Hafren Dyfrdwy Resilience Modelling

Draft Report

Severn Trent Water

11 March 2019

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Document history

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Intro

1. Introduction

The overall objective of this project was to determine the drought resilience of the Hafren Dyfrdwy (HD) supply area, which consists of the Chester and Wrexham Resource Zones (RZ). Deployable output (DO) was determined across a range of drought severities to feed into the Water Resources Management Plan (WRMP) Table 10 Drought Links submission. Additional outputs, for example stochastic flow duration curves (FDC) and drought response surfaces (DRS), were also produced to help inform the Drought Plan.

Supply in the HD area is dominated by abstraction from the River Dee, therefore the drought resilience of this regulated catchment is of paramount importance. Previous assessments using historic hydrological data have demonstrated a high level of resilience. The Dee General Directions (DGD) maximum cut-back, Stage 3, has never been implemented either in practical terms or in model simulations. However, the latest WRMP and Drought Plan guidelines require that companies look beyond historic droughts to plausible “severe” or “extreme” events, with a return period of 1 in 200 years (0.5% annual chance) or 1 in 500 years (0.2% annual chance) respectively.

Fortunately, the project was able to utilise stochastic hydrological data generated for the Dee catchment by Atkins for United Utilities (UU) using a Weather Generator (add footnote). The dataset includes 17,400 years of rainfall and flow data for the following Dee sub catchments:

- Alwen
- Bala
- Brenig
- Celyn
- Manley Hall

These data represent conditions that could have, statistically speaking, happened in the past. As part of the generation process the stochastic probability distributions were matched with the historic ones. Due to the much larger volume of data in the stochastic record, the tails of the distribution are much better represented and therefore provide a range of severe and extreme droughts for assessment.

Natural Resources Wales’ (NRW) and Severn Trent Water Limited’s (STWL) Aquator water resources models were also made available for the project. As shown in Figure 1-1 below, and described in the following sections, the data and models were combined in a series of stages to determine drought resilience and DO.

1. Dee catchment resilience

Run the full stochastic dataset through the NRW Aquator model to determine the resilience of the Dee catchment

↓

2. Hafren Dyfrdwy inflow generation

Use the Dee stochastic record to help derive corresponding synthetic hydrology for the other surface water sources in the HD area

↓

3. Deployable output testing

Using the HD Aquator model, and the outputs from the previous two stages, derive a relationship between DO and return period

Figure 1-1 - Key stages of the project

2. Dee Catchment Resilience

2.1. Introduction

As outlined in Section 1, the Dee stochastic dataset was combined with the NRW Dee Aquator model to help determine the drought resilience of the Dee catchment. In addition to outputs showing the resilience of the catchment, a time series of stochastic DGD cut-backs was derived to use as a boundary condition in the HD model.

2.2. Stochastic dataset

UU provided its stochastic dataset for the Dee catchment, as developed for the 2019 WRMP. The full WRMP19 dataset covers the whole of UU's supply area from Cumbria, through Lancashire, down to Cheshire and North Wales. Of the 12 rainfall gauges used in the Weather Generator, four are located in North Wales.

As a check, FDCs were generated for each of the Dee sub catchments using both the stochastic data and the historic sequences exported from the NRW Aquator model. As shown in Figure 2-1 the fit between stochastic and historic is very strong in all catchments.

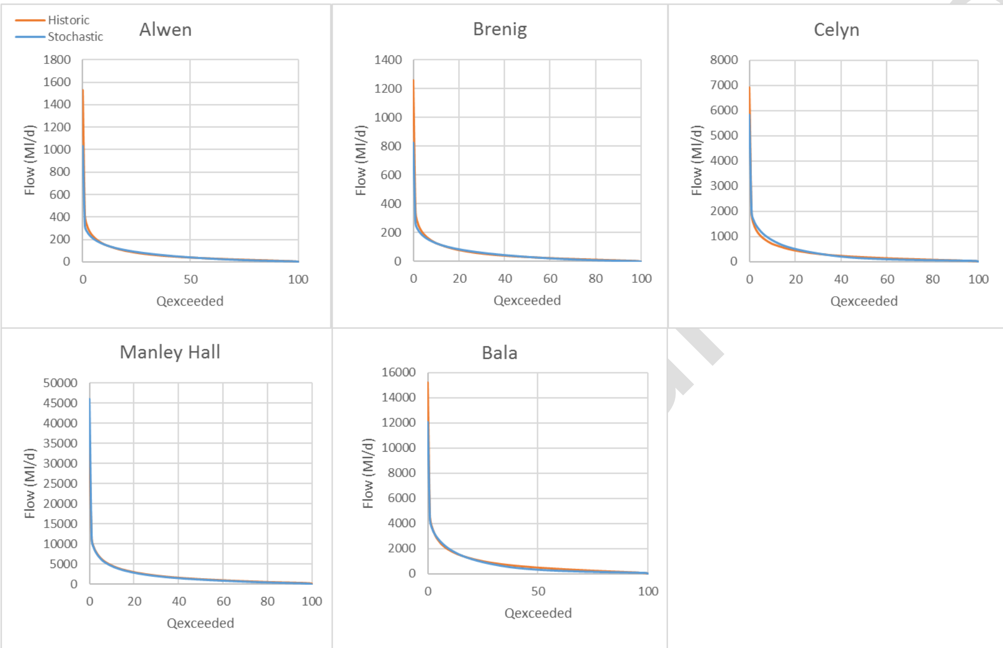


Figure 2-1 - Comparison of Dee catchment stochastic and historic FDCs

The 17,400 year stochastic dataset can be thought of as 200 alternative versions of the historic record. Whilst it can be combined into one contiguous sequence, in this project it was split into 10 batches; 00-19, 20-39, 40-59, 60-79, 80-99, 100-119, 120-139, 140-159, 160-179 and 180-199. These batches were used as follows:

- Model setup and testing: 00-19
- Dee NRW model runs: all batches
- HD model DO runs: 00-19, 40-59, 80-99, 120-139, and 160-179

2.3. NRW Aquator model

NRW maintains the Aquator model of the Dee system to assist with its regulatory obligations in the catchment. A schematic of the model is shown in Figure 2-2. The full stochastic dataset was run through the model to determine the resilience of the Dee catchment, and to generate a timeseries of cut-backs for use in stochastic runs of the HD model (Section 4).

Before undertaking the runs it was necessary to update the model to include DGD Stage 3 cut-backs (Stage 3 is not reached in historic runs, hence there was previously no requirement to include it in the model). Custom parameters were added to the DC1 component (Figure 2-3) and additional VBA code was added to the RG1 component to incorporate Stage 3 cut-backs. The code in RG1 was also modified to improve model run speed and is included in Appendix A.

Unlike previous climate change assessments undertaken by NRW, the DGD maximum yield, safe yield and cut-back amounts were not adjusted. The stochastic dataset is by design based on the same climatic conditions as the historic dataset (Figure 2-1), therefore there is no rationale to change any of the rules. Climate change impacts were not included in the assessment.

We retained the NRW model assumption that all Dee abstractors always take their maximum DGD entitlement. In reality this is not the case as abstractors also take into account operational rules and costs; these however were not available for the assessment. Also, there would always be the risk that other abstractors altered their operating practices in the future, leading to a lower level of resilience than assessed. Updated DGD cut-back rates were provided by NRW as shown in Table 2-1, along with the River Dee maintained flow condition values applied.

Table 2-1 – Model DGD parameters applied

DGD status	Demand (Ml/d)	River Dee maintained flow (Ml/d)
Maximum abstraction	763	381.979
Safe yield	717.12	381.979
Stage 1	687.12	350.4
Stage 2	657.12	318.821
Stage 3	627.12	318.821

Due to the volume of data in the stochastic dataset it was not possible to manually load the inflow timeseries into the model database and undertake a single run. Using scripts previously developed by Atkins, the following automated process was undertaken:

- Make multiple copies of the Aquator database
- Load a proportion of the stochastic dataset into each copy
- Select key output variables (reservoir storage and river flow)
- Run the models in parallel, export the selected data and delete the models

This process was undertaken in two parts (half of the stochastic dataset in each), each taking about 20 hours to complete.

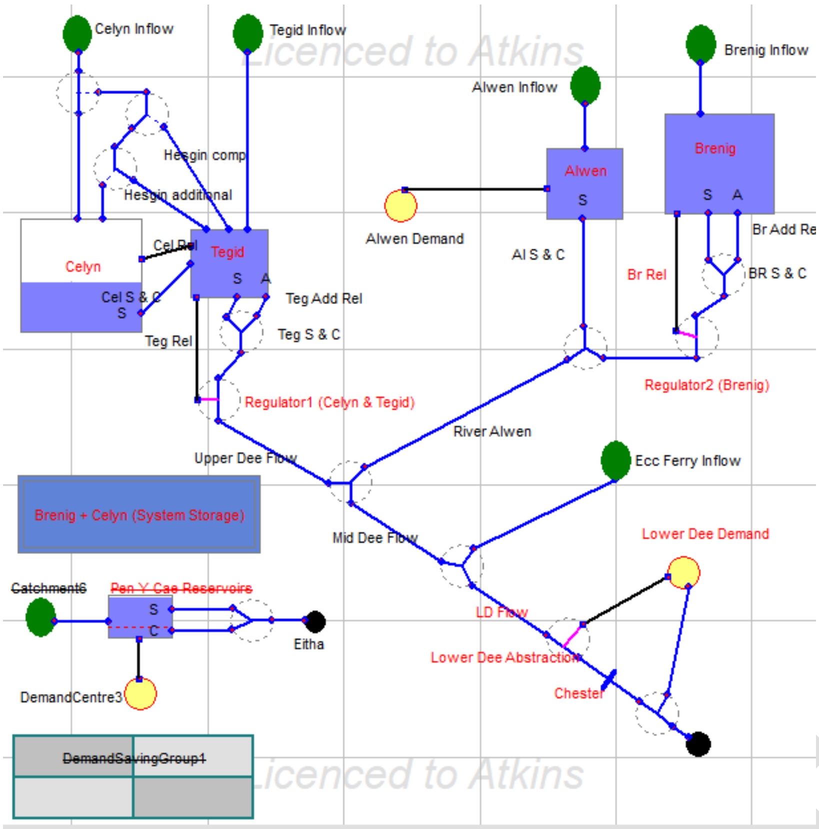
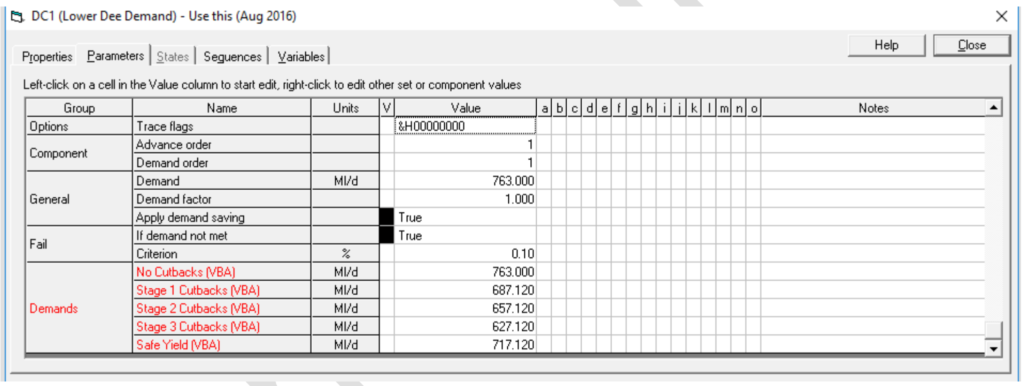


Figure 2-2 - Schematic of NRW Dee Aquator model



DC1 (Lower Dee Demand) - Use this (Aug 2016)

Properties | Parameters | States | Sequences | Variables | Help | Close

Left-click on a cell in the Value column to start edit, right-click to edit other set or component values

Group	Name	Units	V	Value	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	Notes
Options	Trace flags			&H00000000																
Component	Advance order			1																
	Demand order			1																
General	Demand	Ml/d		763.000																
	Demand factor			1.000																
	Apply demand saving			True																
Fail	If demand not met			True																
	Criterion	%		0.10																
Demands	No Cutbacks (VBA)	Ml/d		763.000																
	Stage 1 Cutbacks (VBA)	Ml/d		687.120																
	Stage 2 Cutbacks (VBA)	Ml/d		657.120																
	Stage 3 Cutbacks (VBA)	Ml/d		627.120																
	Safe Yield (VBA)	Ml/d		717.120																

Figure 2-3 – Custom parameters (in red) added to DC1 component to hold DGD abstraction rates

2.4. DGD cut-back post-processing

The NRW model applies cut-backs immediately once Dee storage passes below the corresponding storage curve. In the DGD text, however, delays are applied between crossing the curve and applying the cut-back:

> *"Stage 1: system storage below stage 1 control curve for 2 consecutive months, during the months March to October.*
>
> *Stage 2: system storage below stage 2 control curve for a month after stage 1 is already in place, during the months March to September.*
>
> *Stage 3: system storage below stage 3 control curve for a month after stage 2 is already in place, during the months March to September."*

The rules were applied retrospectively to the model results, using simulated storage from the run, before assessing resilience and generating the cut-back sequence for the HD model. Some difficulties were experienced in converting the written rules into logical code, therefore three interpretations were formulated and tested. A description of each option is provided in Table 2-2, along with the corresponding results in terms of the return periods of implementation. A corresponding run using the historic inflows was also completed for context.

Following discussion with STWL and NRW, Option 1 was taken forward in the assessment. It is recommended that in the future the NRW Dee model is updated to reflect the DGD text. Although the rules were incorporated into this assessment via post-processing, the effects are only partial as the cut-back demand reductions were still applied as the soon as the curves are crossed. This means that storage levels, and therefore resilience levels, are overstated by the model.

Some review of the rules themselves could also be beneficial. One notable effect of the long 1-2 month delays, as interpreted here, is that the simulated frequency of entering into emergency storage is higher than that of implementing stage 3 cut-backs (Table 2-3), i.e. emergency storage would be entered before the cut-back was applied.

Table 2-2 - Options for interpreting the DGD cut-back text

Inflows	Stochastic			Historic (1927-2016)
Rules approach	Option 1 No lag on previous stages For example, Stage 3 cutback is applied if storage is below the stage 3 curve for 30 days between Mar-September, irrespective of what has happened with stages 1 and 2.	Option 2 Lag applied consecutively from March For example, Stage 3 cutback is only applied once Stage 1 has been in place for 60 days and Stage 2 in place for 30 days. Stage 1 cannot start until March. No cutback is applied after September.	Option 3 Lag applied consecutively from January As per March but Stage 1 can start in January. No cutback is applied after September.	No lag on previous stages
Below stage 1 curve	1 in 7 years			1 in 8 years
Below stage 2 curve	1 in 13 years			1 in 11 years
Below stage 3 curve	1 in 54 years			1 in 46 years
Below emergency storage	1 in 212 years			N/A
Stage 1 cutbacks implemented	1 in 24 years	1 in 24 years	1 in 21 years	1 in 46 years
Stage 2 cutbacks implemented	1 in 38 years	1 in 81 years	1 in 70 years	1 in 91 years
Stage 3 cutbacks implemented	1 in 311 years	1 in 512 years	1 in 446 years	N/A

2.5. Results

The results of assessment were compared against the DGD standards of service, as shown in Table 2-3. The service levels are met for Stage 2 but not quite met for Stage 2 (1 in 38 years versus 1 in 40 years). Note that the HD temporary use ban (TUBs) service level of 1 in 40 years is linked to Stage 3. The DGD also has a 60 month refill target. We anticipate that it may not be met at times due to the severity of some stochastic droughts. However, as there is no return period linked to this target we did not undertake testing; it would be difficult to put any stochastic failures into context. Also, as previously mentioned there was no intention to adjust any of the DGD rules, such as the safe yield amount.

Table 2-3 – Modelling results compared to DGD standards of service

Inflows	Simulated return period	DGD standards of service
Stage 1 cutbacks implemented	1 in 24 years	1 in 10 years
Stage 2 cutbacks implemented	1 in 38 years	1 in 40 years
Stage 3 cutbacks implemented	1 in 311 years	Not specified
Below emergency storage	1 in 212 years	N/A

Storage duration curves and FDCs were also generated to help demonstrate the resilience of the Dee catchment; they are shown in Figure 2-4 and Figure 2-5 respectively. The storage duration curve shows that the Dee reservoirs (RG1 corresponds to the Celyn and Brenig storage combined) could plausibly become empty during an extreme drought. However, flow downstream of the abstraction point, as represented by the FDC, always remains above 318 Ml/d. This flow is consistent with the Stage 2 / 3 maintained flow requirement (Table 2-1), demonstrating that even during the most severe conditions, when Celyn and Brenig storage is exhausted, there is still flow in the catchment.

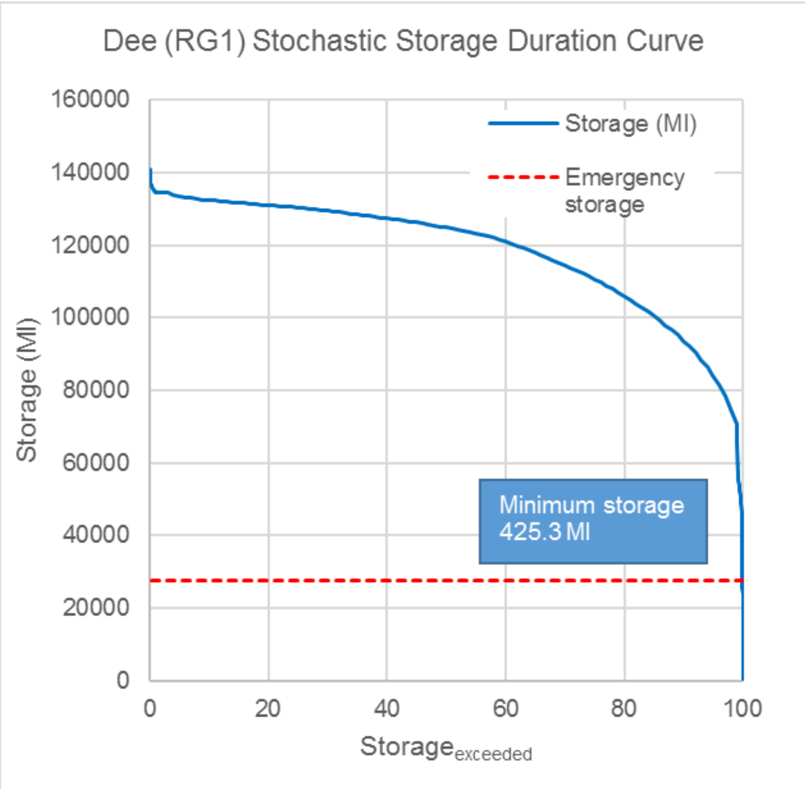


Figure 2-4 - Dee (RG1) storage duration curve

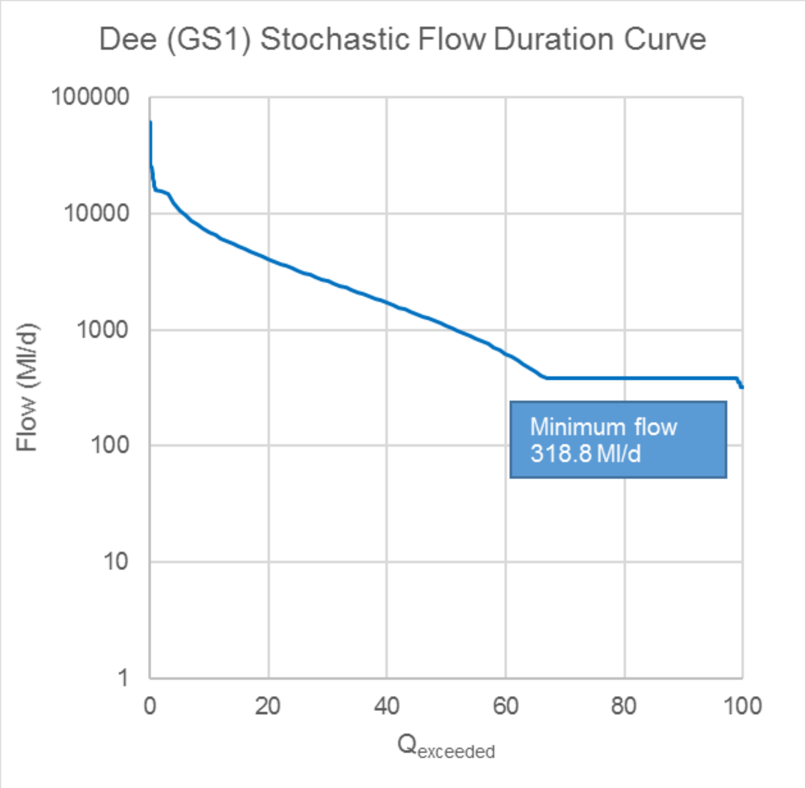


Figure 2-5 - Dee (GS1) FDC

2.6. Drought response surfaces

To add

3. Hafren Dyfrdwy inflow generation

Whilst supply to HD customers is dominated by abstraction from the River Dee there are other sources of supply, as shown in the Aquator model schematic below (Figure 2-5). The groundwater sources are considered to be resilient to drought and constrained only by asset capacity or licence. However, there are several impounding reservoirs in the Wrexham RZ which could be vulnerable to severe or extreme droughts.

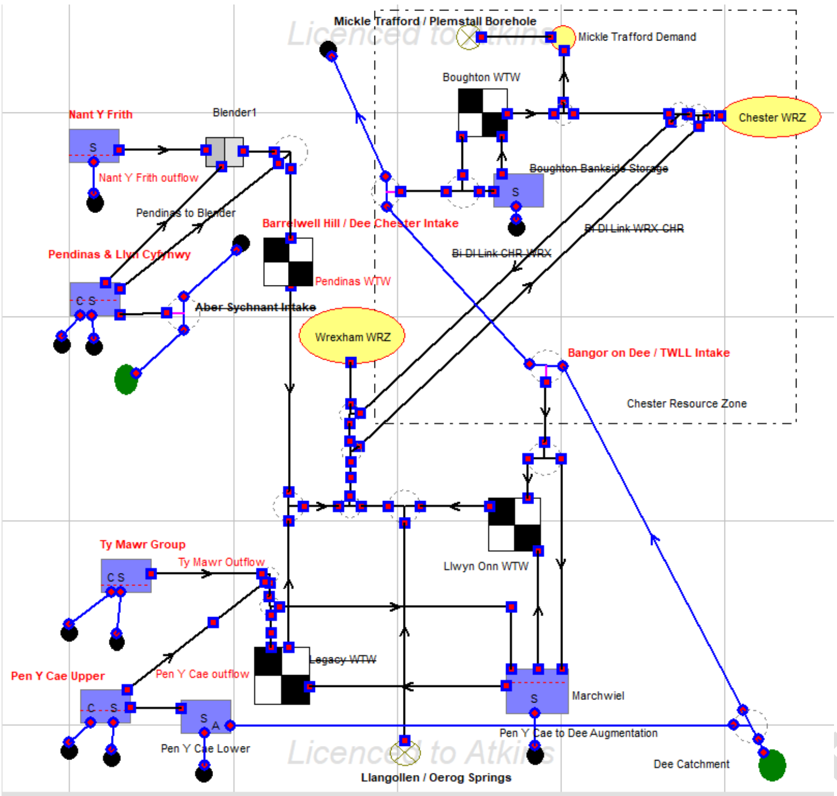


Figure 3-1 – HD supply area Aquator model schematic

As noted in the Atkins model development report[1] the inflows to these surface water sources are ungauged. Therefore, inflows were inferred using flow from gauging stations with similar catchment characteristics. The principle gauge used was Ceiriog at Brynkinalt Weir (67005). NRW's Brenig flow sequence (as used in the Dee Aquator model) was used to infill periods where the Ceiriog data quality was poor.

The method used was to sample the FDCs of the ungauged location, as extracted from the Low Flows Enterprise (LFE) software, and the gauged location. A similar approach was used here to generate stochastic inflows for the Wrexham RZ sources. As Brenig had previously been selected for use due to its hydrological similarity to the Wrexham RZ catchments it was again used here. New data points were included in the extremities of the FDCs to reflect the extra information available from the stochastic dataset. The full process is shown below in Figure 3-2. It was only undertaken for the half of the stochastic dataset used in the DO testing (Section 1).

[1] Aquator model audit and review, Dee Valley Water, March 2017

Stochastic FDC

Create a FDC using the full Brenig stochastic dataset. Include exceedance intervals down to 0.001 between Q1 and Q0 and Q99 and Q100.

↓

Wrexham RZ source FDC

Extend the LFE flow duration curves (produced for the original model build) to include the same intervals as the stochastic FDC. Populate these intervals using the stochastic FDC values (set each interval as a proportion of Q1 or Q99)

↓

Daily sampling

For each day in the Brenig stochastic record:

1. Look up today's flow on the Brenig flow FDC
2. Record the exceedance value, e.g. Q34
3. Look up the Brenig exceedance value on the Wrexham source FDC
4. Use the corresponding flow as today's value in the Wrexham source stochastic record

Figure 3-2 – Stochastic inflow generation process

4. Deployable output testing

4.1. Approach

As noted in Section 1, the main objective of the project was to determine the relationship between DO and drought severity / return period. The Aquator Scottish Method DO analyser was used for this purpose. It is similar to the English and Welsh method but rather than focussing on the demand that can be met without any failures, the number of failures is counted up across a range of demands. The demand interval and window is specified by the user. This results in a matrix of demand failure levels and number of years failure which can then be translated into a relationship between DO and return period (Figure 4-2).

This type of run is very computationally demanding, hence is was infeasible to utilise the full stochastic dataset. The results of the NRW Dee Aquator model runs were used to help determine the volume of stochastic data required to produce results that were representative of the full dataset. As noted in Section 1, the stochastic dataset was spilt into 10 batches and the model results - return periods of stage 1, 2 and 3 cut-backs and breaching emergency storage - from each batch were compared. Using just one batch did not represent the full stochastic dataset well. However, using any combination of half of the results represented the full dataset effectively. Therefore, as introduced in Section 1, alternate batches were selected for use.

Owing to the nature of the supply system, the modelling work was focussed on the Wrexham RZ. The drought resilience of the Chester RZ can simply be derived from the ability of Pen Y Cae to augment the River Dee during cut-backs (Section 4.3).

4.2. Wrexham RZ

4.2.1. Input data preparation

The reservoir inflow data were prepared as described in Section 3. As shown in Figure 3-1, the Dee system is included in the model as a river only, with no simulation of the Dee reservoir storage further up the catchment. Inflow to the Dee catchment is unconstrained (a daily profile of 9999 Ml/d is used) but the intake capacity is limited to either the maximum abstraction or the safe yield (45.5 or 41.5 Ml/d respectively) based on a sequence imported into the model. A new sequence was generated for this purpose based on the simulated Dee storage levels from the stochastic run (Section 2.3).

When stage 1, 2 or 3 cut-backs are enforced Pen Y Cae Lower reservoir is used to augment the River Dee (rates of 0.4, 0.8 and 1.2 Ml/d respectively, to cover both RZs), so that the safe yield level of abstraction can be maintained. Therefore, testing this augmentation process was key to determining the resilience of the HD supply. A sequence of augmentation amounts was also created using the simulated Dee storage levels from the stochastic run. As per the original configuration, flow rates of 1.2 Ml/d were applied on the first two days of augmentation to represent channel wetting. Note that the results of the assessment are not sensitive to this assumption.

4.2.2. Model preparation

As noted above, modelling was focussed on the Wrexham RZ. To reduce model complexity, and run time, the Chester RZ portion of the model was removed to create a Wrexham RZ model. The schematic is shown below in Figure 4-1.

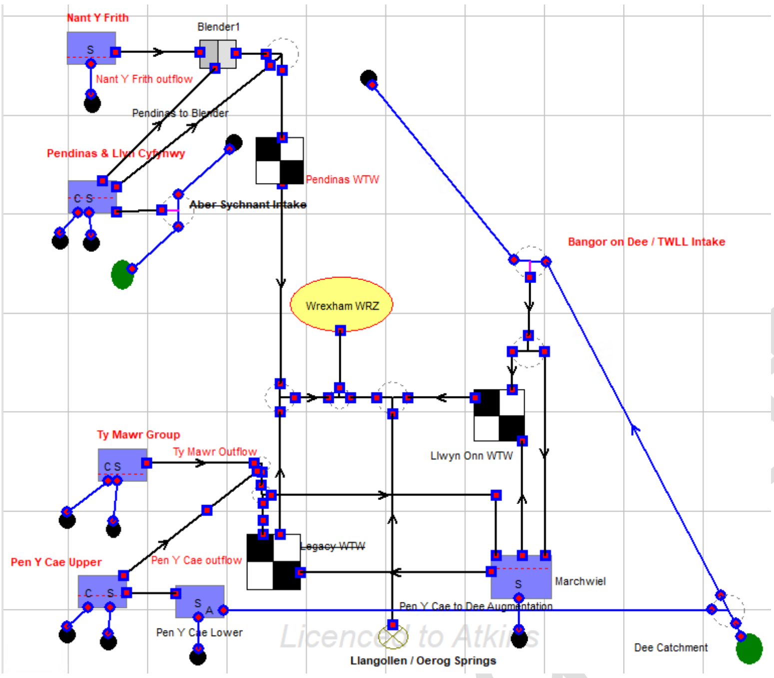


Figure 4-1 – Wrexham RZ Aquator model schematic

Using the first batch of stochastic inflows (00-19) significant testing was undertaken to ensure that the model was able to respond to the severe and extreme droughts in a sensible manner. A number of control curves were adjusted and the resilient Dee and Llangollen / Oerog Springs sources were encouraged to abstract as much water as possible using minimum flow constraints. At lower demands (40-50 M/d) the changes were effective and the number of failures (i.e. emergency storage breaches or demand shortfalls) were reduced. At higher demands, however, the number of failures was increased. This was not investigated in detail but was likely due to the minimum flow conditions which can cause problems for the Aquator optimiser if they cannot be met at high levels of system stress.

Unfortunately, the HD Aquator model is not configured to apply the demand savings associated with the implementation of TUBS or non-essential use bans (NEUB). TUBs restrictions are linked to DGD Stage 3; as this is not reached it historic runs there was no past requirement to include this in the model. Also, demand saving in Aquator is normally by enacted by simulating reservoir storage passing below a drought curve. However, the Dee storage is not simulated in the HD model. There are other ways to implement this, for example VBA to modify the demand saving level based on the sequence used for Pen Y Cae augmentation, which is itself based on the DGD stage. Unfortunately, there was insufficient time available to implement this within the project. It is recommended that this work is undertaken in the future; it would lead to higher DO results for a given return period.

As per the original HD model configuration, the use of emergency storage was not permitted during runs.

4.2.3. Results

Whilst this RZ is dominated by supply from the River Dee, drought resilience can be affected by other sources. These sources have a high level of drought resilience, but not quite matching that of the River Dee. During plausible drought events hydrology, rather than asset capability / licence, can become the DO constraint.

The results from the Scottish Method DO runs are shown in Table 4-1 below, by batch and combined. A further processing step was applied to combine failures occurring in consecutive years into a single failure. The assumption was that in the majority of cases this would be representative of a single, multi-year drought. In any case this had a relatively limited effect on the results. It is recommended that further analysis of some of the individual stochastic droughts is conducted in the future.

The results across the 1700-year batches are relatively consistent but there are some differences, particularly in batch 120-139. The relationship between DO and return period is shown graphically at two different scales in Figure 4-2 and Figure 4-3. The historic asset capacity / licence based DO of 51.2 Ml/d has a return period of 1 in 44 years once a larger selection of hydrological events is used. The return period of an event which would threaten supply at dry year demand plus target headroom[2] is only around 1 in 1,200 years. The 1 in 200 year DO is 50.1 Ml/d and the 1 in 500 year DO is 49.0 Ml/d.

Table 4-1 - Wrexham RZ Scottish Method DO results

Failure demand (Ml/d)	**Stochastic return period (years)**					
	00-19	**40-59**	**80-99**	**120-139**	**160-179**	**Combined (8,700 years)**
39	No failures	No failures	No failures	No failures	No failures	No failures
40	1740	1740	1740	No failures	No failures	2900
41	1740	1740	1740	No failures	No failures	2900
42	1740	1740	1740	No failures	No failures	2900
43	1740	1740	1740	No failures	No failures	2900
44	870	1740	1740	No failures	1740	1740
45	580	1740	1740	No failures	1740	1450
46	580	1740	1740	No failures	1740	1450
47	580	1740	870	No failures	870	1088
48	348	870	870	No failures	870	791
49	348	435	435	1740	580	512
50	290	249	193	193	193	218
51	70	62	54	76	50	61
51.2	50	48	40	44	39	44
52	1	1	1	1	1	1

[2] 46.46 Ml/d, from the year 2020/21 in the Final WRMP

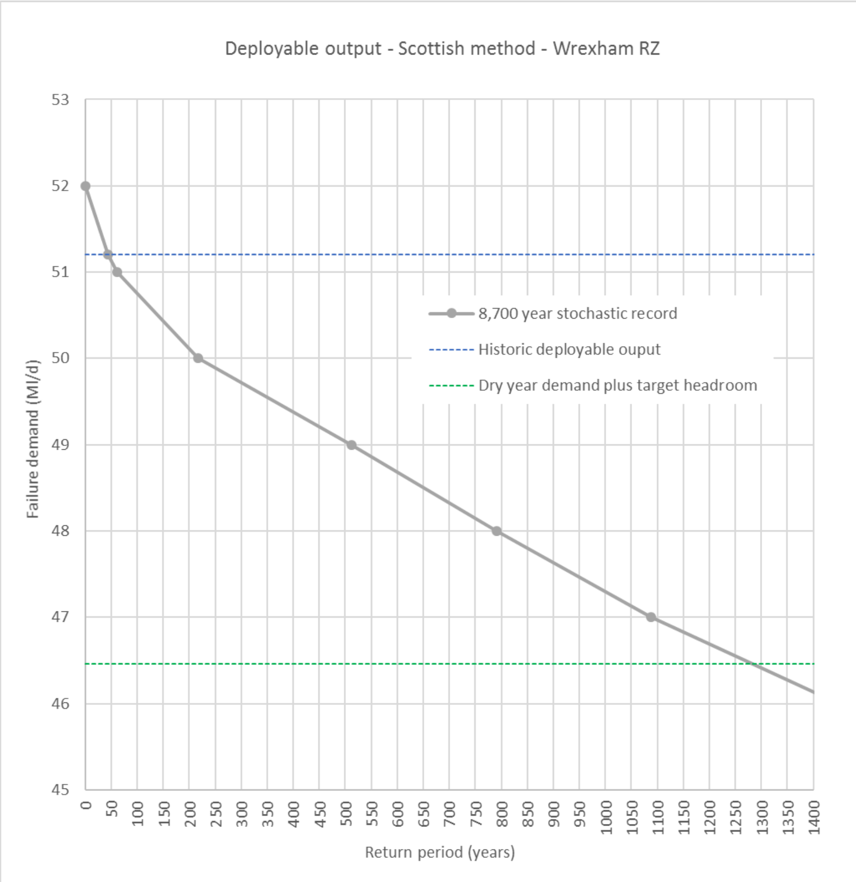


Figure 4-2 - Wrexham RZ relationship between DO and return period (0-1400 year return period)

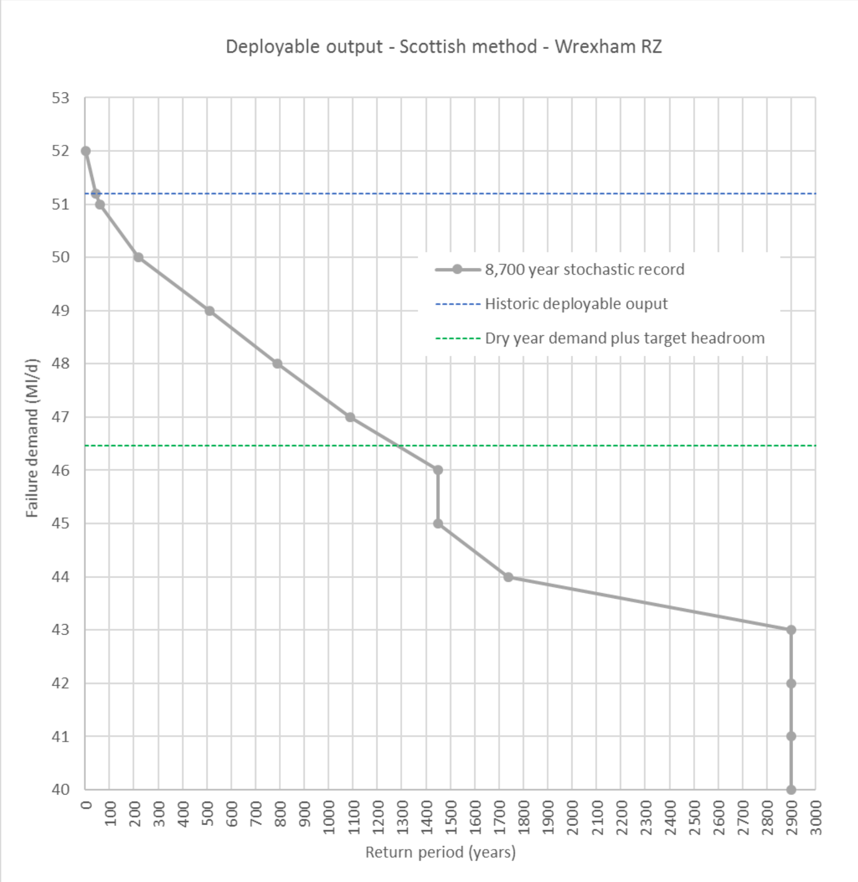


Figure 4-3 - Wrexham RZ relationship between DO and return period (all results)

4.3. Chester RZ

A Chester RZ model was created but not used in the assessment. As shown in Figure 4-4, the only sources in the RZ are the River Dee and Mickle Trafford borehole. The borehole is resilient to drought and the River Dee abstraction is protected from DGD cut-backs by augmentation from Pen Y Cae Lower in the Wrexham RZ, as shown in Figure 4-1.

Therefore, the testing undertaken for the Chester RZ was to run all of the stochastic data prepared for DO modelling (i.e. half of the batches, 8,700 years) through the Wrexham RZ model with a demand of 51.2 Ml/d. This represents the English and Welsh method DO of the Wrexham RZ and is constrained only by asset capacity / abstraction licence. It is well above forecast demand and target headroom for the RZ (46.46 Ml/d).

Augmentation from Pen Y Cae Lower reservoir was fully maintained throughout all plausible severe and extreme droughts. Therefore, the Chester RZ was deemed to be resilient to plausible severe and extreme droughts, and the DO at all return periods is consistent with the historic, asset capacity / licence-based DO of 29.3 Ml/d.

Due to the reliance on sources situated in the Wrexham RZ, further review of the connectivity / risk equivalence between the two RZs is recommended at the next RZ integrity test.

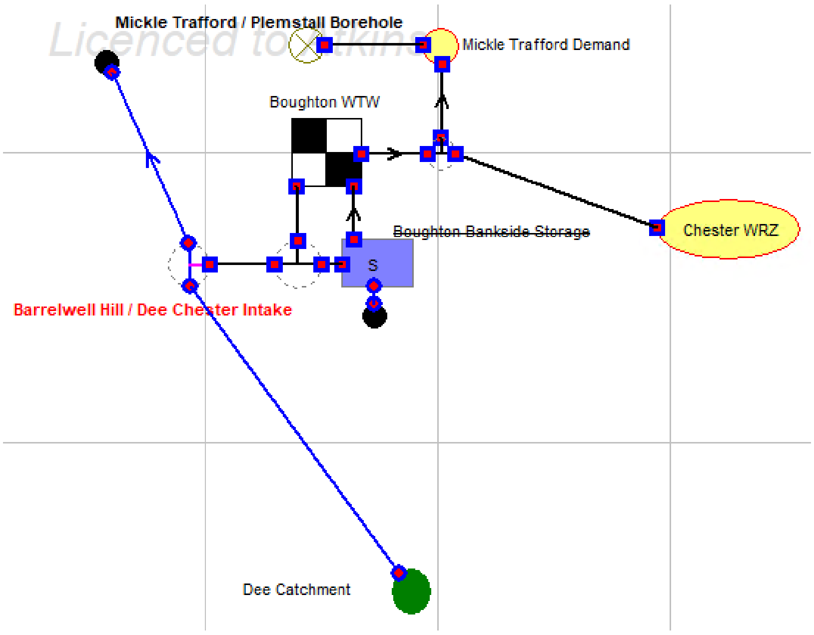


Figure 4-4 – Chester RZ Aquator model schematic

5. Conclusions and recommendations

Owing to the nature of the Dee catchment the HD supply area is very resilient to drought. In the Chester RZ the severe and extreme plausible droughts tested did not impact DO. In the Wrexham RZ some of the other sources are slightly less resistant to drought, but the level of resilience is still very high. The 1 in 200 and 1 in 500 year DO results of 50.1 and 49.0 Ml/d are lower than the existing historic based English DO of 51.2 Ml/d, but significantly higher than dry year demand of 46.46 Ml/d (including target headroom).

This assessment was completed in relatively short period of time. Despite this the method of determining DO for plausible severe and extreme droughts is very robust, and in line with industry-leading practices. As noted in previous sections, there are a few recommended areas for further review or assessment:

- Review the timing of the implementation of DGD cut-backs in the Aquator simulation of Dee storage - application of delays.
- RZ integrity review of the links between the Wrexham and Chester RZs - common reliance on the River Dee and Pen Y Cae.
- Re-assess DO with TUBs demand restrictions implemented during Stage 3 cut-back periods. Consider how NEUBs are represented.
- Conduct some more detailed analysis of individual stochastic drought events.

Appendices

Appendix A. NRW VBA changes – RG1 object

```
Option Explicit

' To hold the value and date of min storage during a run
Private m_fMinStorage As Single
Private m_dtMinStorage  As Date
Private RG_Supply_CC As IAquator.IProfile
Private DS1_CC As IAquator.IProfile
Private DS2_CC As IAquator.IProfile
Private DS3_CC As IAquator.IProfile
Private Dem_NoCutback As Single
Private Dem_SafeYld As Single
Private Dem_Stage1 As Single
Private Dem_Stage2 As Single
Private Dem_Stage3 As Single
Private HOF_NoCutback As Single
Private HOF_SafeYld As Single
Private HOF_Stage1 As Single
Private HOF_Stage2 As Single
Private HOF_Stage3 As Single

Private Sub ReservoirGroup_AfterInitialize(ByVal StartDate As Date, ByVal Steps As Long)
    ' Invalidate results at start of run
    m_fMinStorage = 300000
    m_dtMinStorage = CDate(0)

    'Set curves to control behaviour
    Set RG_Supply_CC = Me.Q_ControlCurve.ActiveProfile
    Set DS1_CC = Me.Q_DemandSavingCurve(1).ActiveProfile
    Set DS2_CC = Me.Q_DemandSavingCurve(2).ActiveProfile
    Set DS3_CC = Me.Q_DemandSavingCurve(3).ActiveProfile

    'Set constraint and demand values from parameters
    Dem_NoCutback = Model.Components("DC1").Parameters("Demands.No Cutbacks (VBA)").Value
    Dem_SafeYld = Model.Components("DC1").Parameters("Demands.Safe Yield (VBA)").Value
    Dem_Stage1 = Model.Components("DC1").Parameters("Demands.Stage 1 Cutbacks (VBA)").Value
    Dem_Stage2 = Model.Components("DC1").Parameters("Demands.Stage 2 Cutbacks (VBA)").Value
    Dem_Stage3 = Model.Components("DC1").Parameters("Demands.Stage 3 Cutbacks (VBA)").Value
    HOF_NoCutback = Model.Components("GS1").Parameters("Flow constraint.No cutbacks
(VBA)").Value
    HOF_SafeYld = Model.Components("GS1").Parameters("Flow constraint.Safe yield
(VBA)").Value
    HOF_Stage1 = Model.Components("GS1").Parameters("Flow constraint.Stage 1 Cutback
(VBA)").Value
    HOF_Stage2 = Model.Components("GS1").Parameters("Flow constraint.Stage 2 Cutback
(VBA)").Value
```

```
    HOF_Stage3 = Model.Components("GS1").Parameters("Flow constraint.Stage 3 Cutback
(VBA)").Value

End Sub

'temporarily block out below for yield search (comment block), see code on DC1
    Private Sub ReservoirGroup_BeforeStartDay(ByVal Timestamp As Date, ByVal Step As Long,
DemandSaving As Single)
    'limit abstraction when system storage is below safe yield, S1 & S2 drought lines

        Dim fControlCurveValue As Single 'Safe yield
        Dim fLevel1CurveValue As Single 'cutback stage 1
        Dim fLevel2CurveValue As Single 'cutback stage 2
        Dim fLevel3CurveValue As Single 'cutback stage 3

        'get control curve value
        Call RG_Supply_CC.GetDataForDay(Timestamp, fControlCurveValue)
        'If system storage < safe yield abstract safe yield other wise take max authorised
        If Me.V_StorageCalculatedPC > fControlCurveValue Then
            DC1.P_Demand = Dem_NoCutback
            AB1.P_FlowConstraintValue = HOF_NoCutback
        Else
            'get control curve value
            Call DS1_CC.GetDataForDay(Timestamp, fLevel1CurveValue)
            If Me.V_StorageCalculatedPC > fLevel1CurveValue Then
                DC1.P_Demand = Dem_SafeYld
                AB1.P_FlowConstraintValue = HOF_SafeYld
            Else
                'get control curve value
                Call DS2_CC.GetDataForDay(Timestamp, fLevel2CurveValue)
                If Me.V_StorageCalculatedPC > fLevel2CurveValue Then
                    DC1.P_Demand = Dem_Stage1
                    AB1.P_FlowConstraintValue = HOF_Stage1
                Else
                    'get control curve value
                    Call DS3_CC.GetDataForDay(Timestamp, fLevel3CurveValue)
                    If Me.V_StorageCalculatedPC > fLevel3CurveValue Then
                        DC1.P_Demand = Dem_Stage2
                        AB1.P_FlowConstraintValue = HOF_Stage2
                    Else
                        DC1.P_Demand = Dem_Stage3
                        AB1.P_FlowConstraintValue = HOF_Stage3
                    End If
                End If
            End If
        End If

    End Sub

Private Sub ReservoirGroup_BeforeTerminate()
```

```
  ' Report min storage in model run log at end of run
  Call Model.AddLog(aqtLogInformational, "RG1", "Min storage = " & Format$(m_fMinStorage,
"0") & " on " & Format$(m_dtMinStorage, "dd mmm yyyy"))
End Sub

Private Sub ReservoirGroup_AfterTerminateDay(ByVal Timestamp As Date, ByVal Step As Long,
AmountAdded As Single, AmountStored As Single, AmountLeaked As Single, AmountLost As
Single, Cost As Single, Status As IAquator.aqtStatus)
  ' Check for min storage each day
  If Me.V_StorageCalculatedQ < m_fMinStorage Then
    m_fMinStorage = Me.V_StorageCalculatedQ
    m_dtMinStorage = Timestamp
  End If

'temporarily block out below for a yield search, see code on DC1 for yield search
'   set emergency storage (30 day storage reserve) at 27475 Ml and fail if used
    If Me.V_StorageCalculatedQ < 27475 Then
        Call Model.AddLog(aqtLogFailure, "RG1", "run failure - below storage reserve")
        Status = aqtStatusFailure
    End If

End Sub
```

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