MOTT MACDONALD

SSW Climate Change Flow Series

9 August 2017

Mott MacDonald
22 Station Road
Cambridge CB1 2JD
United Kingdom

T +44 (0)1223 463500
F +44 (0)1223 461007
mottmac.com

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Contents

1 Introduction

1.1 Background

As part of its next Water Resources Management Plan (WRMP19), South Staffordshire Water Limited (SSW) needs to assess the potential impact of climate change on the deployable output (DO) of its water sources. The purpose of this task is to produce the required flow series for use in SSW's Aquator resource model. The modelling of these flow series within Aquator will be addressed in a separate resilience focussed report.

1.2 Objectives

The objective of the study was to produce climate change flow series for both catchments in the Aquator model, for 40 scenarios (20 for the 2030s estimate and 20 for the 2080s estimate). The HYSIM models at Blithfield used for this study were updated in the Water Resources Drought Modelling project (Mott MacDonald, 2017), taking account of an improved understanding of the hydrology of the Blithe. The 20 selected scenarios for each time slice represent a broad range of climate change projections with a focus on the driest scenarios.

The SSW supply system is dependent on the River Severn, whose flows are impounded and regulated by the Environment Agency (EA) upstream of the River Severn Works intake. Severn Trent Water Limited (STWL) are also significant abstractors from the River Severn. Therefore, an accurate representation of the SSW system performance requires accounting for these artificial influences, implying that a consistent approach in the characterisation of the effect of Climate Change is desirable. This was defined at a joint workshop, where, following an ongoing collaboration between both water companies, STWL agreed to provide climate change scenario choices and flow series to allow SSW to follow a similar methodology.

Aquator flows received from STWL, together with climate change perturbed flows for the Blithe for the selected scenarios are then to be used to estimate the DO's of the 20 scenarios for each time slice. The EA guidance for estimating the impacts of climate change on water supply (Environment Agency 2017) state that the requisite approach is to use 2080s flows. However, given the high uncertainty of the 2080s projection, the alternative use of the 2030s time slice is possible if the 2080s lead to an unrealistic impact or requires further validation.

2 Approach

2.1 Key steps

The key steps in the study were as follows:

1. Agree with STWL on the 20 scenarios to be modelled using their methodology (outlined in the next section)
2. Obtain rainfall and temperature data (for 40 scenarios) for the 2030s and 2080s time slices from UKCP09 (UK Climate Impacts Programme, 2009);
3. Derive monthly rainfall factors for the selected scenarios (from the projected % change in rainfall);
4. Derive monthly potential evapotranspiration (PET) factors for the scenarios from the projected change in temperature and an assumed relationship between temperature and PET;
5. Apply the factors to the baseline rainfall and PET series for each catchment, producing a total of 80 new datasets (20 rainfall and 20 PET series for each of the time slices).
6. Run the HYSIM models for each of the catchments, obtaining flow series for the baseline and all 40 scenarios. The models are as previously calibrated.

The 20 scenarios were selected by STWL and SSW have adopted the same scenarios to utilise flows derived by STWL within their water resource modelling.

2.2 Climate scenarios

A selection of 20 scenarios were chosen from the UKCP09 climate change database for each of the 2030s and 2080s time slices, for use in this project. The initial 10,000 UKCP09 projections were reduced to 100 scenarios by applying a Latin Hypercube Sample. These 100 scenarios were subsequently “smart sampled” using the mean April to September flow change in 5 exemplar catchments of the Severn region as a suitable Drought Indicator. This approach is provided in detail in STWL WRMP14 (2014). The Severn region was considered to be the most suitable choice for the overall area of interest to STWL; it would have been inappropriate to use the Humber region information for the River Trent area because the UKCP09 information is not spatially coherent between regions.

Even though the Blithe is located in the Humber region, a similar choice of scenarios was adopted by SSW so that flows from STWL could be used in the SSW Aquator model. Further, a comparison between potential impacts on rainfall and temperature between the Severn and the Humber regions did not reveal significant discrepancies. Table 1 outlines the scenarios used in this project with their rank and original ID from the UKCP09 database. The selection is skewed towards lower ranked scenarios (with one scenario for each rank between 0 and 10), according to the adopted Drought Index. Therefore, the middle scenario (10) does not represent the 50% rank. Consequently, averaging across the scenarios would not provide a mean across the ranks. In the following tables, **bold text** indicates the median (50%) scenario.

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

2.3 Rainfall factors

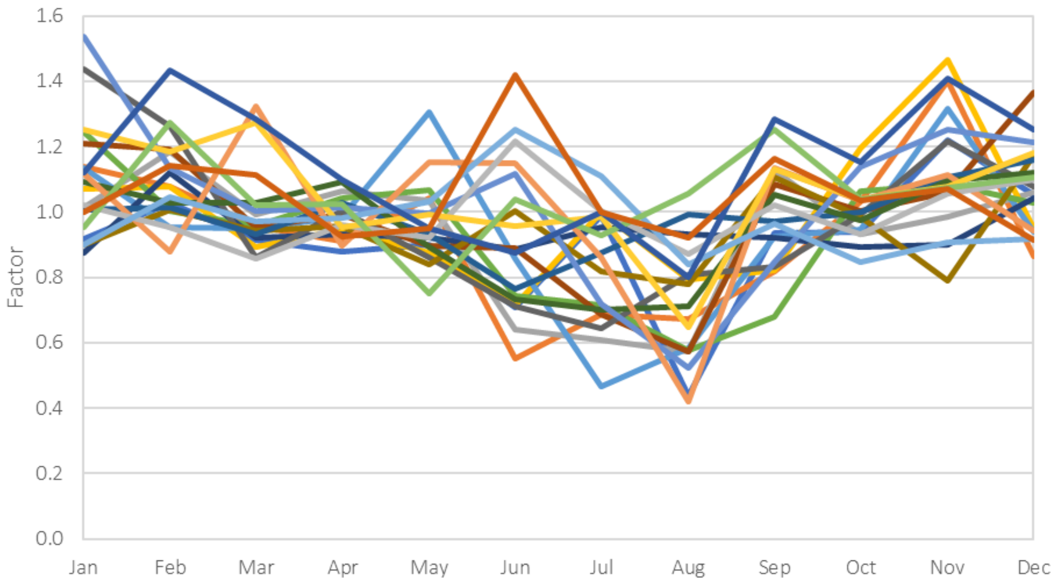
UKCP09 can directly output projected percentage change in rainfall for the Severn basin, for all scenarios. These were converted to rainfall factors, which are provided in tabular form in Table 2 and Table 3 and graphical form in Figure 1 and Figure 2. The rainfall factors show notable scatter, but a general pattern of higher factors in winter and lower in summer is evident. April and October show relatively little variation between the scenarios; across those two months the average factor is very close to 1 and the range is 0.85 to 1.2 (across both time slices). Greater ranges apply in the remaining months, most notably in February and June where several scenarios show an increase in rainfall, including an increase in scenario 19 rainfall for February of 43% and 96% for the 2030s and 2080s time slices, respectively. A significant reduction in rainfall is forecasted in August where scenario 14 shows a decrease of 58% and 76% for the 2030s and 2080s time slices, respectively.

Table 2: Monthly rainfall factors for 2030s scenarios

Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.92	1.03	0.91	0.88	0.90	0.71	0.99	0.44	0.94	0.94	1.22	1.05
2	1.14	1.08	0.96	0.91	1.04	0.55	0.69	0.67	0.82	1.03	1.40	0.86
3	1.01	1.18	0.99	1.06	1.04	0.64	0.61	0.57	1.13	0.93	0.99	1.06
4	1.07	1.08	0.89	0.95	0.87	0.72	1.00	0.79	0.82	1.20	1.47	0.95
5	1.14	0.96	0.95	0.98	1.30	0.86	0.47	0.58	0.92	0.95	1.31	0.94
6	1.24	1.00	0.96	1.04	1.07	0.74	0.72	0.58	0.68	1.06	1.08	1.03

Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
7	0.88	1.12	0.92	0.93	0.92	0.89	0.95	0.93	0.92	0.89	0.90	1.04
8	1.21	1.19	0.95	0.99	0.90	0.89	0.69	0.57	1.08	1.00	1.06	1.36
9	1.44	1.26	0.86	1.00	0.86	0.71	0.64	0.81	0.83	0.99	1.21	1.08
10	0.90	1.01	0.94	0.96	0.84	1.00	0.82	0.78	1.11	0.99	0.79	1.17
11	1.01	1.01	0.93	1.03	0.93	0.76	0.88	0.99	0.97	1.00	1.11	1.16
12	1.09	1.03	1.03	1.09	0.89	0.73	0.70	0.71	1.05	0.97	1.10	1.12
13	1.54	1.14	1.00	1.01	0.99	1.12	0.72	0.52	0.85	1.14	1.25	1.21
14	1.12	0.88	1.32	0.90	1.15	1.15	0.86	0.42	1.13	1.03	1.11	0.94
15	**1.02**	**0.95**	**0.86**	**0.96**	**0.92**	**1.22**	**1.00**	**0.87**	**1.02**	**0.93**	**1.06**	**1.10**
16	1.25	1.18	1.27	0.95	0.99	0.96	0.98	0.65	1.13	1.04	1.08	1.18
17	0.90	1.05	0.97	0.98	1.03	1.25	1.11	0.84	0.97	0.85	0.91	0.92
18	0.95	1.27	1.02	1.02	0.75	1.04	0.93	1.06	1.25	1.04	1.07	1.11
19	1.12	1.43	1.28	1.10	0.95	0.88	1.00	0.80	1.28	1.15	1.41	1.25
20	1.00	1.14	1.12	0.92	0.95	1.42	1.00	0.92	1.16	1.03	1.07	0.92

Figure 1: Rainfall factors for 2030s scenarios

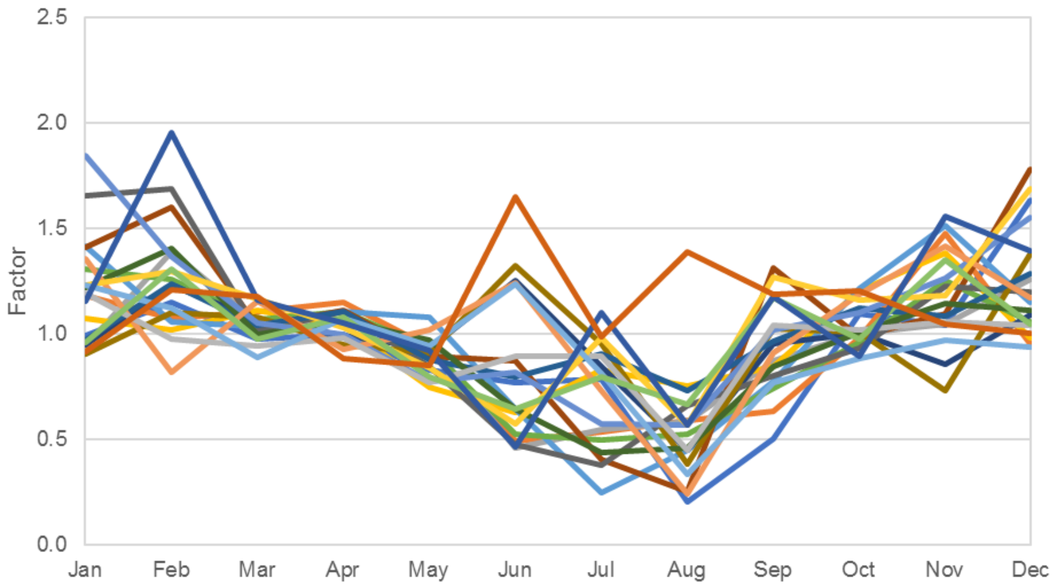


Source: UKCP09 raw data, processed by Mott MacDonald

Table 3: Monthly rainfall factors for 2080s

Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.99	1.15	0.97	1.00	0.83	0.77	0.78	0.21	0.50	1.10	1.04	1.63
2	1.18	1.08	1.10	1.15	0.94	0.49	0.54	0.59	0.63	0.98	1.48	0.95
3	0.94	1.39	1.06	1.07	0.96	0.46	0.55	0.58	0.87	1.00	1.04	1.26
4	1.07	1.02	1.11	1.04	0.75	0.63	0.83	0.75	0.84	1.20	1.38	0.98
5	1.42	1.06	1.03	1.11	1.08	0.65	0.25	0.45	0.77	1.22	1.52	1.15
6	1.31	1.26	1.07	1.11	0.93	0.52	0.50	0.52	0.74	0.96	1.26	1.06
7	0.95	1.23	1.07	0.99	0.93	1.26	0.85	0.45	0.95	1.01	0.85	1.09
8	1.41	1.60	1.04	1.11	0.89	0.87	0.40	0.25	1.31	0.98	1.09	1.78
9	1.66	1.69	1.01	1.11	0.85	0.47	0.38	0.66	0.80	0.93	1.23	1.20
10	0.91	1.10	1.08	0.95	0.91	1.32	0.95	0.38	1.03	1.01	0.73	1.38
11	0.97	1.23	1.04	1.11	0.88	0.79	0.91	0.73	0.96	1.12	1.08	1.29
12	1.22	1.41	0.99	1.06	0.97	0.64	0.44	0.46	0.85	1.01	1.15	1.11
13	1.84	1.37	1.05	1.00	0.77	0.82	0.57	0.57	1.02	1.10	1.26	1.55
14	1.36	0.82	1.16	0.93	1.02	1.24	0.73	0.24	0.91	1.19	1.42	1.17
15	**1.19**	**0.97**	**0.94**	**0.98**	**0.77**	**0.90**	**0.90**	**0.45**	**1.04**	**1.02**	**1.06**	**1.04**
16	1.23	1.30	1.17	1.03	0.84	0.57	0.98	0.57	1.27	1.16	1.18	1.69
17	1.23	1.12	0.89	1.07	0.94	1.24	0.81	0.34	0.77	0.88	0.97	0.94
18	0.96	1.31	0.97	1.08	0.80	0.65	0.80	0.66	1.17	0.98	1.35	1.05
19	1.16	1.96	1.16	1.05	0.92	0.47	1.10	0.57	1.18	0.89	1.55	1.39
20	0.92	1.21	1.17	0.89	0.85	1.65	0.99	1.39	1.19	1.21	1.05	1.00

Figure 2: Rainfall factors for 2080s



Source: UKCP09 raw data, processed by Mott MacDonald

Across the scenarios, the change in the seasonal distribution of rainfall is generally more significant than the change in the overall rainfall quantity.

2.4 PET factors

The available options within UKCP09 do not include change in PET. There is information about climate parameters from which PET can be estimated, including temperature which is the main driver for PET. This study uses a relationship between temperature and PET to convert projected changes in temperature to PET factors.

Oudin *et al*. (2004) demonstrated that temperature-based estimates of PET could be superior (in terms of accuracy of simulating flows using a rainfall-runoff model) to those derived using the more complex Penman formula (which incorporates humidity, radiation and wind speed, as well as temperature). Oudin *et al*. proposed the following equation:

$$PET = C \times \frac{(T_a + 5)}{100} \qquad \text{if } (T_a + 5) > 0$$

$$PET = 0 \qquad \text{otherwise}$$

where T_a is the average temperature (ºC), and the constant C is related to radiation, and can be found from the latitude of the location and the day of the year.

For the purpose of determining PET factors the exact value of C is not relevant – the key is simply that PET is proportional to $(T_a + 5)$. Consequently, the PET factors can be found as follows:

$$PETj = \frac{\left(T_{aj} + dT_j + 5\right)}{\left(T_{aj} + 5\right)} \qquad \text{if } (T_a + 5) > 0$$

where: j = month

$PETj$ = PET factor for month j

T_{aj} = average temperature in month j (baseline)

dT_j = projected change in average temperature for month j

By these means the monthly PET factors were derived for each of the 40 scenarios, using the projections of temperature change for the Severn basin obtained from UKCP09.

The average temperature was taken to be the mean of values from the Central England Temperature (CET) series, for the standard baseline period of 1961-90. The CET is the longest instrumented temperature record in the world, with daily data from 1772 and monthly from 1659. The data is representative of a roughly triangular area of the United Kingdom enclosed by Lancashire, London and Bristol which substantially overlaps the Severn basin and the Blithfield catchments. The CET values are shown in Table 4 and derived PET factors in Table 5 for 2030s and Table 6 for 2080s.

The PET factors are presented graphically in Figure 3 and Figure 4; the most notable feature is that every factor is greater than 1 – because every scenario shows a projected increase in temperature in every month. There is a lot of scatter, and some extremely high factors in winter, but it should be noted that because PET is low in winter a large factor represents a relatively small change in the actual value of PET.

Table 4: Mean Central England Temperature (1961-90)

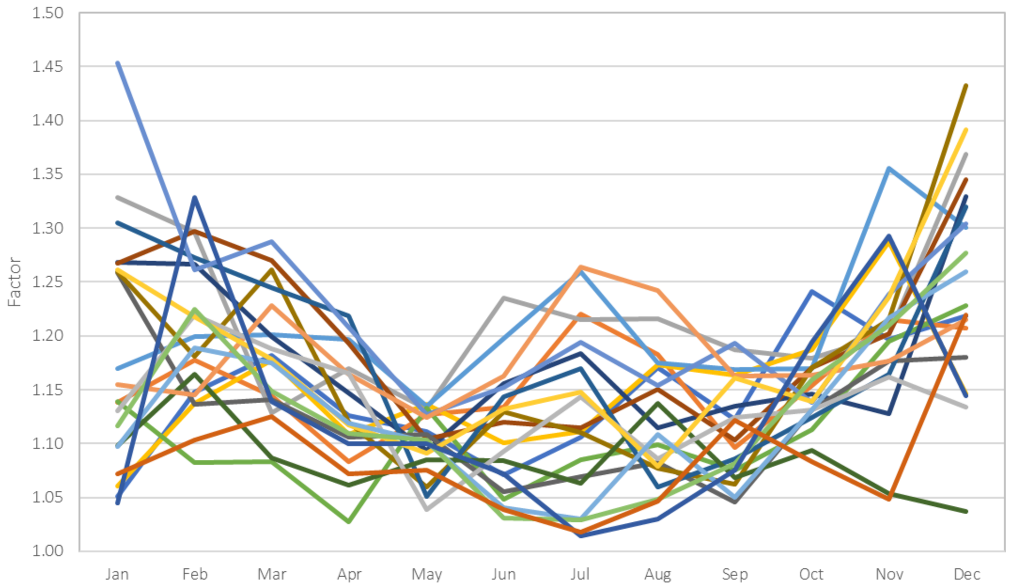
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp (°C)	3.8	3.8	5.7	7.9	11.2	14.2	16.1	15.8	13.6	10.6	6.6	4.7

Table 5: PET factors for 2030s scenarios

Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.05	1.15	1.18	1.13	1.11	1.07	1.11	1.17	1.12	1.24	1.20	1.22
2	1.14	1.18	1.14	1.08	1.13	1.13	1.22	1.18	1.10	1.15	1.21	1.21
3	1.33	1.30	1.13	1.17	1.13	1.24	1.21	1.22	1.19	1.18	1.20	1.37
4	1.06	1.14	1.18	1.11	1.14	1.10	1.11	1.17	1.16	1.19	1.29	1.15
5	1.17	1.20	1.20	1.20	1.14	1.20	1.26	1.18	1.17	1.17	1.36	1.30
6	1.14	1.08	1.08	1.03	1.13	1.05	1.08	1.10	1.08	1.11	1.19	1.23
7	1.27	1.27	1.20	1.15	1.09	1.16	1.18	1.11	1.13	1.15	1.13	1.33
8	1.27	1.30	1.27	1.19	1.10	1.12	1.11	1.15	1.10	1.17	1.20	1.34
9	1.26	1.14	1.14	1.11	1.11	1.06	1.07	1.08	1.05	1.13	1.18	1.18
10	1.26	1.18	1.26	1.12	1.06	1.13	1.11	1.08	1.06	1.17	1.22	1.43
11	1.31	1.27	1.24	1.22	1.05	1.14	1.17	1.06	1.09	1.12	1.16	1.32
12	1.10	1.16	1.09	1.06	1.09	1.08	1.06	1.14	1.07	1.09	1.05	1.04
13	1.45	1.26	1.29	1.21	1.13	1.15	1.19	1.15	1.19	1.14	1.24	1.30
14	1.15	1.15	1.23	1.16	1.12	1.16	1.26	1.24	1.16	1.16	1.18	1.21

Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
15	**1.13**	**1.22**	**1.19**	**1.17**	**1.04**	**1.09**	**1.14**	**1.09**	**1.12**	**1.13**	**1.16**	**1.13**
16	1.26	1.22	1.18	1.12	1.09	1.13	1.15	1.08	1.16	1.14	1.24	1.39
17	1.10	1.19	1.18	1.12	1.10	1.04	1.03	1.11	1.05	1.13	1.22	1.26
18	1.12	1.22	1.15	1.11	1.10	1.03	1.03	1.05	1.08	1.16	1.21	1.28
19	1.04	1.33	1.14	1.10	1.10	1.07	1.01	1.03	1.08	1.19	1.29	1.14
20	1.07	1.10	1.13	1.07	1.08	1.04	1.02	1.05	1.12	1.08	1.05	1.22

Figure 3: PET for 2030s scenarios



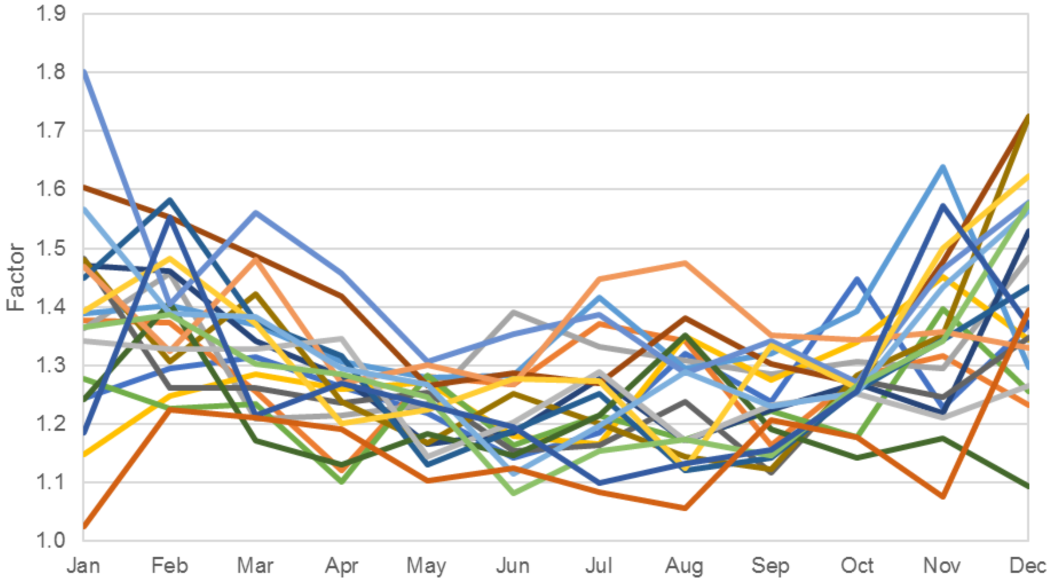
Source: UKCP09 raw data, processed by Mott MacDonald

Table 6: PET factors for 2080s scenarios

Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.24	1.29	1.31	1.26	1.22	1.14	1.18	1.32	1.24	1.45	1.23	1.37
2	1.38	1.37	1.26	1.12	1.28	1.27	1.37	1.34	1.16	1.28	1.32	1.23
3	1.36	1.46	1.21	1.21	1.23	1.39	1.33	1.31	1.29	1.31	1.29	1.49
4	1.15	1.25	1.28	1.26	1.27	1.18	1.17	1.35	1.28	1.34	1.45	1.34
5	1.39	1.40	1.37	1.31	1.28	1.28	1.42	1.29	1.32	1.39	1.64	1.30
6	1.28	1.23	1.23	1.10	1.28	1.16	1.22	1.17	1.22	1.18	1.40	1.25
7	1.47	1.46	1.34	1.28	1.17	1.19	1.28	1.17	1.22	1.27	1.22	1.53
8	1.60	1.55	1.49	1.42	1.27	1.29	1.27	1.38	1.30	1.27	1.48	1.72
9	1.48	1.26	1.26	1.24	1.25	1.15	1.16	1.24	1.12	1.27	1.25	1.35
10	1.48	1.31	1.42	1.24	1.17	1.25	1.20	1.14	1.12	1.28	1.35	1.72

Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
11	1.45	1.58	1.37	1.32	1.13	1.19	1.25	1.12	1.14	1.26	1.34	1.43
12	1.24	1.41	1.17	1.13	1.18	1.15	1.21	1.35	1.19	1.14	1.18	1.09
13	1.80	1.40	1.56	1.46	1.31	1.35	1.39	1.29	1.34	1.27	1.46	1.58
14	1.47	1.32	1.48	1.27	1.30	1.27	1.45	1.47	1.35	1.34	1.36	1.33
15	**1.34**	**1.33**	**1.33**	**1.34**	**1.14**	**1.20**	**1.29**	**1.17**	**1.23**	**1.25**	**1.21**	**1.26**
16	1.39	1.48	1.37	1.20	1.22	1.28	1.27	1.12	1.33	1.26	1.50	1.62
17	1.57	1.39	1.38	1.30	1.27	1.11	1.20	1.29	1.23	1.25	1.43	1.56
18	1.36	1.39	1.30	1.29	1.25	1.08	1.15	1.17	1.15	1.27	1.34	1.58
19	1.18	1.55	1.22	1.27	1.23	1.20	1.10	1.13	1.15	1.25	1.57	1.37
20	1.03	1.22	1.21	1.19	1.10	1.12	1.08	1.06	1.21	1.18	1.08	1.39

Figure 4: PET for 2080s scenarios



Source: UKCP09 raw data, processed by Mott MacDonald

3 HYSIM modelling

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

The rainfall and PET scenarios described in Section 2 provide the inputs for the HYSIM hydrological models, with the factors being applied to the baseline rainfall and PET series. These two HYSIM models (BL-UPS and BL-DWS) were recalibrated in response to improved hydrometric information of the catchment and reported on in the Hydrology Update of the Blithe report (Mott MacDonald, 2017).

The full details of the HYSIM procedure, including details of the python script developed for this project, are provided in Appendix A.

This modelling produced 40 series of flow data for each of catchments modelled. For purposes of quality control and error checking the annual flows for the 40 scenarios have been plotted against the baseline and the percentage change of each baseline presented in the results section.

4 Results

The output flows from HYSIM have been compared to the baseline for the two catchments of interest in Appendix B for the 2030s and 2080s scenarios. These figures show that the climate change scenarios are consistent with the baseline. The percentage change in the average flow, presented in Table 7 and Table 8, tend to show large negative changes for the lowest ranked scenarios and large positive changes for the highest ranked scenarios. However, there is some variation around this tendency.

Additionally, the climate change scenarios tend to show higher flows in winter and lower flows in the summer compared to the baseline (see Figure 6, Figure 7, Figure 9, Figure 10). This might promote refilling of Blithfield, which might help in avoiding severe reservoir drawdown in summer. On the contrary, lower inflows in summer might lead to a deeper drawdown in critical droughts.

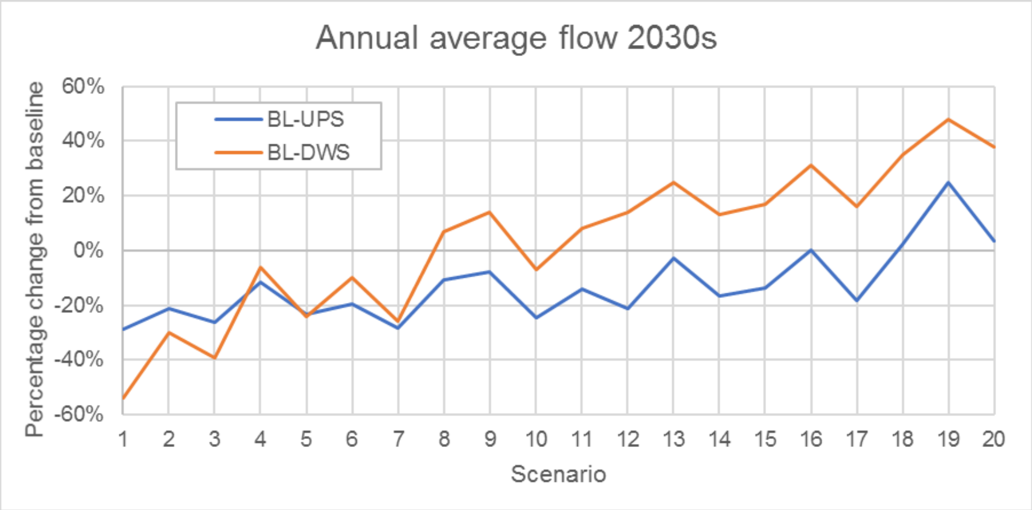
4.1 2030s

Table 7 shows the average annual flow of the 2030s scenarios as a percentage of the baseline. The downstream flow tends to show a slightly more extreme change (either positive or negative) than the upstream flow. This is showed more clearly in Figure 5, which suggests that the downstream model is more sensitive to changes in PET and rainfall than the upstream catchment.

Table 7: Percentage change in the annual average flow of the 2030s scenarios compared to the baseline.

Scenario	Percentage change in average flow from baseline	
	BL-UPS	BL-DWS
1	-29%	-54%
2	-21%	-30%
3	-26%	-39%
4	-12%	-6%
5	-23%	-24%
6	-19%	-10%
7	-28%	-26%
8	-11%	7%
9	-8%	14%
10	-25%	-7%
11	-14%	8%
12	-21%	14%
13	-3%	25%
14	-17%	13%
15	-14%	**17%**
16	0%	31%
17	-18%	16%
18	2%	35%
19	25%	48%
20	3%	38%

Figure 5: Percentage change in annual average flow of the 2030s scenarios compared to the baseline



The monthly average flows for the baseline and climate change scenarios are presented in Figure 6 and Figure 7. The combination of the rainfall and PET factors tends to produce drier springs, summers and autumns, whilst the change during winter is more mixed, with scenarios showing either an increase or decrease, and a large range of flows.

In most months scenario 19 (grey line) is the wettest scenario for BL-UPS compared to the baseline, while for BL-DWS it is the wettest in almost every month, and usually by a clear margin. This can be traced back to the rainfall and PET factors obtained from the UKCP09 data.

Figure 6: BL-UPS 2030s monthly average flows

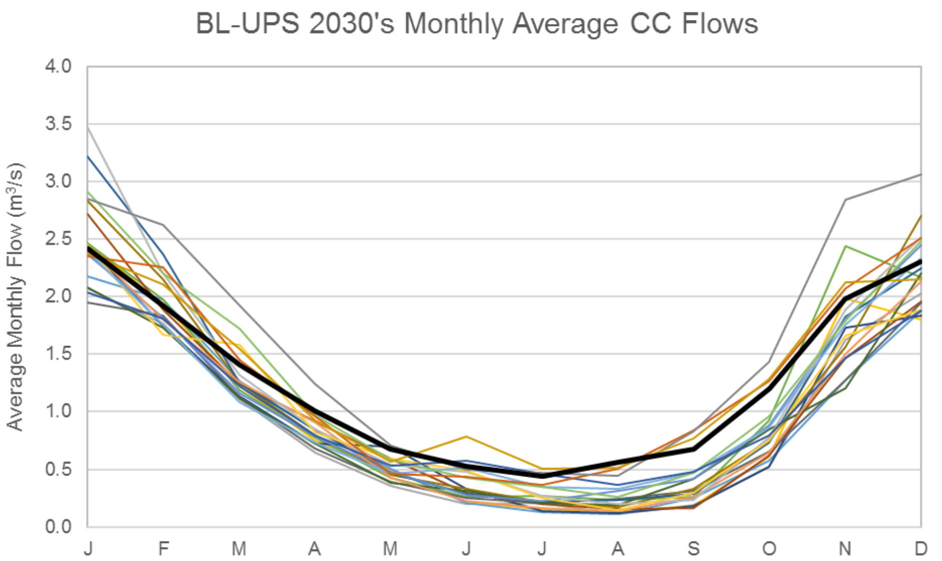
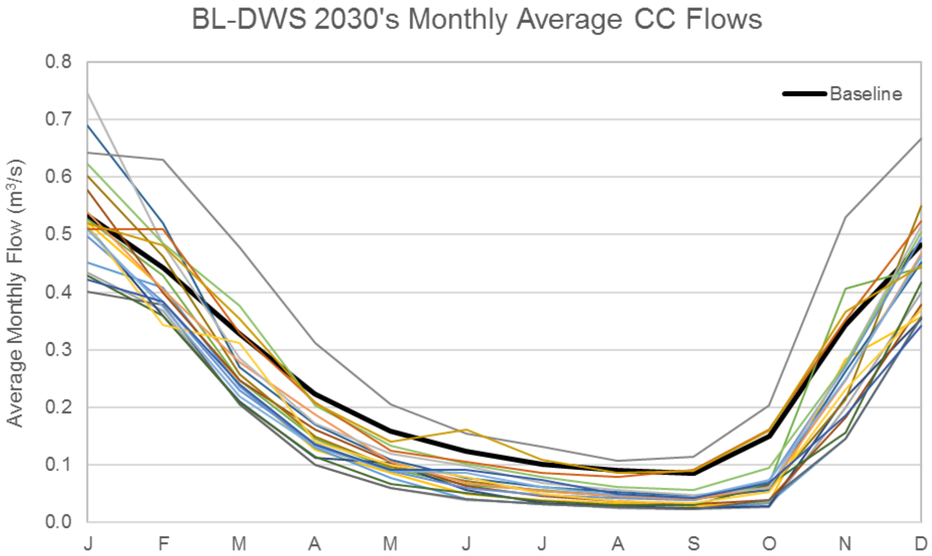


Figure 7: BL-DWS 2030s monthly average flows



4.2 2080s

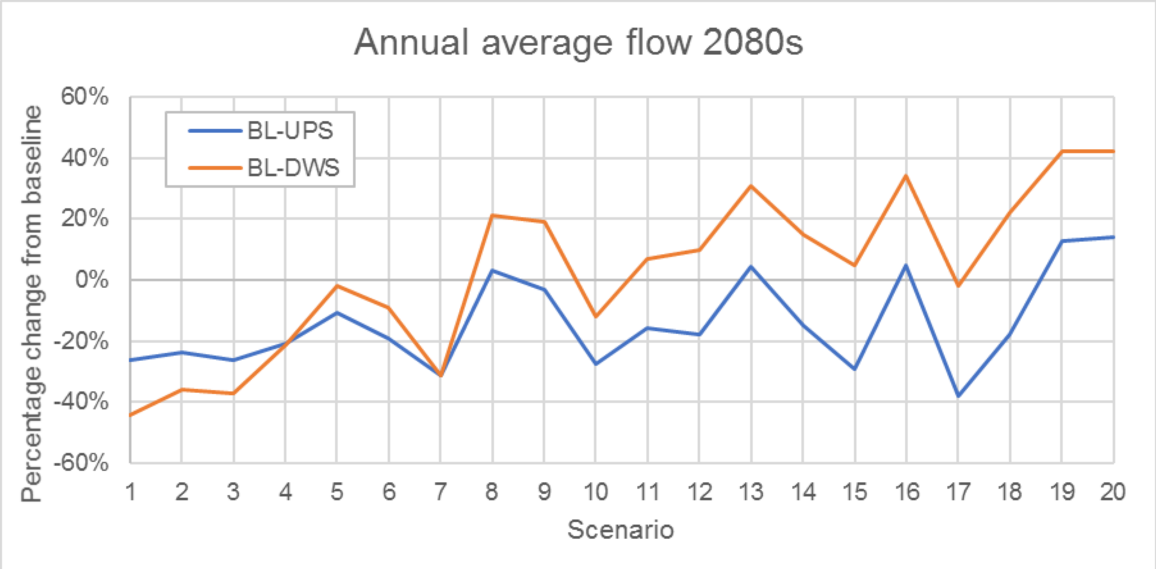
Table 8 shows the average annual flow of the 2080s scenarios as a percentage of the baseline. The impact of climate change is more pronounced than for the 2030s. As before, the downstream flow tends to show a more extreme change (either positive or negative) than the upstream flow. This is showed more clearly in Figure 8, which suggests that the downstream model is more sensitive to changes in PET and rainfall than the upstream catchment.

Table 8: Percentage change in the annual average flow of the 2080s scenarios compared to the baseline.

Scenario	Percentage change in average flow from baseline	
	BL-UPS	BL-DWS
1	-26%	-44%
2	-24%	-36%
3	-26%	-37%
4	-21%	-21%
5	-11%	-2%
6	-19%	-9%
7	-31%	-31%
8	3%	21%
9	-3%	19%
10	-28%	-12%
11	-16%	7%
12	-18%	10%
13	5%	31%
14	-15%	15%
15	-29%	**5%**
16	5%	34%

Scenario	Percentage change in average flow from baseline	
	BL-UPS	BL-DWS
17	-38%	-2%
18	-18%	22%
19	13%	42%
20	14%	42%

Figure 8: Percentage change in annual average flow of the 2080s scenarios compared to the baseline



The monthly average flows for the baseline and climate change scenarios are presented in Figure 9 and Figure 10. Similar to the 2030s scenarios, the downstream flows tend to be less than the baseline throughout the spring, summer and autumn with more variability above and below the baseline in winter (November to March). The flows show variability both above and below the baseline with a larger range during the winter months, which aligns with the rainfall and PET factor characteristics. The scale of the changes is broadly similar to that for the 2030s (Figure 5); further comment on the comparison is contained in the next section.

The wettest scenario compared to the baseline is either scenario 19 (dark grey line) or scenario 20 (light grey line). This can be traced back to the rainfall and PET factors obtained from the UKCP09 data.

Figure 9: BL-UPS 2080s monthly average flow

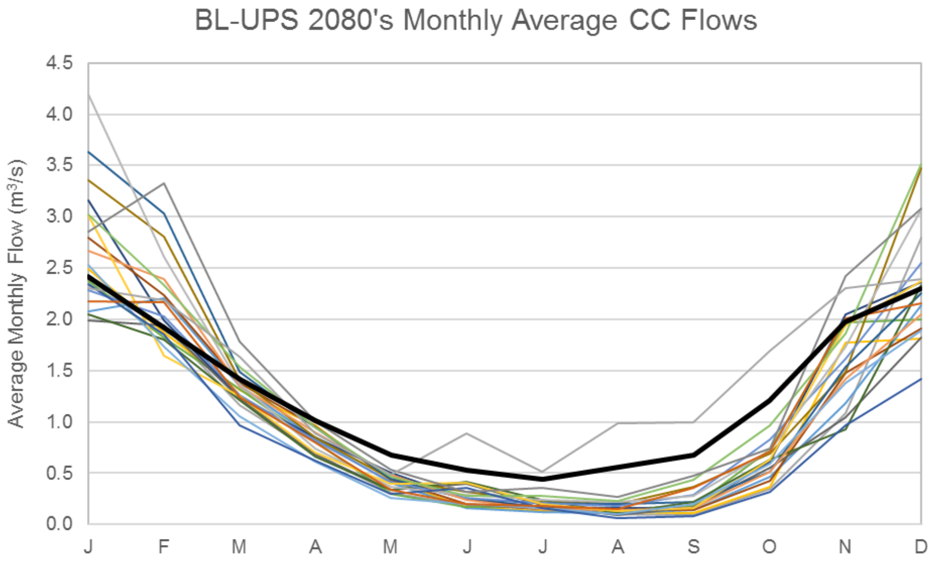
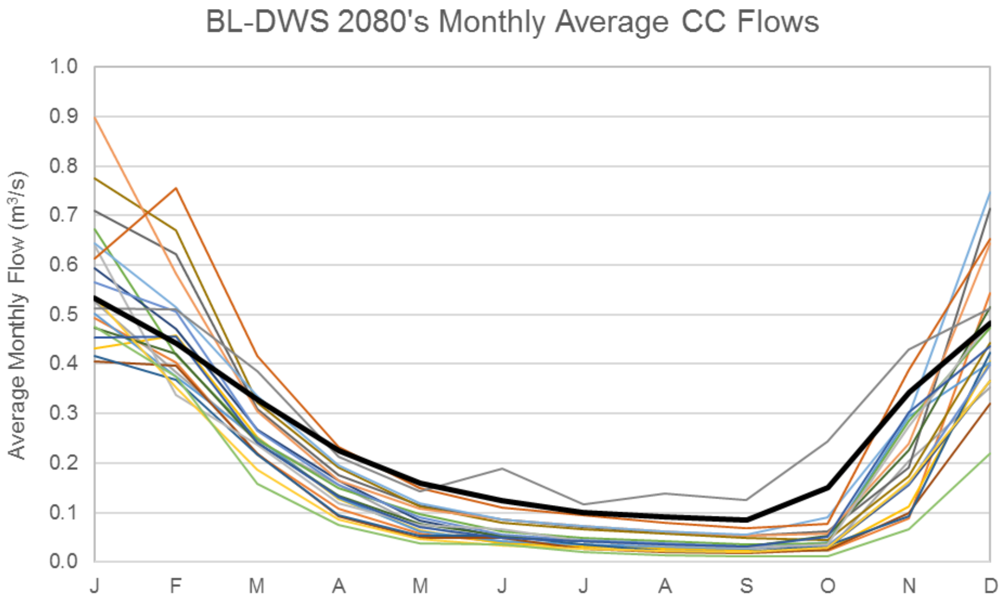


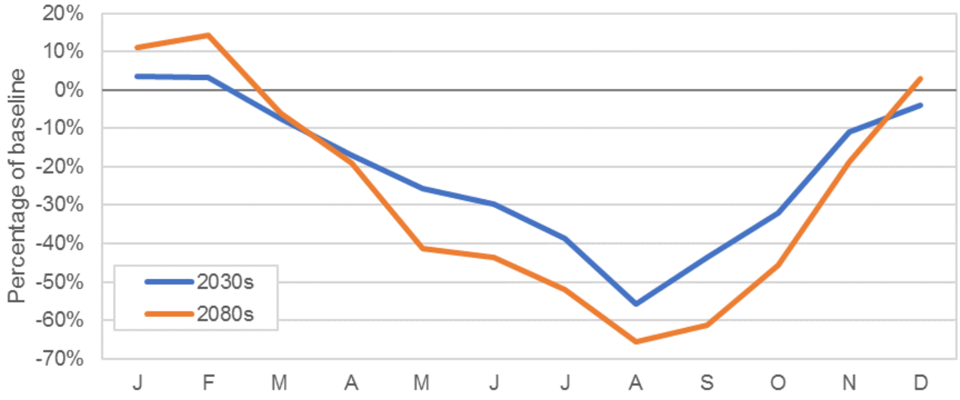
Figure 10: BL-DWS 2080s monthly average flow



4.3 2030s and 2080s comparison

Although the average flows of the 2030s and 2080s times series do not show much difference, there are significant differences in seasonal flows. Figure 11 shows the changes in average monthly flow, averaged across all 20 scenarios. The 2080s exhibit more substantial reductions from April to November, and bigger increases in winter, compared to the 2030s scenarios. (Note that scenarios should not normally be averaged in this way, but it is considered reasonable for this purpose of illustrating the greater severity of seasonal changes projected for the 2080s.)

Figure 11: Average monthly flows of the 20 scenarios compared to the baseline.



Note: Flows averaged across all 20 scenarios for each time slice.

5 Summary

Rainfall and PET climate change factors have been derived from the UKCP09 database for 20 climate change scenarios for each of the 2030s and 2080s time slices. These 40 scenarios have been run using previously calibrated HYSIM models, focussing on the upstream and downstream Blithfield catchments. The outcome of this modelling was 40 time series of flows for each of the two catchments of interest.

The 2030s and 2080s scenarios will subsequently be used as inputs to the SSW Aquator model and the DO of the water supply system analysed. This work is reported on separately to this report.

6 References

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UKCP09, 2009. United Kingdom Climate Impacts Programme, Department for Environment, Food and Rural Affairs.

Appendices

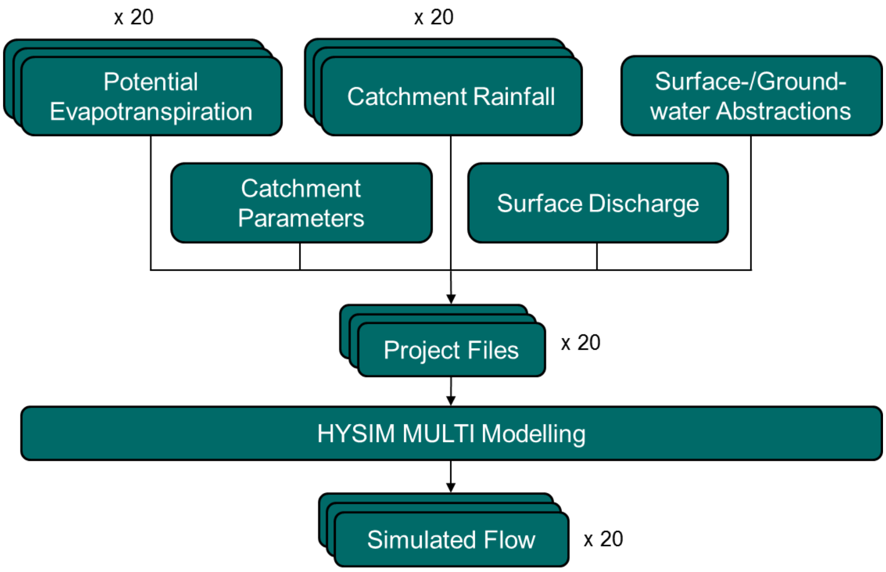
A. HYSIM modelling procedure

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 20 scenarios of rainfall and PET data for each catchment were efficiently created by perturbing the baseline series using python coding. These were manually converted into binary within HYSIM. The groundwater abstractions and surface discharge time series were the same as previously used with this generation of HYSIM models.

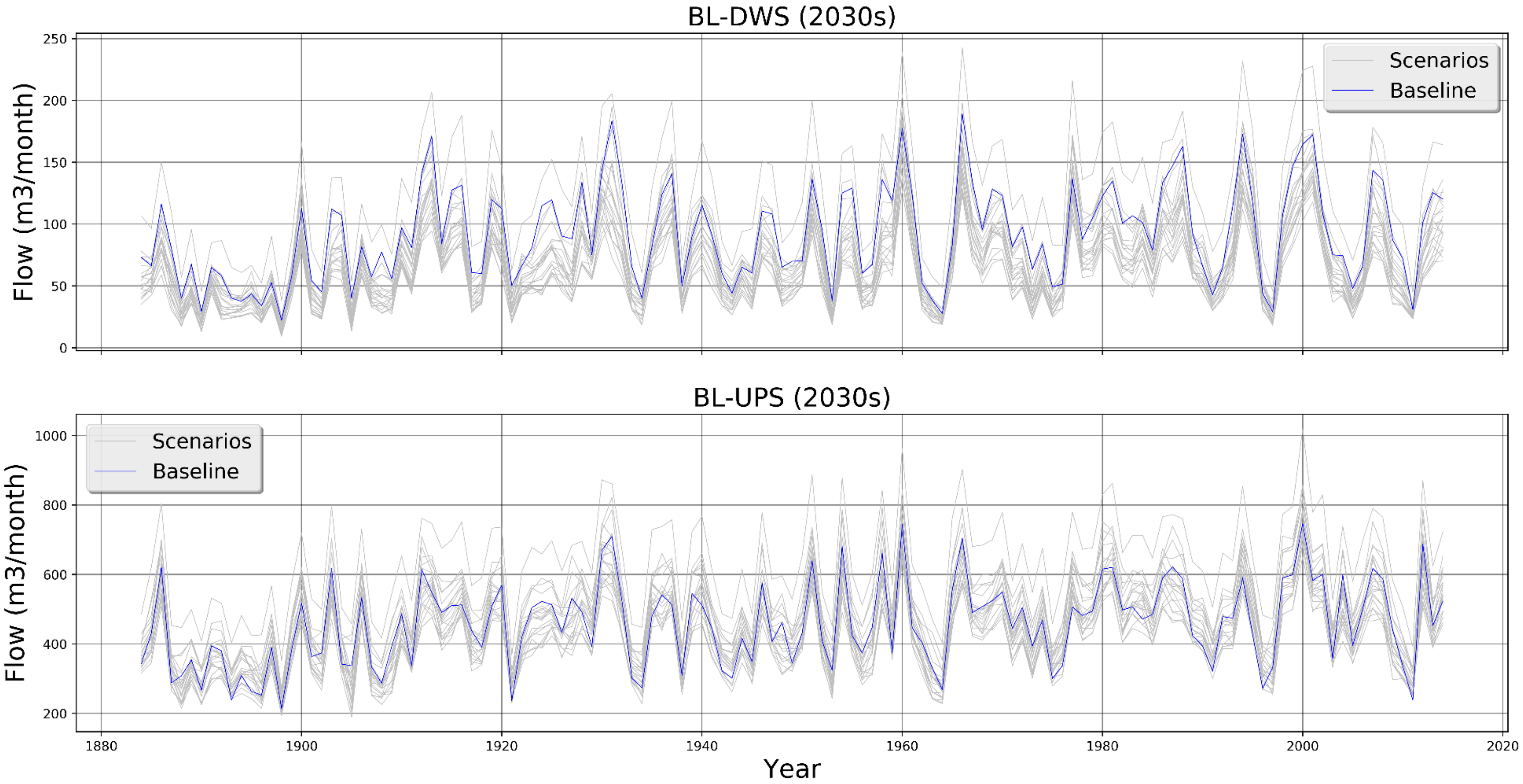
Whilst HYSIM supports the construction of the project files, the large number of model runs required meant this was not a feasible option. To create the project files outside of HYSIM required the CSV files to be constructed for each catchment outlining the file path names for each input component (i.e. 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 coding. Each catchment was run one at a time through HYSIM Multi which sequentially ran the 20 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 12.

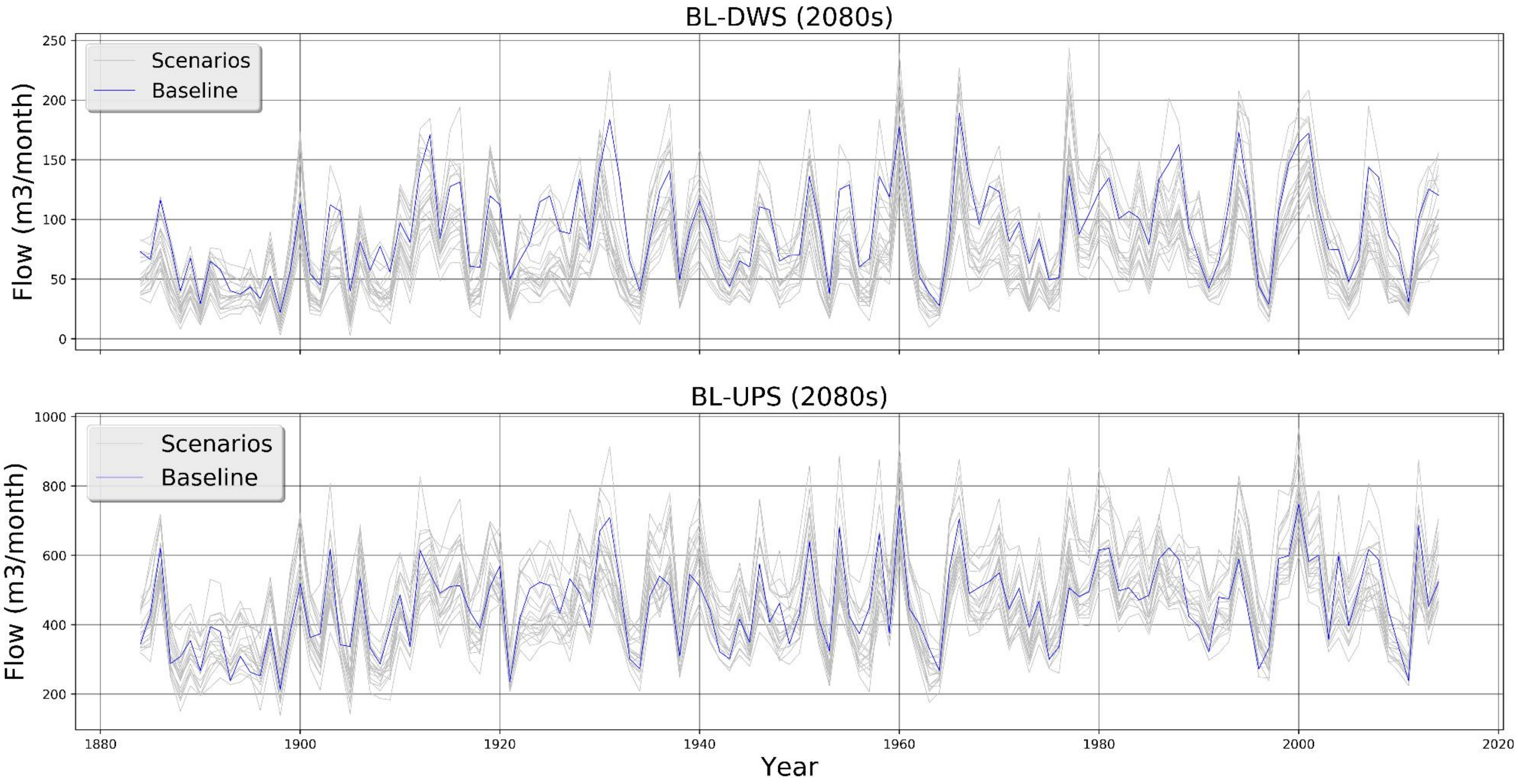
Figure 12: Flow chart for the HYSIM multi processing of 20 scenarios for a single catchment.



Note: “x 20” refers to the 20 scenarios series that were run through each HYSIM model.

B. Annual flow for CC scenarios and baseline




BL-DWS (2080s)
Scenarios
Baseline
Flow (m3/month)
250
200
150
100
50
0
BL-UPS (2080s)
Scenarios
Baseline
Flow (m3/month)
1000
800
600
400
200
1880
1900
1920
1940
1960
1980
2000
2020
Year

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