October has been selected as a reasonable compromise. For 18 and 30-month events there was a choice as to whether they should start on 1st October or end on 30th September, but the former has been adopted because of the importance of winter refill.

4.3 Results

The synthetic drought events are selected on the basis of the accumulated flow during the defined duration. The 200 and 500-yr accumulated flows for different drought durations are given in Table 5, along with the chosen extreme probability distribution.

Figure 11 to Figure 13 shows the Goodrich distribution fitted to the 18, 24 and 30-month accumulated flows.

It should be noted that return period estimates for extreme events are subject to significant uncertainty. The tail of the fitted curve is extremely flat, therefore a small change in flow may lead to a large change in the probability/return period.

Table 5: Drought selection summary

Catchment	Accumulation duration (months)	Worst Historic Drought		Distribution	200-year				500-year			
		Year	Accumulated Flow		Target Accumulated Flow	Closest Scenario	Origin Year	Difference	Target Accumulated Flow	Closest Scenario	Origin Year	Difference
Blithfield	18	1889	35.0	Gamma	35.7	27	1946	0.1%	32.9	172	1982	0.3%
	24	1889	41.4		41.1	99	1970	0.2%	37.8	124	1975	1.1%
	30	1893	62.1		63.3	64	1958	0.2%	59.2	167	1959	0.6%

Note: Accumulated flows in million m^3

Figure 11: Upstream Blithfield catchment 18-month accumulated flow fitted to the Gamma distribution.

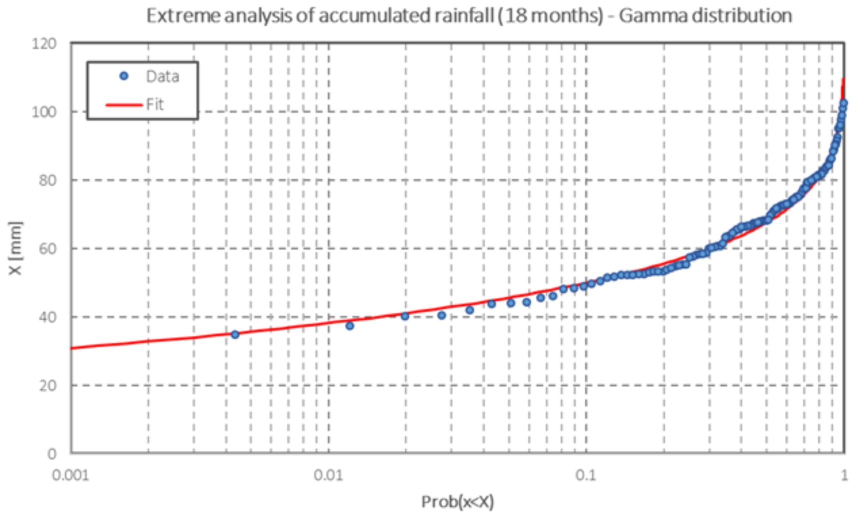


Figure 12: Upstream Blithfield catchment 24-month accumulated flow fitted to the Gamma distribution.

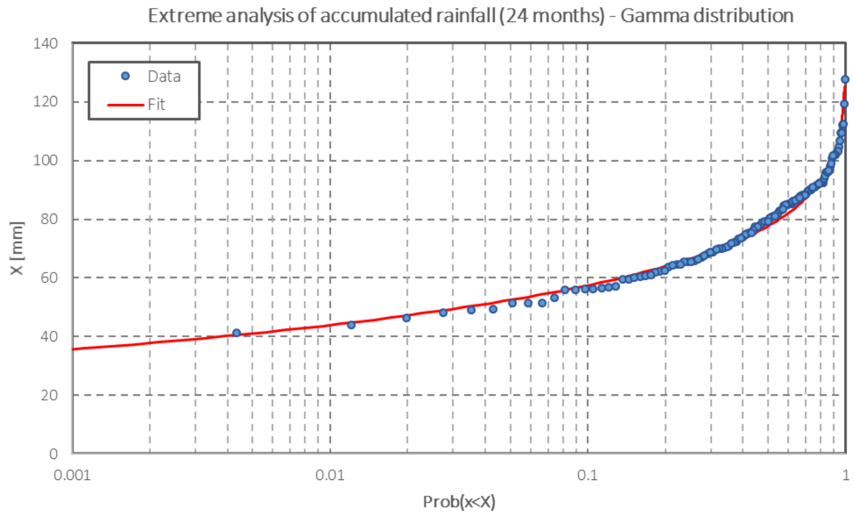


Figure 13: Upstream Blithfield catchment 30-month accumulated flow fitted to the Gamma distribution.

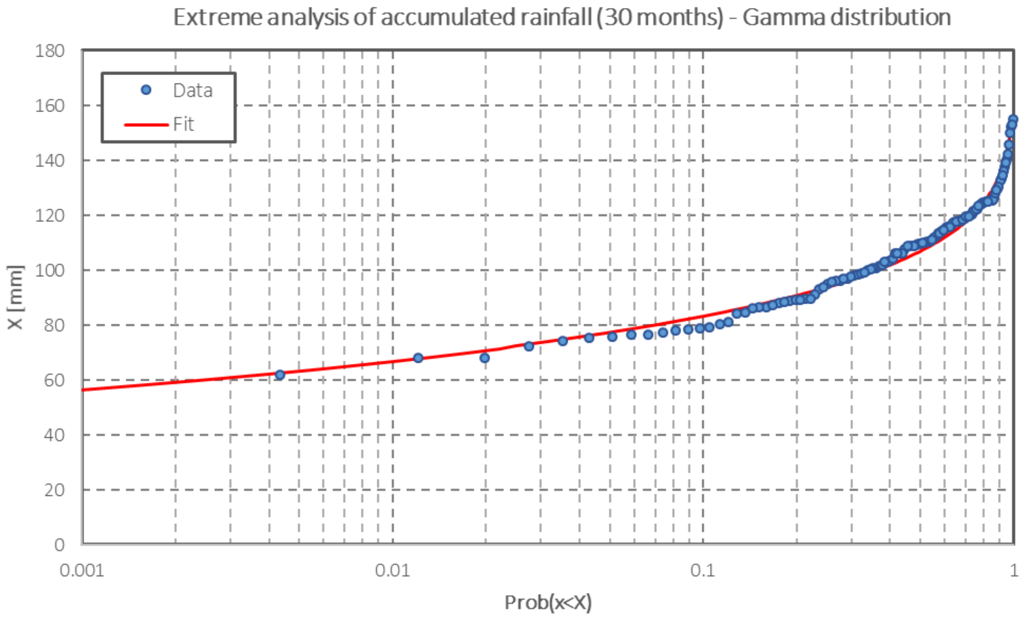


Table 5 identifies the number of the synthetic scenario (0-199) which includes an 18, 24 or 30-month period with flow closest to the target drought, and the year in which this drought began. The difference between the target accumulated flow and selected synthetic flow has been calculated and is 1.1% or less, indicating consistency in the selection process and between the baseline and synthetic flows.

The intention was to obtain 6 unique drought scenarios for this study, whilst also avoiding picking scenarios selected by STWL in the Severn, Trent and Wye catchments and intended to check their supply system. Therefore, upon any occasion where the same scenario appeared twice, the longer duration scenario was reselected to the next closest scenario. This was the case for the 30-month, 200-year scenario, which has already been selected by the 24-month, 500-year event, therefore the next closest scenario was tested. Also, the closest scenario for the 24-month 500-year event scenario was not able to be chosen as this had been selected in the Severn Trent work.

In a few instances, the selected drought exhibited a more severe return period for a shorter drought within the period (for example, the 30-month drought having an 18-month or 24-month drought with a higher return period, starting at the same date). Table 6 provides an example of this for the 200-year drought event. The 24-month accumulation period produced a return period of 200 years; to check whether a more severe drought occurred, the 18-month accumulation (using the same drought start year) return period was calculated. In this instance a return period of 310 was calculated. This indicates that the first 18 months experienced a worse drought than desired whilst the last 6 months reduced the severity of this to an event with a return period of 200 years. As this would make the subsequent analysis of the effect of the drought difficult, any scenario which displayed a greater return period at shorter periods (18 month or 24-month for the 30-month drought) was disregarded.

Table 6: Return period of varying accumulation periods for initial selected drought events

Catchment	Start of drought	Accumulation Period	Return period of accumulation period (from drought start year)		
			18 months	24 months	30 months
Blithfield	1946	18 months	200	-	-
	1960	24 months	310	200	-
	1948	30 months	130	280	200

Notes: Return periods <100 are provided to the nearest whole number, 101-500 to the nearest 10 and 501-1000 to the nearest 100.

The final selection of droughts with the return periods is provided in Table 7.

Table 7: Return period of varying accumulation periods for final selected drought events

Drought magnitude	Scenario	Scenario rank	Start of drought	Accumulation period (months)	Return period of accumulation period (from drought start year)		
					18 months	24 months	30 months
200-year	27	1	1946	18	200	-	-
	99	2	1970	24	94	200	-
	64	3	1958	30	19	42	200
500-year	172	1	1982	18	500	-	-
	124	8	1975	24	280	440	-
	167	4	1959	30	41	96	500

Notes: Return periods <100 are provided to the nearest whole number, 101-500 to the nearest 10 and 501-1000 to the nearest 100.

4.3.1 Spatial consistency

A comparison between the Severn, Trent and the Blithfield catchments allowed some appreciation of the spatial consistency of drought events across the catchments. To achieve this the return period of accumulated flows for the Trent, Wye and Blithfield when selecting a drought based on the Severn were calculated for each accumulation period and magnitude (200-year and 500-year events). This was then repeated for droughts selected based on the Trent, Wye and Blithfield catchments (Table 8).

Table 8: Drought return period

Catchment	Accumulation Period (months)	Return period					
		200-year			500-year		
		Severn	Trent	Blithfield	Severn	Trent	Blithfield
Severn	18	200	360	>1000	490	700	170
	24	210	46	57	480	330	450
	30	210	>1000	200	500	60	90
Trent	18	18	200	180	60	500	>1000
	24	>1000	200	1000	220	500	>1000
	30	>1000	200	160	>1000	500	>1000
Blithfield	18	200	360	200	490	700	500
	24	210	46	200	480	330	440

Catchment	Accumulation Period (months)	Return period					
		200-year			500-year		
		Severn	Trent	Blithfield	Severn	Trent	Blithfield
	30	210	>1000	190	500	60	500

Source: Return periods <100 are provided to the nearest whole number, 101-500 to the nearest 10 and 501-1000 to the nearest 100.

Although severe drought events such as 1976 may have been experienced across the Severn and Trent basins (hence the Blithfield catchment also), the relative severity of conditions may vary. Analysis of the return periods of the selected scenarios indicates that there is limited consistency between the Severn and Trent catchments. For example, the Severn 30-month 200-year event produces a return period of >1000 in the Trent catchment. This highlights the need to test different spatial distributions and supports the selection methodology followed in this study.

5 Summary

5.1 Methodology

The received 200 stochastic rainfall series for each catchment were identified as having suitable mean and standard deviation compared to the historical series. However, there were some differences with regard to their skewness and Lag-1 autocorrelation; which is a consequence of the manner in which they were created. Nonetheless, the rainfall was deemed suitable for use in this project. The received 200 PET series matched well with the historical series.

These 200 series were modelled using calibrated HYSIM models for the catchments of interest.

The computational cost for running 200 scenarios in Aquator is substantial. Therefore, SSW required a sub-set of scenarios to be selected. To obtain this sub-set, historical flows were accumulated over 3 periods (18, 24 and 30 months) and a statistical distribution fitted to each period. A target accumulated flow was calculated for the 200-year and 500-year return period events from the historical data for each accumulated flow. The synthetic scenarios were then searched and the closest accumulated flow to the target was identified.

5.2 Key decisions

The key decisions made in this project were:

- Selection of 18, 24 and 30-month accumulation periods.
- Deciding on the most suitable statistical distribution for the historical accumulated flow.

The first of these points was determined by agreeing with SSW that it was reasonable to use the same durations as set by STWL, and the second by MM.

5.3 Uncertainty

The use of data created by a weather generator and then modelled using a calibrated rainfall-runoff model understandably has uncertainty associated with it. Models are representations of the physical environment and although our quantitative understanding of these system is comprehensive it is not always possible to replicate realistic conditions, particularly as HYSIM is a highly-parameterised rainfall-runoff model and the weather generator is only able to partially capture the variability seen in the historical record.

Another important source of uncertainty for this project was the fitting of the statistical distributions to the historical accumulated flows. Despite the strong fit of the statistical distributions to the data values, it is important to be aware that the flat nature of the curve, particularly at low probability events, introduces uncertainty.

5.4 Results

The 6 unique scenarios selected along with the origin drought year (starting in October) are provided in Table 9.

Table 9: Selected droughts and origin year for each of the accumulation periods for Blithfield.

Catchment	Accumulation duration (months)	200-year		500-year	
		Closest Scenario	Origin Year	Closest Scenario	Origin Year
Blithfield	18	27	1946	172	1982
	24	99	1970	124	1975
	30	64	1958	167	1959

Note: Years have been taken as water years (October to September).

6 References

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

Mott MacDonald, 2017b. Aquator Historical Drought Flow Series for Severn Trent Water Ltd.

Appendices

A. HYSIM modelling procedure

To process and model this large number of scenarios and catchments, an extension to HYSIM, called HYSIM Multi, was used. This allows automated sequential model runs, albeit with a restricted user interface and without the functionality to construct the model project files.

The 200 time series of stochastic rainfall and PET data for each catchment were provided in CSV form. Transforming these series into binary form, so they can be read into HYSIM, was undertaken using python script 1 (Figure 14). The groundwater abstractions and surface discharge time series were the same as the Water Resources Drought Management study (Mott MacDonald, 2017a).

Whilst HYSIM supports the construction of the project files, the large number of model runs required meant this was not a feasible option. To create the project files outside of HYSIM required the CSV files to be constructed for each catchment outlining the file path names for each input component (i.e. rainfall, PET, groundwater abstractions, surface discharge etc.) of the model for each scenario. These were created automatically using VBA coding to improve the efficiency of the process. The CSV files were then used to create the 200 project files for each catchment with python script 2 (Figure 14). Each catchment was run one at a time through HYSIM Multi which sequentially ran the 200 scenarios, producing output flow files in HYSIM (binary) and CSV form. A summary of modelling a single catchment using HYSIM multi is provided in Figure 15.

The large quantity of data produced covering 200 scenarios over a period of 73 years meant that it was most suitable to store the project data in a database. Python script 3 was used to transform the HYSIM simulated flow files into the hdf5 database format.

Figure 14: Flow chart of the full HYSIM procedure and the python scripts used.

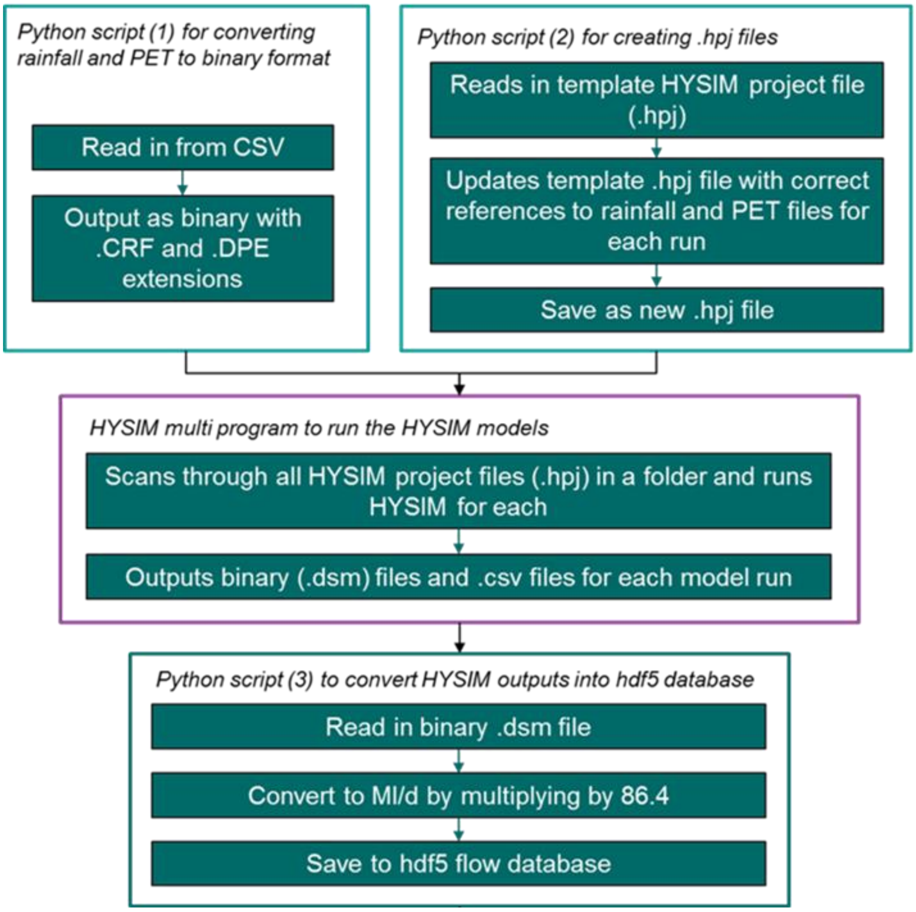
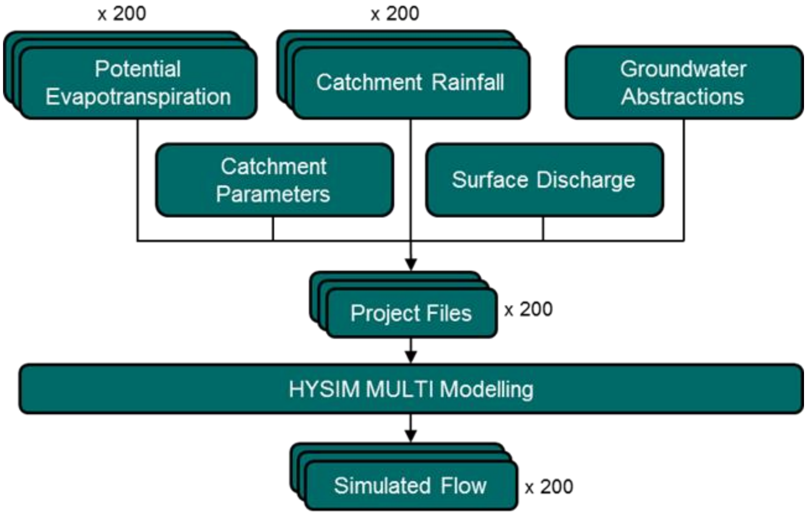


Figure 15: Flow chart for the HYSIM multi processing of synthetic droughts for a single catchment.



Note: “x 200” refers to the 200 synthetic series that were run through each HYSIM model.

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