ST Classification: OFFICIAL SENSITIVE

Draft Water Resources Management Plan

Appendix A: Supply - How much water we have

RHAGOROL O'R TAP
WONDERFUL ON TAP

HAFREN DYFRDWY
severn dee

Appendix A: How much water we have

A1 Defining our Water Resource Zones

Water resource zones, often referred to simply as WRZs, are the building blocks of our draft Water Resource Management Plan (dWRMP). They provide a strategic framework for water resources supply-demand management and investment. The full definition of a WRZ is **"an area within which, managing supply and demand for water is largely self-contained (apart from defined bulk transfers of water); where the resource units, supply infrastructure and demand centres are linked such that customers in the WRZ experience the same risk of supply failure"**.

We have maintained the same four WRZs as our WRMP19. These are:

- Saltney
- Wrexham
- Llanfyllin
- Llandinam and Llanwrin.

The WRZs are shown in Figure A1.1.

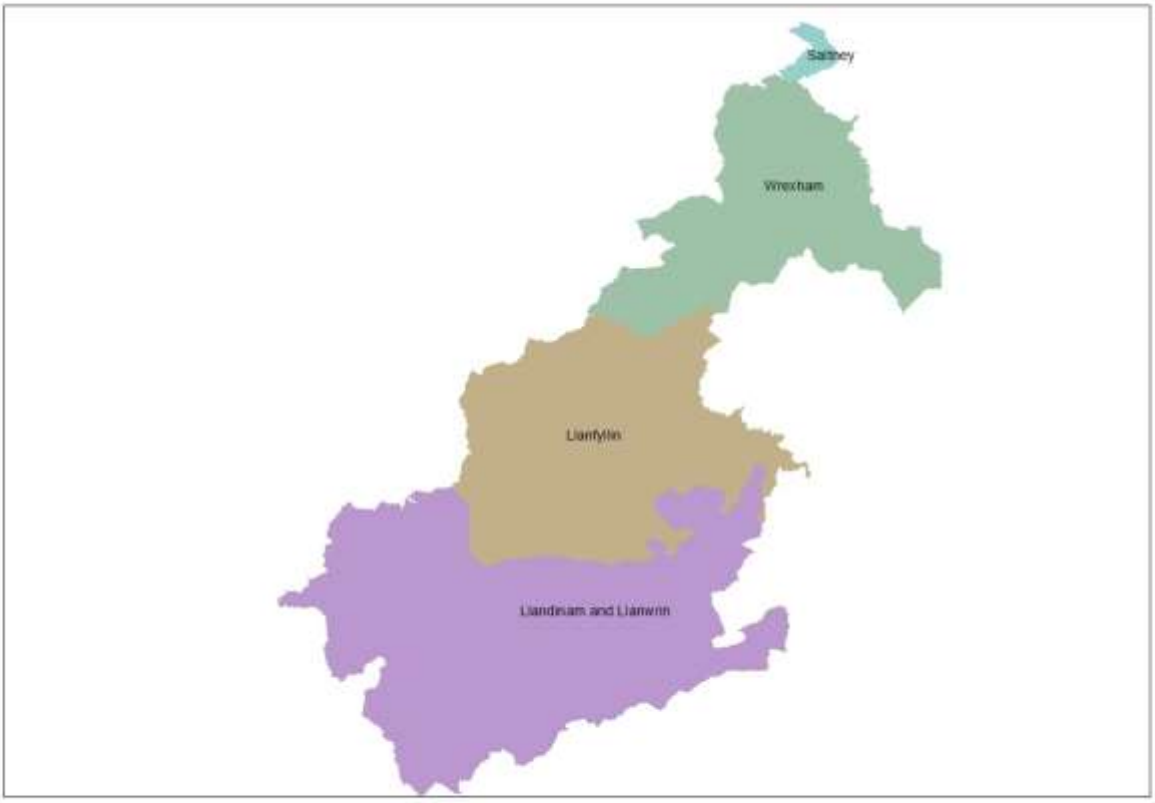

Figure A1.1: Our water resource zones

A2 Calculating deployable output

Once we have defined our Water Resource Zones, we need to establish the amount of water available for use (commonly referred to as WAFU). The starting point for this is the 'deployable output' or 'DO' – the maximum amount of water that we can output from a source or a group of sources.

As discussed in section A1, we have four water resource zones. One zone is conjunctive use (supplied by a river abstraction, raw water reservoir abstractions and a small groundwater source), one zone is supplied by groundwater only and two zones are supplied by bulk supplies from Severn Trent. The deployable output for water resource zones is calculated differently depending on which type of zone they are. The zones and methods used are tabulated below in Table A2.1.

Table A2.1: Deployable Output Methodologies Used

WRZ Name	Type	Method	Reason
Wrexham	Conjunctive Use	Aquator modelling	River and reservoir surface water supplies with a complex network.
Llandinam and Llanwrin	Groundwater Only	UK Water Industry Research (UKWIR) Assessment	Groundwater Only
Saltney	Bulk Import	Agreed Import amount	Import from Severn Trent Water
Llanfyllin	Bulk Import	Agreed Import amount	Import from Severn Trent Water

Wrexham WRZ – deployable output methodology

We used modelling software called Aquator to calculate an initial[1] DO. An Aquator model is set up to mimic the various components of a water company network (water sources, treatment works, key trunk mains, demand management zones etc), and each component can then be manipulated within the model to assess how the network would perform against a range of scenarios.

An Aquator model was originally built for the Dee Valley Water network in 2015, when the company was looking for alternative options to rebuilding Legacy water treatment works (WTW) in Wrexham WRZ. Prior to the development of WRMP19, an audit and review of the model was conducted and followed by an initial assessment of the DO for Wrexham WRZ. In March 2017, Dee Valley Water produced a report[2] describing the setup of the revised model, the inputs, parameter values and operating rules implemented, and the outcome of initial DO assessment. The report also made a number of recommendations for future improvements to the model and operating procedures within Dee Valley Water which could optimise the DO of the system.

Assumptions

Assumptions made during the model build are listed below. No changes have been made to these assumptions in the model used for dWRMP24. The same model was used for the drought plan modelling too.

- The model assesses supply only, therefore the demand that the system can meet will not match the DO provided.
- No account has been taken of leakage, process losses or headroom etc.

[1] I.e. does not take account of leakage, outage, headroom or any other losses, and the model does not incorporate any imports or exports.
[2] *Aquator model audit and review – Dee Valley Water: 22 March 2017*

- No imports or exports have been included in the model. These are accounted for in the dWRMP24 tables.
- All runoff from the Pendinas Indirect and Direct catchments enters Pendinas reservoir.
- Pen Y Cae Upper reservoir will be used to refill Pen Y Cae Lower reservoir when it drops below top water level.
- Water used to augment the River Dee from Pen Y Cae Lower is considered to be abstracted under the Pen Y Cae annual licence.
- Nant Y Ffrith reservoir can supply 0.6 Ml/d from May to December if the water is mixed with water from Pendinas / Llyn Cyfynwy in a 25:75 ratio.
- 36 Ml/d of water can be transferred from Ty Mawr, Pen Y Cae and the Dee to Llywn Onn WTW through Marchwiel storage reservoir if available in the sources. Any other water in Marchwiel reservoir cannot be used for supply under normal conditions.
- Legacy WTW has been decommissioned for the baseline.
- Oerog Springs compensation flow has been accounted for when calculating the yield as 2.8 Ml/d.

Hydrology – river sources
As previously stated, our main source of water in this WRZ is the River Dee. The Industrial Revolution led to many rivers in industrial areas becoming too polluted to use directly for drinking water but the Dee was a notable exception. The Chester Waterworks Company was formed in 1826, drawing water from the River Dee to supply the City of Chester; during drier summer months, the natural flows of the river weren't always sufficient to support the high levels of abstraction needed to support the Shropshire Union Canal and these drinking water abstractions. Therefore, sluices were built at Bala Lake outlet to allow controlled releases of water to support the natural flow of the Dee. Nearly 150 years on, this scheme was expanded with new sluices being built at Bala Lake in the 1950s and the construction of two new reservoirs - Llyn Celyn and Llyn Brenig – in the 1960s and 1970s respectively.

In 1989, following the privatisation of the water industry, the regulation of the River Dee came under the control of the National Rivers Authority, which was succeeded by Environment Agency Wales in 1996. In 2013 the regulation of flows came under the joint control of Natural Resources Wales (NRW) and the Environment Agency.

The Dee Consultative Committee (DCC), which represents the interests of all the major abstractors and river interests, was set up under the Dee and Clwyd River Authority Act 1973. Chaired by NRW, current membership is made up of representatives from the Environment Agency, United Utilities, Hafren Dyfrdwy, Severn Trent, Dŵr Cymru Welsh Water and the Canal and River Trust. The complex rules used to operate the regulation scheme are prepared with this Committee's advice, and the special conditions for operation in severe droughts must be approved by all members of the Committee, largely the additional abstraction restrictions which are invoked at various drought trigger points as dictated by reservoir storage levels.

The maximum daily abstraction at Bangor on Dee in the Wrexham model depends on the Dee General Directions (DGD) active stage. As discussed below (in Dee abstractions section), output from NRW's River Dee model prescribes the abstraction level that would be available for us at any time and as a result the Dee catchment in our Wrexham model was given an essentially infinite flow sequence (9999 Ml/d).

Hydrology – impoundment reservoirs
In the Wrexham zone, our second largest water source is our impoundment reservoir system. We have 9 licenced impoundment reservoirs, combined into three reservoir 'groups' for the purpose of contribution to the overall DO.

Observed weather records which were used in previous planning periods, provide just one possible time series out of thousands of alternatives that could have occurred under the same long-term average climate conditions. Stochastic datasets that represent the various possible versions of weather events over the historical years (1950 – 1997) are thus generated and used to investigate and test water resource system based on a much wider range of possible drought events with different magnitude, durations and extents. The reservoir catchments in Wrexham are currently ungauged and no rainfall-runoff models were developed for these catchments. Therefore, alternative generation of stochastics and climate change flow data that could be used as reservoir inflows was required. When considering which datasets to use for generating the inflow sequences, the most important consideration was to ensure the variability in the flow record was similar to that in the stochastics flow data used in the nearby catchments, so that the system is tested under similar conditions to those seen in the past. For example, in generating the hydrology it was particularly important that different characteristics of the stochastic droughts are reproduced for the reservoir catchments. Furthermore, given that prolonged events cause the greatest risk to supply from reservoirs (as the effects of daily variability in inflows are damped by the storage), it is important to have a representative mean flow.

A sampling method was used to create inflow sequences for the Wrexham impounding reservoir catchments. The Wallingford Hydrosolutions Low Flows 2000 (LF2K) software package was used to generate catchment flow statistics for the ungauged catchments using data from gauged catchments with similar characteristics, considering factors such as geology, soil type, estimated rainfall and run-off. Stochastics flows were generated for the Wrexham impounding reservoir catchments using the sampling technique, which involves combining the derived flow duration curve (FDC) from the Brenig catchment stochastic dataset with data from the LF2K software package. This allowed for ungauged flows to be estimated based on the FDC percentile flow each day for Brenig, based on the corresponding FDC. The catchment details used in the LF2K software are set out in Table A2.2. Figure A2.1 shows Brenig FDC and equivalent flow duration curves derived for each of impounding reservoir catchments represented in our model.

Table A2.2: Catchment details used in the LF2K software

Catchment shapefile name	Catchment Area (km^2)	Base Flow Index	Annual run off (mm)	Mean flow (Ml/d)
Nant Y Ffrith	1.247	0.367	679.3	2.33
Pen Y Cae Upper	6.217	0.398	687.5	11.75
Pen Y Cae Lower	0.349	0.631	541.7	0.52
Pendinas (res group)	3.524	0.425	715.6	6.91
Llyn Cyfynwy	0.17	0.667	639.4	0.26
Ty Mawr (res group)	4.834	0.328	722.9	9.59

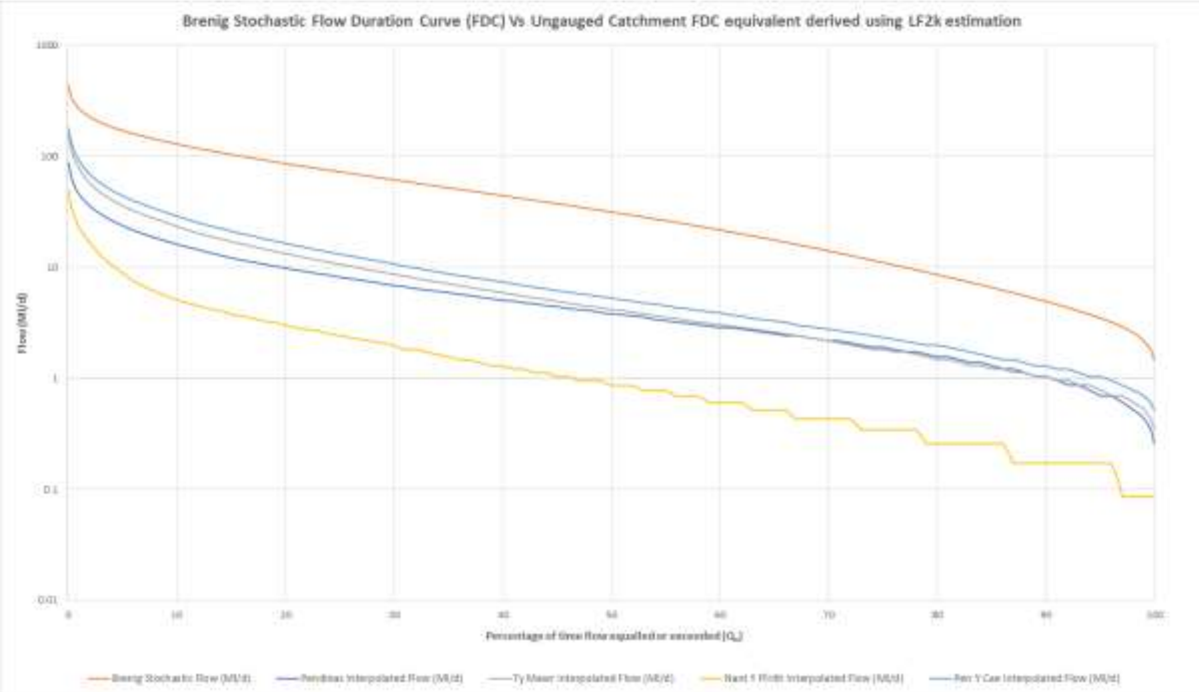

Figure A2.1: Brenig FDC vs ungauged catchments FDC equivalents derived using LF2K estimation

Operational rules used in Aquator

The operational rules are broken down into two main components – Dee abstractions and reservoir operation. A summary of these is provided below.

Dee abstractions

The Dee General Directions (as published in June 2016) sets out the volumes that we can abstract under different conditions. NRW authorises four levels of abstraction from the River Dee at Bangor on Dee and Barrelwell Hill abstraction points (Table A2.3); the abstraction volumes authorised under Stage 1 and Stage 2 cutbacks in drought conditions are reliant upon augmentation of the River Dee from Pen Y Cae reservoirs.

For modelling purpose, running NRW's River Dee model provides a daily time series identifying when abstraction cutbacks would be imposed over the stochastic years as discussed below (in calculating deployable output section). This time series was used to control the maximum abstraction at Bangor on Dee and Barrelwell Hill *(now a S*evern Trent asset), and when augmentation of the Dee from Pen Y Cae Lower was required to maintain the abstraction at these abstraction sites.

Table A2.3: River Dee abstractions as set out in the Dee General Directions

Abstraction Regime	Barrelwell Hill / Dee Chester Abstraction Limit (Ml/d)	Bangor on Dee / Twll Abstraction Limit (Ml/d)
Above system safe yield line	32.5	45.5
Safe yield allocation	28.8	41.5
Stage 1 cutbacks	28.8[3]	41.5
Stage 2 cutbacks	28.8[4]	41.5

Reservoir operation

The following rules for reservoir operation were built into the model:

[3] Based upon augmentation of 0.4 Ml/d from Pen Y Cae
[4] Based upon augmentation of 0.8 Ml/d from Pen Y Cae

- Nant Y Ffrith can be used all year round; the maximum take is 0.6 Ml/d (25m^3/hr); water from Nant Y Ffrith must be mixed with water from Pendinas / Llyn Cyfynwy in a 25:75 ratio.
- Pendinas and Llyn Cyfynwy storage was aggregated as the water is equally accessible from both sources and it simplified the model to allow shorter run times. The same below curve take limits are imposed on supply that is blended with Nant Y Ffrith water and that which is supplied directly to Pendinas WTW.
- Storage in Ty Mawr and Cae Llwyd was aggregated as the water is equally accessible from both sources.
- Pen Y Cae Lower is no longer used for supply but can be used to augment the River Dee, to offset the Dee stage 1 and stage 2 cutbacks in accordance with the time series provided by NRW.
- Pen Y Cae Upper fills Pen Y Cae Lower whenever storage in the latter drops below top water level. To ensure the annual abstraction licence limit was applied, the inflows to the Upper and Lower reservoirs were modelled as flowing into the Upper reservoir and the transfer to the Lower reservoir was constrained by the annual licence, in addition to the output from the Upper reservoir for supply.
- The daily output from the Pen Y Cae Upper and Lower reservoirs could not exceed the daily licence, therefore any flow released for Dee augmentation from the Lower reservoir reduces the abstraction available from the Upper reservoir. A single control curve was used to control abstraction when storage was below the curve.

Reservoir yields

A simple reservoir yield assessment model was created in Aquator and used to assess the yield of each reservoir group/system individually in WRMP19. The yields and storage curves from the model runs indicate the supply that could be maintained from each reservoir under historic conditions, and can be used to inform the abstraction rates that our sources can support.

No control curves or abstraction limits were implemented so the only constraining factor was historical hydrological conditions. Constant demands were placed on the abstraction demand centre and were increased using the English and Welsh Deployable Output analyser, until the reservoir failed to satisfy modelled demands and levels decreased to emergency storage level. The highest demand that could be met without causing failure was considered to be the yield of the reservoir. The emergency storage volume was re-calculated by the model for each DO run as the dead water volume plus 30 days of supply at the demand being tested, plus 30 days of compensation flow.

In the case of Pen Y Cae, the second reservoir was enabled to represent Pen Y Cae Lower reservoir, which was able to supply the Dee augmentation demand but not the abstraction potential demand. The lower reservoir was refilled from the upper reservoir as soon as storage dropped below 100%.

The outputs of this assessment are shown in Table A2.4 below. The majority of the reservoirs failed under 2011 conditions in the yield assessment.

Table A2.4: Results of reservoir yield assessment

Reservoir	Dead water (Ml)	Compensation flow (Ml/d)	Yield (Ml/d)	Emergency storage (Ml)	Failure date for yield run
Nant Y Ffrith	5	0.00	0.59	22.7	27/10/2011
Pendinas / Llyn Cyfynwy	205	0.57	2.10	285.1	31/10/2011
Ty Mawr	59	0.11	3.72	173.9	26/11/2011
Pen Y Cae	1	0.01	1.24	38.5	08/10/1933

Wrexham WRZ deployable output assessment

In previous WRMPs, our historic level of service has been to make sure we experience no more than one temporary use ban (also known as a hosepipe ban) every 40 years. So, our conjunctive use water resource zone was historically modelled using the Aquator inbuilt English and Welsh method to estimate deployable output based on 89 years (01/01/1927 to 31/12/2015) of historical flow data. The WRMP24 guidelines requires companies in Wales to assess a design drought – the worst drought on record for their company area – as a minimum. However, water companies in England are required to assess the resilience of their systems to droughts with a return period of 1 in 500-years. As the River Dee catchment crosses into both England and Wales and is used as a source of water by English and Welsh companies, the river Dee system and thus supply to the Wrexham zone is assed with a view to accommodate the 1 in 500-year drought resilience target and adapt to the likely impacts of UKCP18 climate change projections.

The new 1 in 500 year resilience standard makes sure that exceptional demand restrictions, such as Emergency Drought Orders are not required due to drought more than once every 500 years on average (i.e. systems should be resilient with a 0.2% annual chance of stand pipes and rota cut implementation). The 1 in 500 year supplementary guidance advises the use of system response (Scottish method) based approach to estimate deployable output versus return period relationships linked to Level 4 restrictions (i.e. standpipe s and rota cuts). The UKWIR risk-based planning system outlines different methods to look at the relationship between the deployable output and the return period of failures. Due to the specific requirements for estimating the dWRMP DO using large stochastic time series, the Scottish DO method was adopted for DO analysis of the Wrexham zone. This method enabled us to run our Aquator model through the stochastic dataset at different levels of demand and record number of failure years associated with each demand level and the kind of restrictions imposed in the model in each year (level 4, 3 or 2 restrictions). The Scottish DO analysis model run outputs (different demand levels and number of failure years) were then post-processed to create the DO vs return period relationships, thus enabling us to estimate DO based on return periods associated with different levels of system failures.

Modelling work was carried out by NRW with a view to identify how the operation of the Dee system may have to change to accommodate the 1 in 500 year resilience target, and adapt to the likely impacts of UK Climate Projections (UKCP)18 climate change projections. The steer from the Dee Consultative Committee, as with previous climate change work, was also to identify the likely scale of change to available supply whist retaining the current levels of service. Output from NRW's modelling work showed that the introduction of the stochastically generated data (to enable long return period resilience testing) to water resources modelling of the Dee has reduced baseline levels of service as compared to previously calculated based on historical data. The system was shown to meet the 1 in 500 year resilience target at the current Safe Yield, but other levels of service specified in the Dee General Directions are not met. A 5% reduction in safe yield abstraction would be required to meet current Dee General Directions levels of service. It's been agreed with NRW that the use of the stochastic dataset is not expected to cause such a change in system behaviour and there is uncertainty in the modelling results. Thus, NRW recommended that changes to abstraction allocations identified by the modelling using the stochastics data are deferred until they are more confident that it is a good representation of baseline hydrology. Consequently, we have used existing safe yield and cutback values when calculating baseline deployable output using the stochastic dataset.

The DO assessment for Wrexham zone follows a bespoke approach that requires the simulations of two models in sequence. The first step to calculate the Wrexham zone stochastic DO is the simulation of NRW's River Dee model for the stochastic record. This is completed at a defined target demand (set based on storage levels in the Dee system) with the specific cut-backs applied in the model depending on the scenario. This simulation was carried out individually for each selected scenario (e.g. baseline stochastic, climate change Regional Climate Models (RCM), climate change probabilistic) applying the specific cutback levels for each scenario. A bespoke variable called 'combined failures' is created to record model outputs from the Dee Model such as daily data on DGD state crossings (cutback levels), storage crossing below emergency level and hitting dead storage level in the Dee storage system. On the second stage, this variable was imported into the Wrexham zone Aquator model and used to inform the amount of abstraction volumes available each day.

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. However, drought resilience modelling based on all Dee abstractors always taking their maximum DGD entitlement would help to account for the risk that might be caused by other abstractors altering their operating practices in the future.

The frequency of Pen Y Cae reservoirs failing to release augmentation flows to the River Dee is recorded in the Wrexham model. During these augmentation failure days, the model reduces the Bangor on Dee abstraction volume to compensate for any DGD net cutbacks that are not fulfilled through augmentation. The number of years in which Pen Y Cae reservoirs fail to release the required augmentation flows are used to calculate the return period of augmentation failures. This information is used to determine the type of DO calculation method required for Severn Trent's Chester WRZ. Outputs from the baseline stochastic model run for the Wrexham zone have showed that augmentation release failures meet the 1 in 500 year resilience metric (return periods of augmentation failures are higher than 1 in 500 years). Thus, to determine 1 in 500 year DO for the Chester WRZ, the Chester Aquator model was run using the English and Welsh DO calculation method as Chester zone is constrained by the safe yield cutback condition only (other DGD staged cutbacks are fulfilled by augmentation release from Pen Y Cae reservoirs).

Wrexham zone Aquator model was developed with the application of English and Welsh DO analysis in mind using historic (or climate impacted historic) hydrological data. However, the use of the 19,200 years of stochastic data is now required to assess 1 in 500 year DO for Emergency Drought Order (EDO) events, which has been driven by new regulatory guidance and fundamentally changes the modelling approach required from previous WRMP rounds. To enable the use of stochastic hydrology, refinements have been made to the model in particular to set appropriate failure criteria linked to EDO failures, allow suitable access to emergency storage during dry conditions, and implement suitable resetting of model states every 48 years (at the end of every stochastic version of the 1950 – 1997 period) to enable continuous DO simulation across all the stochastic scenarios. Following these adjustments, a full stochastic dataset of 19,200 years was used in the Scottish method to estimate baseline DO for the Wrexham zone.

Failure condition
The 1 in 500 year supplementary guidance states the following about failure condition:

You should be resilient to drought so that you do not use exceptional demand restrictions, such as with emergency drought orders more than 1 in 500 years on average. Failure is considered to be the point at which you would need to implement these emergency drought orders.
You will not be considered to have met the required level of resilience if you are planning that this failure will happen with a frequency greater than 0.2% per annum.
The point at which such restrictions would come into force will vary from company to company. You should therefore identify the trigger point at which you would actually implement emergency drought orders. You should clearly state this point in your WRMP. This could be at the point at which emergency storage is reached, or a specific groundwater level. You should be able to relate this to the modelling used to generate the '1 in 500' drought events, irrespective of the trigger used. The triggers used for your WRMP should be related and consistent with the operational triggers defined in your drought plan.

We defined the point at which EDO restrictions would come into force as follow:

- The Dee storage system hitting dead water level
- Demand centre failures

Llandinam and Llanwrin WRZ – deployable output methodology

The DO of the operational groundwater sources within Llandinam and Llanwrin WRZ were reassessed in 2020 in accordance with the UKWIR methodology documents (UKWIR, 1995, 2000) to inform dWRMP24. This review builds on those completed for WRMP14 and WRMP19.

For the latest assessment, we have updated all available groundwater datasets. Our current assessment of groundwater DO incorporated the 2011/12 drought, which represented some of the lowest groundwater levels recorded in our supply area. Since mid-2012, groundwater levels have recovered to expected normal ranges in many areas and therefore the DO update for this dWRMP does not introduce new drought operational data that could change the shape or positioning of the drought curves on the Source Performance Diagrams (SPDs). The 2022 drought was still emerging at the time our update was being undertaken, meaning that we have not incorporated data from this period in the dWRMP. The dWRMP DO assessment update is based on recent operational data (to inform an assessment of the effective operational pumped output), infrastructure constraint information (e.g. pumps, treatment processes and network restrictions) and water quality trends. Consideration has also been given to the potential impacts of climate change and sustainability changes on groundwater DO. The SPD diagrams were derived for each borehole source to determine the drought year average deployable yield and also the peak week deployable output.

The latest review of groundwater DO was carried out in several stages:

Stage 1: Review of previous WRMP19 DO assessment

We reviewed the groundwater source information reported for WRMP19. This forms part of the audit trail for our dWRMP24 groundwater DO values.

Stage 2: Abstraction licence verification

We verified the average daily and daily peak abstraction licence details reported in WRMP19 for each groundwater source. The Llanwrin source was previously licence exempt, the licence now granted and active is representative of the historical usage rates.

Stage 3: Confirmation of any known DO changes

We confirmed that there have been no changes to source DO capacities from recently delivered capital schemes.

Stage 4: Borehole pump capacity assessment

We identified the output capacities of all borehole pumps for all operational boreholes. Some pumps are fixed speed; others are variable speed. These data form the basis for many of the DO records as many boreholes showed no yield reductions in historical drought events, thus, pumping capacity becomes the primary driver that defines the DO value of the source.

Stage 5: Review of all treatment and network constraints

We re-reviewed all treatment work process constraints and verified the output capacities of each component. Likewise, all downstream network constraints, which impact a given source's ability to put water into supply, were verified. These include booster pumping stations, water mains restrictions and treated water service reservoir capacity limitations that could affect the source output.

Stage 6: Blending constraint reviews

There are no strategic water blends for groundwater sources in our area.

Stage 7: Groundwater level data

The final dataset used to inform and update the SPDs were groundwater level dip records. These manual measurements are recorded at regular intervals by the on-site operations teams and provide key evidence to assess overall borehole yield. Groundwater level dip data is plotted on SPDs in the form: abstraction flow rate versus groundwater level.

Stage 8: Source Performance Diagrams update

We completed a systematic update of the SPDs on a site-by-site basis, by compiling the data collated from the previous stages 2 to 7. The updated curves were then used to determine the current year and predicted 2025 DO values.

Other groundwater considerations for DO calculations

- ***Groundwater treatment process losses:***

Many water treatment works processes (e.g., for nitrate or cryptosporidium) are designed with a requirement for waste flow diversion. As found in the WRMP19 DO assessment, no process water losses have been accounted for in the groundwater DO numbers reported. This is because the effective losses from these processes are small in comparison with the groundwater output (generally <1%, but up to 4.5%). We do not consider treatment process losses to be significant for the Llandinam and Llanwrin WRZ.

- ***Time Limited Licences:***

NRW have not identified any Hafren Dyfrdwy abstractions in their WFD 'no deterioration' investigations in this dWRMP and we have assumed a presumption of renewal for time limited licences. This is discussed further in section A2.1.3.

- ***Sources with compensation requirements:***

No sources in the Llandinam and Llanwrin WRZ have compensation requirements associated with their abstraction licences. However, the only groundwater source in the Wrexham WRZ has a conjunctive usage requirement, public water supply and compensation, which may restrict the source output for dWRMP24 DO assessment there.

The deployable output assessment, not accounting for the potential effects of climate change, concluded that for the Llandinam source, the DO is 18.0 Ml/d and for the Llanwrin source is 0.73 Ml/d The effects of climate change on these values are discussed further in section A2.1.1.

Saltney and Llanfyllin WRZs – deployable output

Neither Saltney nor Llanfyllin WRZs have their own water sources and are supplied solely via bulk supply transfers from Severn Trent. Therefore DO is reported as 0 Ml/d.

Baseline Deployable Output

The WRMP24 guidance requires the estimation of a deployable output linked to a return period equivalent to 500 years for Level 4 restrictions (i.e. standpipes and rota cuts). The guidance states that the expected level of 1 in 500 year resilience should be achieved as early as possible, or by 2039 at the latest. Our assessments show that all our four WRZ's systems meet the 1 in 500 resilience from the start of the planning period (from 2025). The baseline deployable output (DO) for each zone based on the 1 in 500 year resilience metric are presented in Table A2.5. These are the 1 in 500 year DO (linked to a return period equivalent to 500 years for Level 4 restrictions) provided by our current supply system that also complies with our current level of service (ensuring customers do not experience a Temporary Use Ban (TUB) more frequently than once in 40 years). The baseline DOs do not include the potential impacts of future climate change or sustainability changes.

Table A2.5: Deployable output of our WRZs

WRZ	WRMP24 1 in 500 DO (Ml/d)	Constraint
Wrexham	51.02	Zonal Constraint. Surface and groundwater sources yields and licences constraints causing system failures during a set of 1 in 500 drought events.
Llandinam and Llanwrin	18.73	Groundwater yield
Saltney	0	Bulk Supply Agreement
Llanfyllin	0	Bulk Supply Agreement

A2.1 Changes in deployable output

Once the baseline DO has been established, we then need to take account of any current or future issues that could affect the DO. As a minimum, we are required to consider the following issues with regards to how they could impact our dWRMP and any actions required:

- Climate change
- Invasive non-native species (INNS)
- Possible changes to abstraction licences

The following sections deal with each of these in detail and set out how we intend to address them through the dWRMP and/or wider work programmes.

A2.1.1 Climate change

Wrexham WRZ DO

The Water Resource Planning Guidelines, 2021 and the climate change supplementary guidance outline how we can use the UKCP18 climate projections to estimate impacts of climate change on water resource zone's deployable output. The supplementary guidance on climate change indicated that multiple sources of climate change evidence should be used, including UKCP18 Met Office climate models and probabilistic data. The UKCP18 projections provide Global Climate Models (60km), Regional Climate Models (RCM) (12km), a high-resolution RCM (2.2/5km) and probabilistic data (25km) for the most severe climate change scenario Representative Concentration Pathway (RCP) 8.5. Probabilistic data are also provided for scenarios RCP2.6, RCP4.5, RCP6.0 and A1B Medium Emissions. The UKCP18 probabilistic projections were generated based on the use of multiple variations of a specific climate model to simulate a wide range of different climate outcomes and are considered suitable to understand uncertainties in future risk assessment. Figure A2.2 shows comparison of different climate model data for England and Wales in the 2070s.

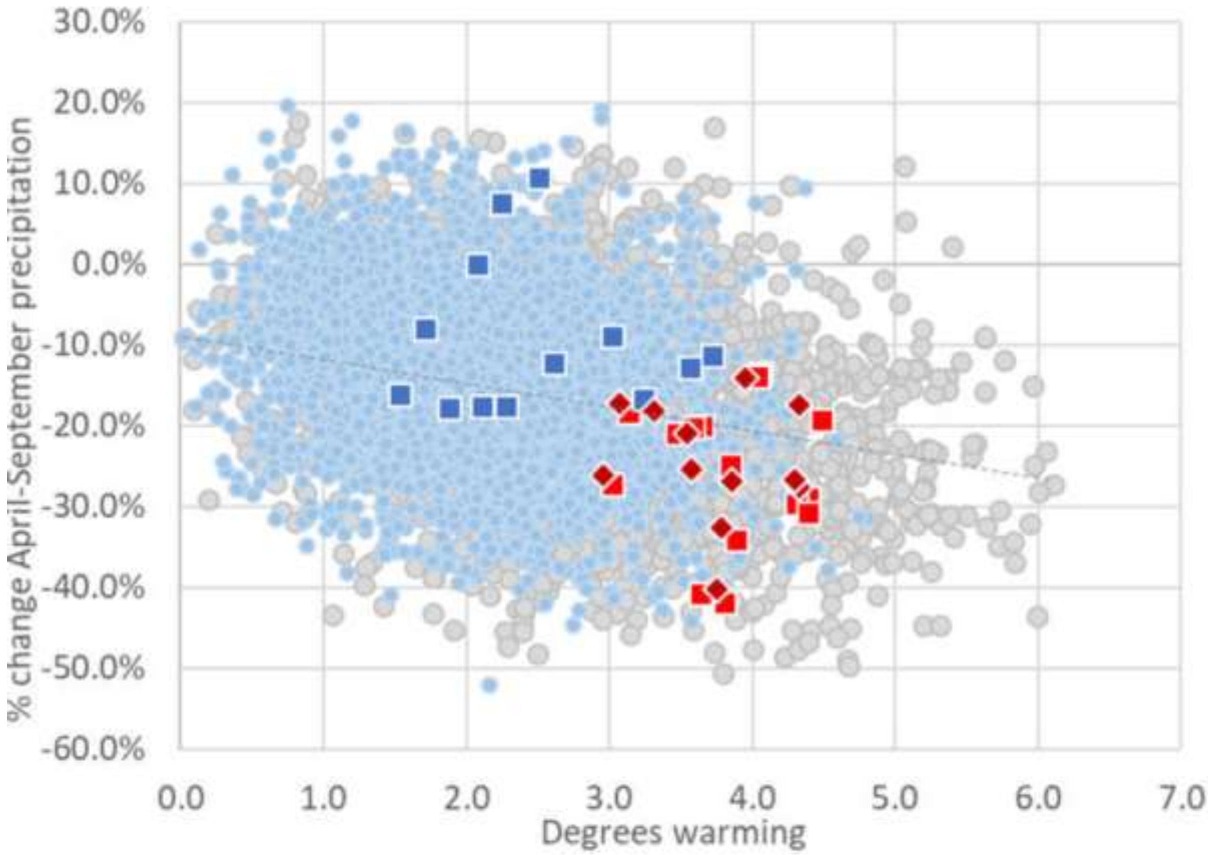

Figure A2.2: Comparison of different climate model data for England and Wales in the 2070s. (UKCP probabilistic A1B blue circles; RCP8.5 grey circles; CMIP5 blue squares; HadGEM red squares and RCM red diamonds) Source: Atkins climate change scaling report (2021)

All companies in WRW adopted common methodologies to ensure that a consistent climate change approach has been used across the region, particularly for strategic resource schemes, reflecting the requirements of the supplementary guidance on climate change. As agreed across WRW we have used the RCMs and probabilistic dataset in our climate change analysis. RCMs are considered to provide comparable climate change outputs across regions due to their better representation of spatial coherence of climate change. The median of the RCM scenarios have been used to inform central estimate climate change impacts. The probabilistic projections scenarios have been used to assess and represent the uncertainty range of climate change impacts in headroom. The RCM RCP8.5 data indicate warming of around 4°C (3.1 –4.3 °C) above the 1981-2000 baseline in England and Wales, with wetter winters and drier summers. The climate change guideline does not specify which emission scenario to use in dWRMP or for regional planning. However, the Addendum on UKCP18 scenarios for use in WRMP24 (Wales) issued by NRW states that the use of projections based on both the RCP 8.5 and RCP 6.0 emission scenarios are required for high or medium vulnerability climate change zones, which will likely require an adaptive plan. Although the Wrexham zone is a low vulnerability zone, consistent with the other water companies who also abstract from the River Dee catchment, we carried out all climate change rainfall-runoff and water resources systems modelling using RCP8.5 scenarios with a view to include RCM scenarios (that are only available as RCP8.5 scenarios) in our climate change analysis.

The use of RCP8.5 2070s scenarios in our analysis has also helped to understand the “business as usual” type scenario – what could happen if greenhouse gas emissions remain unchecked - that demonstrates the impact of climate change most clearly, over and above natural variability and model uncertainties. It was also agreed at WRW level to use RCP6.0 impacts for the supply demand balance purpose in the planning tables. Thus, modelled climate change impacts based on RCP8.5 scenario are scaled down to impacts that reflect RCP6.0 scenario as explained below.

Taking the above into consideration, the method we adopted is summarised below.

Step 1: Processing climate change projections

Following the release of the UKCP18 projections we commenced the "Regional Climate Data" project to support water resources planning at regional and company level, which provided rainfall, average temperature and Potential Evapo-transpiration (PET) data for drought risk assessment and climate change modelling. This included processing and bias-correction (BC) of UKCP18's 12km Regional Climate Models (RCM) for river basins, as well as climate change factors for UKCP18 Probabilistic projections and Global Climate models for England and Wales. This is summarised in Table A2.6.

Table A2.6: Climate change datasets used in dWRMP24 climate change assessment

Data set	Rationale	Resolution
UKCP18 RCM bias-corrected factors	Climate change risk assessment. 12 bias corrected RCM RCP8.5. Precipitation (P), Temperature (T) and PET change factors to apply to stochastic data sets, to create stochastics plus climate change. Factors for the 2060-2080 period.	River basin
UKCP probabilistic	Climate change factors for P and T for RCP8.5 and A1B for the 2060-2080 period. To provide a broader context to the RCM data sets.	England and Wales

All climate change factors were provided on a monthly basis for both rainfall and temperature. The 12 bias corrected RCM projections have factors that are unique to each river basin and have been assigned to each model catchment based on spatial location. Probabilistic projections apply the same England and Wales factors to all catchments so that the same coherent data sets can be used in all regions. All climate change factors were provided on a monthly basis for both rainfall and PET.

Step 2: Sampling probabilistic projections

The UKCP18 dataset provides 3000 samples of probabilistic projections, which needed to be sampled down to 100 representative samples to be used in our climate change rainfall-runoff model simulations. The NRW guidance acknowledges that companies may not be able to apply the whole 3000 scenarios for multiple RCPs. The following points are required to be considered when applying sampling methodologies:

- Select a sufficient number of samples to estimate the average impact and range of impacts
- Retain important multivariate correlations between changes in precipitation and temperature and changes from season to season or month to month
- Be based on relevant metrics for the specific water resources zones, for example some areas may require the best sample for winter rainfall and others for summer rainfall

We have used a simulator in '@Risk', which is a Monte Carlo based risk analysis tool, to fit distributions to the 3000 UKCP18 probabilistic samples for 24 change variables and modelled the correlations between these variables. The simulator was then used to resample these distributions and produce 100 coherent sub-samples of the full data set. This used 3000 monthly Precipitation and Temperature change factors for 2060-79 to simulate a set of 100 scenarios, while retaining the correlation between Precipitation and Temperature changes for each month (a simulation with 24 dimensions). This method used a Monte Carlo simulation using Latin Hypercube Sampling rather than a strict selection procedure, but it provides a robust set of representative scenarios for RCP8.5 and 2060-79. Sampling performance statistics have shown that this method reproduces the average and range more reliably than the random sample that can be generated using the UKCP user interface. Probabilistic data along with two simulated sub-samples of 100 scenarios are presented in Figure A2.3. Statistical comparison of simulated UKCP change factors for precipitation percentage and degrees of warming for 2060-2079 are shown in Table A2.7.

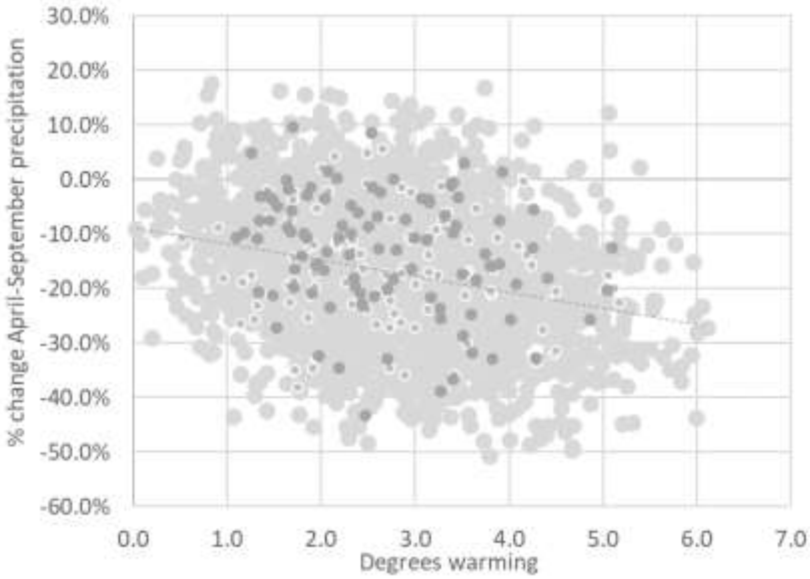

Figure A2.3: Probabilistic data along with two simulated sub-samples of 100 scenarios

Table A2.7: Simulated UKCP change factors for precipitation percentage and degrees warming for 2060-2079

Summary statistics	RCP 8.5					A1B		
Annual average temperature rise °C	Probabilistic 3000	Random 100	LHS 100	RCM HadGEM3 n=12	GCM CMIP5 n=13	Probabilistic 3000	Random 100	LHS 100
Median warming	2.7	2.5	2.7	3.8	2.3	2.0	2.0	2.0
10th percentile	1.4	1.5	1.4	3.1	1.7	1.0	1.0	1.0
90th percentile	4.1	3.9	4.2	4.3	3.5	3.1	3.1	3.1
April-Sept rainfall change								
Median change	-17%	-12%	-17%	-26%	-12%	-13%	-13%	-13%
10th percentile	-32%	-27%	-28%	-32%	-18%	-27%	-26%	-27%
90th percentile	-2%	-1%	-2%	-17%	6%	0%	-1%	0%

Step 3: Flow generation and subsampling probabilistic projections

Catchmod Rainfall-runoff model simulations were carried out by United Utilities (UU) to generate climate change impacted flows for the River Dee catchments using perturbed datasets for 100 UKCP18 probabilistic scenarios and 12 RCM projections using 2070s factors (totalling 112 climate change scenarios). Calibrated and validated models used for generating flows for the baseline stochastic scenarios were used with no other changes to the model simulation. The Catchmod modelling generated 112 sets of climate change perturbed flow series for each of the River Dee Aquator catchments, which was used by UU's Pywr model to estimate impacts of climate change on their water resources DO. The 100 probabilistic scenarios were required to be subsampled to 20 representative scenarios to enable us to cover the distribution across the full range of probabilistic scenarios using Aquator modelling of the River Dee and the Wrexham zone's system. To produce a targeted sample of 20 probabilistic projections, the 100 projections were ranked based on their modelled DO impacts on UU's zone that consist the River Dee system. Every 5th ranking was taken with the addition of the 99th ranking to give a total of 20 probabilistic scenarios. Flow series for these selected 20 probabilistic scenarios and 12 RCM scenarios (totalling 32 climate change scenarios) were used in the River Dee climate change impact modelling.

A sampling method using LF2K was used to create inflow sequences for the Wrexham impounding reservoir catchments as discussed in section A2. Climate change impacted flows are generated for each of the 32 climate change scenarios for the Wrexham impounding reservoir catchments using the sampling technique, which involves combining flow duration curve (FDC) derived from climate change flow series for the Brenig catchment with data from the LF2K software package.

Step 4: Modelling climate change impacts in Aquator

To enable us to model the impact of climate change on the Wrexham zone DO, we created a sequence set (to incorporate the climate change impacted inflow series) for each of our 32 climate change scenarios in the River Dee Aquator model, using the UKCP18 sample IDs as identifiers. We imported the climate change impacted flow series into our Aquator model, assigning them to the relevant catchment. For each climate change run we used the sequence set with the same UKCP18 sample ID to ensure consistency between the datasets used. To ensure consistency with the baseline modelling, the climate change impacts were applied to the same version of the Aquator model which was used to derive our baseline DO.

Modelling the impact of Climate Change on Deployable Output

The climate change modelling was largely a repeat of the modelling and post processing procedures discussed in the stochastic modelling section in A2 for a range of climate change scenarios. As discussed in section A2, modelling work was carried out by NRW with a view to identify how the operation of the Dee system may have to change to accommodate the 1 in 500 year resilience target, and adapt to the likely impacts of UKCP18 climate change projections. NRW used outputs from the UKCP18 RCM RCP 8.5 for the 2060-2079 period to estimate the likely impact on the Dee System. Monthly air temperature and precipitation change data from the 12 models were processed into flow change factors using the existing Dee rainfall-runoff models (using the same method as for previous Dee Climate Change assessments). Under all RCM scenarios, significant changes in monthly rainfall and temperature are seen to occur, both positive and negative. These changes in climate could have a knock-on effect to the flows in the River Dee. Figure A2.4 shows the monthly flow change projections for the Manley Hall sub-catchment for the 12 RCM scenarios. The two blue lines represent the scenarios found either side of the median when modelled with historic inflows at a reduced safe yield and ranked on minimum system storage.

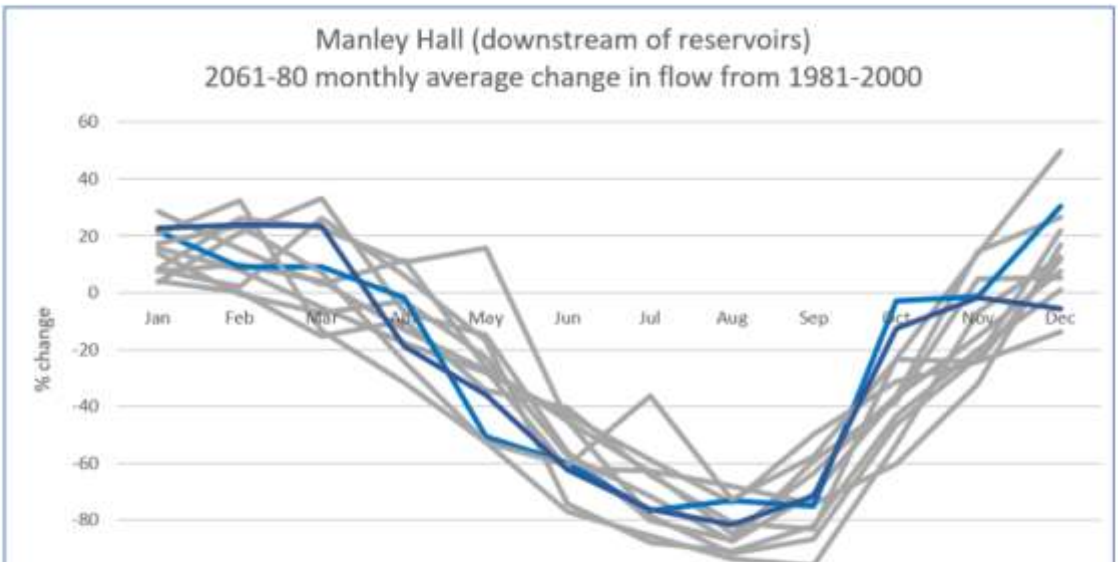

Figure A2.4: Monthly flow change factors for Manley Hall sub-catchment, UKCP18 RCM

The monthly flow change factors were applied to baseline inflows within the Water Resources model. Yield searches incorporating the median climate change scenarios were carried out using both the stochastically generated and historical inflow data as the baseline. When applied to the historical inflows the central estimate of climate change impact shows that 26% net reduction in River Dee safe yield abstraction is required to meet current DGD levels of service. Subsequently, a recommended breakdown of allocations for individual companies was provided by NRW based on the 26% net reduction.

Simulation of NRW's River Dee model for Wrexham zone DO assessment used NRW's recommended net reduction of 26% for the RCM climate change scenarios. A temperature based scaling method was used to estimate the potential level of net reductions required for the probabilistic scenarios. The temperature based scaling approach, which was produced by Atkin's climate data tools scaling project, is discussed below in detail.

Based on this assessment, Bangor on Dee Abstraction net safe yield abstraction volume for the RCM climate change scenarios for was reduced by 2.03 Ml/d. The cutback levels remained the same as they were in the baseline run, as did the maximum allowable abstraction. The updated abstraction levels for the RCM climate change scenarios are given in Table A2.8.

Table A2.8 River Dee abstraction limits for the RCM climate change scenarios

Abstraction Regime	Dee Chester Abstraction Limit (Ml/d)		Bangor on Dee Abstraction Limit (Ml/d)	
	Gross	Net	Gross	Net
Above system safe yield line	32.50	32.50	45.50	8.60
DGD Baseline Safe Yield Allocation, Ml/d	28.80	28.80	41.50	7.8
Reduced Safe yield allocation	21.31	21.31	31.36	5.77
Stage 1 cutbacks	~	21.11	~	5.57
Stage 2 cutbacks	~	20.91	~	5.37
Stage 3 cutbacks	~	20.71	~	5.17

~ depends on the use of Pen y Cae augmentation

Simulation of NRW's River Dee model for the climate change assessment of the Wrexham zone was carried out applying these net reductions. This was completed at a defined target demand (set based on storage levels in the Dee system) with the specific cut-backs applied in the model depending on the climate change scenario. This simulation was carried out individually for each climate change scenario (12 RCM and 20 probabilistic scenarios) applying the specific cutback levels for each scenario. The frequency of Pen Y Cae reservoirs failing to release augmentation flows to the River Dee was also recorded in the Wrexham model for each scenario, which was mainly used to make reduction in Bangor on Dee abstraction volumes during Pen Y Cae augmentation failure days. The return period of Pen Y Cae reservoirs failing to release augmentation flows was also used to inform the STW's Chester zone DO calculation. Outputs from the baseline stochastic model run for the Wrexham zone have showed that augmentation release failures meet the 1 in 500 year resilience metric (return periods of augmentation failures are higher than 1 in 500 years) under the climate change scenarios. The current guidance on how to apply the climate change methodologies does not include any recommendations for how water companies should derive a suitable "central estimate" for use in the supply/demand balance calculations. Similarly, there is no best practice guidance on how to appropriately deal with the wide range of uncertainties presented by the multiple scenarios. The 12 RCM projections we modelled are generated based on a dynamical downscaling method that embeds regional features within coarse-resolution global climate models (GCMs), which are widely considered as the most complex and precise models for understanding climate systems and predicting climate change. In addition, RCMs provide comparable climate change outputs across regions due to their better representation of spatial coherence of climate change. Thus, we decided to use the DO impacts from the median of the 12 RCM scenarios as the central estimate climate change impact, which was also agreed across WRW. We believe this better represents a physically plausible hydrological scenario and is more representative of what could happen to our region. DO impacts from the probabilistic scenarios directly fed into our target headroom model to assess the range of uncertainty around this central estimate. A detailed description of how we have tested and used the range of uncertainty around climate change is provided in Appendix C.

The full range of the modelled impact of the RCM climate change scenarios on our deployable output in 2070s under RCP6.0 scenario are shown in Figure A2.5. Wrexham WRZ is affected by the potential impacts the changing climate may have on surface water sources and the main impact to the zone is associated with reservoir drawdowns in the Dee Storage system. The use of a single River Dee abstraction cutback levels across the RCM scenarios has resulted in low variability in the levels of climate change impact observed across the modelled scenarios.

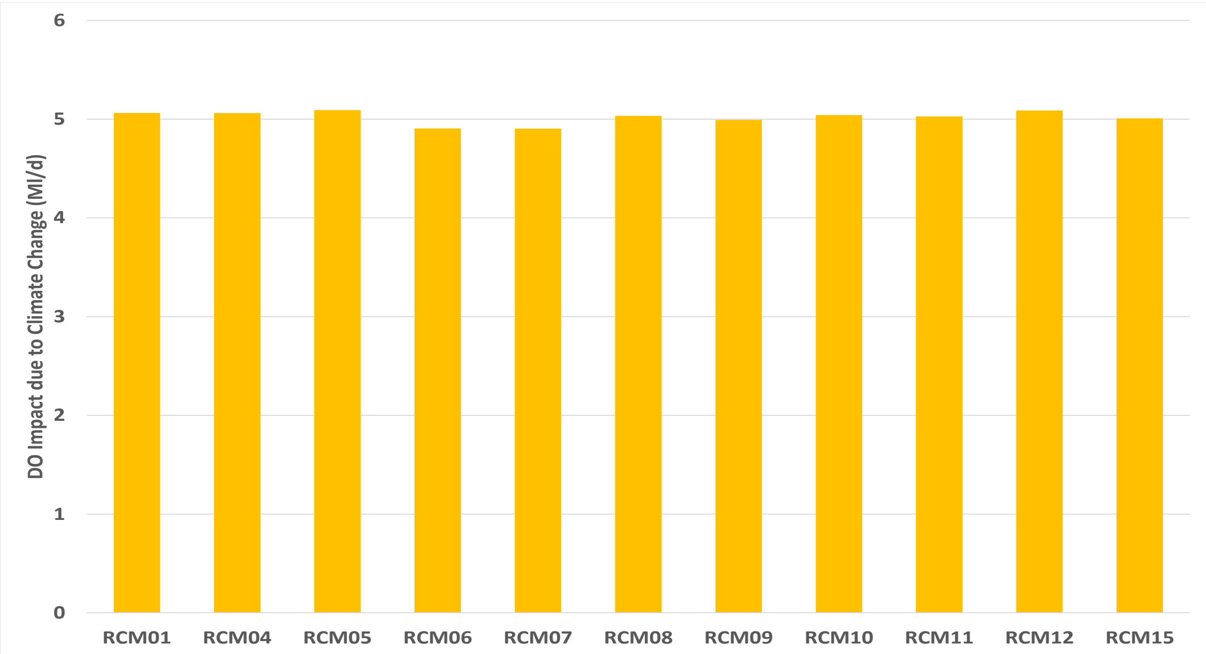

Figure A2.5: Wrexham zonal impacts of climate change using the RCM scenarios RCP6.0

The same demand profiles as described in section A2 were used to vary the demand during the climate change DO runs. This makes the implicit assumption that future demand will vary over the year in a similar way to the variation observed in the past. This is a simplistic assumption, and may not accurately represent varying future weather patterns and demographic changes that could cause the pattern of demand to alter, however it is more robust to test the system with a varying demand than to use a flat demand that would not be expected.

Scaling climate change impacts across emissions scenarios

We have also assessed impacts of climate change on our water resources based on RCP6.0 emission scenario, which is widely considered as approximately equivalent scenario to the SRES A1B emissions scenario that was used in WRMP19. All water companies across WRW have carried out an assessment using the RCP6.0 emission scenario, the outputs of which are shown in the draft regional plan tables.

Modelled climate change impacts based on RCP8.5 scenario needed to be scaled down to impacts that reflect RCP6.0 emission level. In the absence of comprehensive hydrological and systems modelling of different RCPs, temperature based scaling methods were adopted to estimate potential climate change impacts from RCP8.5 to RCP6.0. Atkin's climate data tools scaling project produced temperature based linear equations (y = m . x +

c) that relate monthly temperatures of RCM RCP8.5 scenarios with monthly temperatures of probabilistic RCP6.0 50th percentile scenario for each region. Scaling factors for UKCP basins are provided in Table A2.9 to scale down impacts estimated based on RCP8.5 scenarios down to RCP6.0. We used the scaling factor derived for the Severn River Basin as the majority of our strategic water resource sources are located within or near to this basin. Thus, the median of RCP8.5 RCM DO impacts in 2070s were scaled down by 49% for use as the central estimate climate change impact. A relationship between warming levels at RCP8.5 and RCP6.0 levels for the probabilistic scenarios at 50th percentile was also derived and applied on the modelled probabilistic scenarios to scale down modelled DO impacts for use in target headroom.

Table A2.9: Impact scaling factors for scaling the range of possible impacts across the UKCP18 probabilistic projections

	Warming °C	Prob.	GCM	Probabilistic				GCM
UKCP River Basin	**RCP 8.5 bc (3.7°C)**	**RCP 2.6 (1.3°C)**	**RCP 2.6 (1.7°C)**	**RCP 4.5 (1.8°C)**	**RCP6.0 (1.9°C)**	**A1b (2°C)**	**RCP8.5 (2.3 °C)**	**RCP8.5 (2.7°C)**
Anglian	3.9	34%	47%	47%	48%	52%	70%	89%
Dee	3.6	34%	46%	47%	49%	53%	71%	90%
Humber	3.7	34%	47%	47%	49%	52%	70%	89%
Northumbria	3.5	34%	46%	48%	49%	53%	71%	90%
NW England	3.6	34%	46%	47%	49%	53%	71%	90%
SE England	4.0	34%	47%	47%	48%	52%	70%	89%
Severn	3.8	34%	47%	47%	49%	52%	70%	89%
SW England	3.7	34%	47%	47%	49%	53%	70%	89%
Thames	4.0	34%	47%	47%	48%	52%	69%	89%
W Wales	3.5	34%	46%	48%	49%	53%	71%	90%
Median	**3.7**	**34%**	**46%**	**48%**	**49%**	**53%**	**71%**	**90%**

Scaling the impacts of climate change through time

The Supplementary Guidance on Climate Change provides a linear scaling equation to scale the impacts of climate change from 1990 to 2100. This method is based on the assumption that observed rising temperatures have already translated to observed impacts or there is an elevated level of risk in terms of water resource availability. The guidance mentions that companies may depart from using this method, particularly if impacts of climate change are going to drive significant level of investment and if they can present a rationale for alternative approaches. Atkins climate data tools scaling project report showed that changes in temperature over time in UKCP18 climate modelling products are non-linear and typically follow an upward curve. Moreover, hydrological impacts are anticipated to emerge later in the planning horizon and few companies have yet observed statistically significant changes in river flows and deployable outputs. Atkin's climate data tools scaling project has provided an alternative universal scaling equation, which scales the impacts of climate change from 1990 to 2100 based on impacts modelling for the 2070s (the latest period available for RCM data). This scaling method uses a power relationship rather than linear relationship, which has a marginally lower impact at the beginning of the planning period and higher impact after 2070.

Figure A2.6 below shows power curves fitted to the median of UKCP18 annual average warming for a range of different products. Figure A2.7 shows curves fitted to dimensionless rate of impact between 1990 and 2100 for all scenarios and temporal scaling based on the straight line method (described in WRMP guidance) and power relationship method.

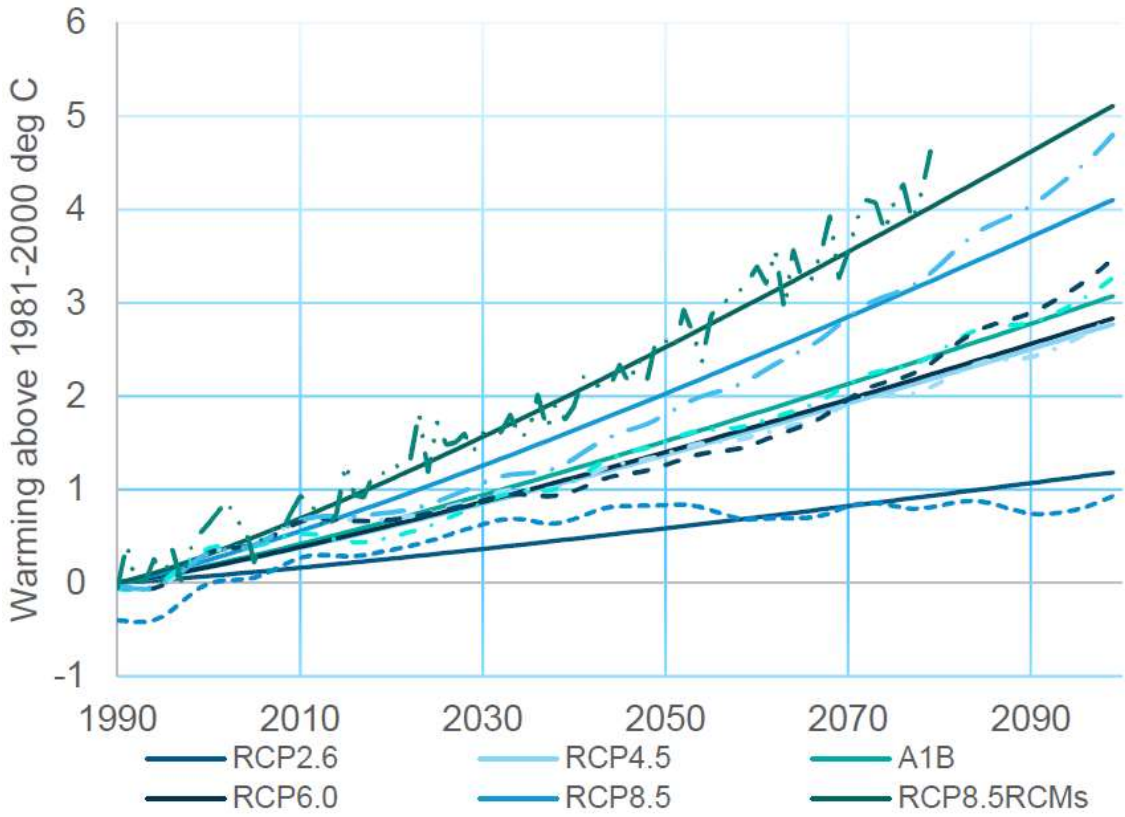

Figure A2.6: Curves fitted to the median of UKCP18 annual average warming using the power relationship

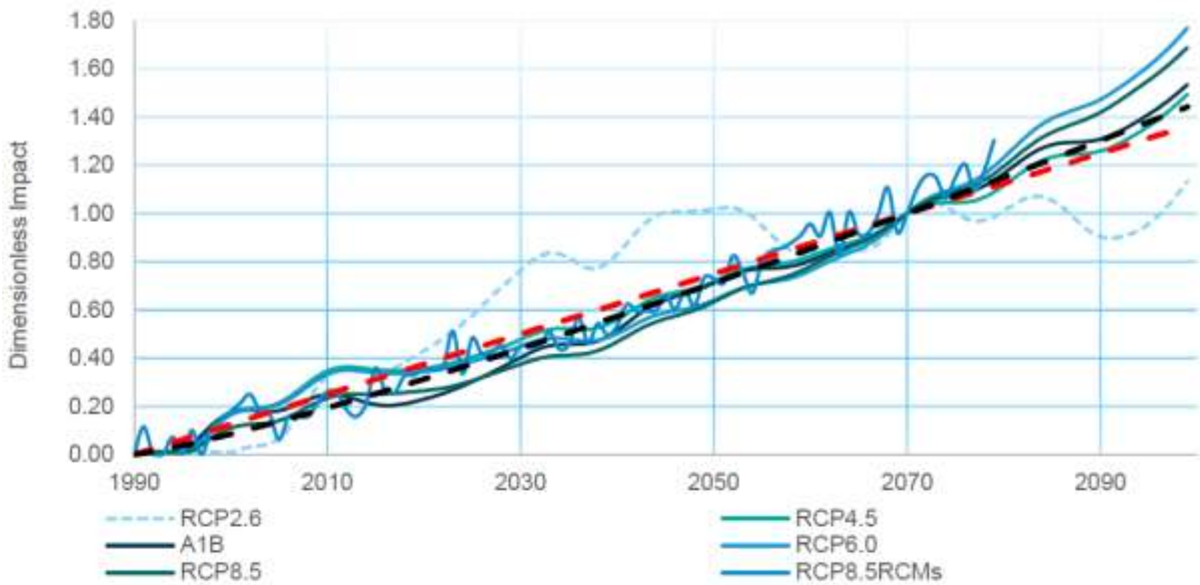

Figure A2.7: Curves fitted to dimensionless rate of impact based on EA's straight line method and power relationship method

As shown in Figures A2.6 and Figure A2.7, rates of warming and temperature related impacts follow typically non-linear projection. Thus, the following power relationship equation is derived based on the assessment of the rates of warming in UKCP18 climate models:

$$\text{Time Scale Factor} = a\,(\text{Year} - 1990)^{b}$$

Where a is 0.0056 and b is 1.1835. This has been shown to fit all RCPs well, with the exception of RCP2.6 as the rate of warming levels off at the end of the century (Atkins). These parameters were based on fitted equations to the normalised modelled warming in 2070, which were then averaged and the power was optimised to ensure that the result in 2070 was 1 or 100%. We have used this power relationship based scaling approach (as recommended by Atkin's project) to scale down impacts through time from 2070s to the start of planning period.

Llandinam and Llanwrin WRZ DO

As discussed earlier in the Wrexham climate change methodology section, stochastic rainfall and potential evapotranspiration (PET) datasets have been generated using a consistent methodology by all companies in Water Resources West (WRW). The stochastic data comprise of 48 years x 400 series, giving a total of 19,200 years' worth of data.

The stochastic climatic sequences were generated for relatively large geographical areas. These data have been derived from historical data for regional rainfall gauges (and spatially distributed using Thiessen polygons) and PET datasets. In contrast, the GR2 spreadsheet for Llandinam, which was originally developed in previous WRMP cycles and represent groundwater levels or surface water flows at key locations, has been calibrated using local climatic data. The stochastic datasets were factored to make them appropriate for use in the GR2 spreadsheet.

To derive these factors, the historical datasets underlying the stochastic data were correlated with the historical data stored in the GR2 spreadsheets. These relationships were then applied to the stochastic data to generate a stochastic rainfall and PET dataset.

The impact of climate change on DO has been assessed using the 1 in 500 year DO as the baseline and a suite of UKCP18 scenarios. These include 12 Regional Climate Model (RCM) scenarios and 3000 probabilistic scenarios, which were subsampled to 100 probabilistic scenarios. The probabilistic scenarios have been further subsampled by to generate a suite of 20 scenarios.

The climate change data were created in the form of monthly factors representing percentage change from baseline. Whilst the probabilistic scenarios are spatially coherent, the RCM scenarios have spatial variability.

Climatic scenario application in DO assessment

The climate change factors were applied to perturb the GR2 stochastic PET and rainfall datasets. The GR2 model was then run for each climate change scenario, frequency analysis undertaken and the DO determined, following the methodology previously set out. The results are presented compared to the baseline 1 in 500 year DO.

Llandinam - climate change DO results

The results of the climate change DO assessment are summarised in Table A2.10 in comparison to the 1 in 500 year baseline. The minimum and maximum DO reduction climate change scenarios are presented along with a 'central' climate change scenario which was the mean of RCM scenarios 8 and 9. It is only under the maximum climate change probabilistic scenario that a reduction in DO is observed; under all other scenarios the DO remains unaffected.

Table A2.10: Climate change results for Llandinam

	DO total (Ml/d)	DO reduction (Ml/d)
1 in 500-year baseline DO	18.0	-
RCM Scenarios		
Min climate change (CC) DO	18.0	0.0
Max CC DO	18.0	0.0
Central CC DO (mean of RCM Sc8 & Sc9)	18.0	0.0
Probabilistic Scenarios		
Min CC DO	18.0	0.0
Max CC DO	16.81	1.19

Llanwrin – climate change DO results

Llanwrin is not considered to be constrained by groundwater levels. However, we have assessed the potential impact of a 1 in 500-year event and climate change on this source.

A GR2 spreadsheet was not available to enable Llanwrin to be assessed in the same way as Llandinam. Therefore, a comparison between the WRMP14 and dWRMP24 source DO value was undertaken to identify how the DO has changed. The DO has decreased since the WRMP14 assessment (from 1.86 to 0.73 Ml/d). Based on this and considering the outcomes from the assessment for Llandinam, a high-level consideration has been given first to the likelihood of Llanwrin becoming constrained by hydrogeological factors, and second to the likely implications on the DO value.

The decrease in DO is related to a change in the abstraction licence constraint and so water level headroom is likely to have increased rather than decreased, and therefore Llanwrin is unlikely to have become level dependent. The DO change is estimated to be zero. This is derived from a simple high-level assessment, applying average impacts observed from the level dependent source to the non-level dependent source; the assessment does not necessarily consider source specific details and is considered to be precautionary, with the resulting impact on overall DO being nil.

Results for 1 in 500 year assessment for Llandinam and Llanwrin WRZ

The results of the 1 in 500 year DO assessment for Llandinam is summarised in Table A2.11. The 1 in 200 year DO has also been calculated by the same method and stated for comparison. There is no forecast change in the current operational DO value of 18 Ml/d forecast for either the 1 in 200 year or 1 in 500 year scenario.

Table A2.11 - DO results summary for Llandinam for 1 in 200 and 1 in 500-year scenarios

	Operational DO (Ml/d)	1 in 200 yr DO (Ml/d)	1 in 500 yr DO (Ml/d)	1 in 500 yr DO reduction in Operational DO (Ml/d)	1 in 500 yr DO reduction in 1 in 200 yr DO (Ml/d)
ADO	18.0	18.0	18.0	0.0	0.0

The combined DO assessment is presented in Table A2.12. The individual source DO values have been combined into a single figure; 18.0 Ml/d (Llandinam) and 0.73 Ml/d (Llanwrin).

Table A2.12: Climate change assessment results for Llandinam and Llanwrin WRZ

WRZ	ADO (Ml/d)	1 in 500-yr		1 in 500-yr + max climate change		1 in 500-yr + 'central' climate change	
		1 in 500-yr ADO (Ml/d)	1 in 500-yr ADO reduction from operational ADO (Ml/d)	Max climate change ADO (Ml/d)	Maximum climate change ADO reduction from 1 in 500-yr ADO (Ml/d)	Central climate change ADO (Ml/d)	Central climate change reduction from 1 in 500-yr ADO (Ml/d)
Llandinam and Llanwrin	18.73	18.73	0.00	17.54	1.19	18.73	0.00

Saltney and Llanfyllin

As Saltney and Llanfyllin WRZs are supplied by bulk supplies we have assumed that this water will continue to be available, with the climate change risk sitting with the donor WRZ or donor Company.

A2.1.2 Invasive non-native species (INNS)

We have reviewed our current abstraction operations to determine the risk of spreading invasive non-native species (INNS) or create pathways which increase the risk of spreading INNS.

For our existing operations we are developing a risk assessment across all of our assets and business activities in AMP7. We have also developed a business-wide Biosecurity Plan that covers all our activities. Our Biosecurity Plan identifies realistic, pragmatic and cost-effective procedures and behaviours that reduce the risk of INNS introduction and establishment.

We are also undertaking individual risk assessments of our existing raw water transfers using the INNS risk assessment tool developed by the Environment Agency. Transfer biosecurity plans have been developed, which include actions such as biosecurity measures and longer-term plans to continue to test and develop feasible mitigations measures.

A2.1.3 Possible changes to abstraction licences

NRW have not identified any Hafren Dyfrdwy abstractions in their WFD 'no deterioration' investigations as part of the latest update to the National Environment Programme. We are not considering any new water supply-side options in our dWRMP but we will continue to work closely with NRW to ensure that our current abstractions, and any other activities on or near vulnerable waterbodies, continue to support 'good' status and not pose a risk of deterioration.

Time limited licences

One of our licences in the Llandinam and Llanwrin WRZ is subject to a time limited licence condition, which means that after a certain date (which is linked to the Catchment Abstraction Management Strategy) the licence quantities would be reduced unless we apply to renew the licence. NRW's licensing advice is that if an abstraction licence has an expiry date in accordance with the relevant Catchment Abstraction Management Strategy it will have a **presumption of renewal** where the following tests are met:

- continued environmental sustainability
- continued justification of need for the water
- water is used efficiently

We recently renewed this time limited licence until 2034.

A2.2 Resilience of Supply

A2.2.1 Drought Resilience

A key change for this dWRMP is a greater focus on ensuring the new 1 in 500 year resilience is met while maintaining compliance to our existing level of services. The UKWIR (2016) WRMP19 Methods – Risk Based Planning document provides comprehensive guidance on the various drought resilience assessments water companies can undertake which are designed to be proportional to the scale and complexity of each companies' problem characterisation. It is suggested that water companies should, as a minimum, use the worst drought on record to assess drought risk; an approach that has been conventionally applied across the sector for previous WRMPs.

For our WRMP19 the problem characterisation exercise we carried out identified that there is a low level of concern regarding the future water resources situation for Wrexham. Consequently, during our WRMP19 our approach to drought resilience was proportional to this problem characterisation – we followed a "Risk Composition 1- conventionally tested plan" approach as defined in the UKWIR (2016) WRMP 2019 Methods – Risk Based Planning document. Therefore, the drought scenarios used to test our plan at dWRMP24 included only those observed in the historic records included in our baseline DO calculations. This baseline modelling period (1927 to 2015) captured a number of drought events including 1933-34, 1995-96 and 2010-2011.

For WRMP24 water companies in England are required to assess the resilience of their systems to droughts with a return period of 1 in 200-years and 1 in 500-years. The new 1 in 500-year resilience standard makes sure that exceptional demand restrictions, such as Emergency Drought Orders are not required due to drought more than once every 500 years on average (i.e. systems should be resilient with a 0.2% annual chance of stand pipes and rota cut implementation). As a minimum, the requirement for Wales is for companies to assess a design drought – the worst drought on record for their company area. As the River Dee catchment crosses into both England and Wales and is used as a source of water by English and Welsh companies, modelling work has been carried out by NRW and all of the English and Welsh water companies who abstract from the catchment to understand the potential impacts on the operation of the River Dee system under the 1 in 500-year drought resilience target and the UKCP18 climate change projections.

For conjunctive use zones, the 1 in 500 year supplementary guidance advises the use of system response (Scottish method) based approach to estimate deployable output versus return period relationships linked to Level 4 restrictions (i.e. standpipes and rota cuts). Thus, we have now carried out further work to look at droughts outside of the historic period, using stochastic drought scenarios as discussed in section A2.

For the groundwater supplied Llandinam and Llanwrin WRZ, we carried out an assessment of groundwater DO under 1 in 200 and 1 in 500 year drought events using stochastic data which was applied to the source GR2 spreadsheet. This assessment showed that our groundwater sources in this zone are resilient to events of these magnitudes, even with the added impacts of the potential changes in the future climate.

Drought Resilience Statement

We have planned our system so that it can withstand the drought patterns and severities that have been seen over the last 89 years (with a suitable climate change allowance) without having to resort to the additional measures described in our Drought Plan. Furthermore our stochastic modelling has shown that our system is resilient to 1 in 500 year drought scenarios with only a negligible drop in deployable output.

A2.2.2 Levels of Service

Reference Level of Service

As a minimum, the requirement for Wales is for companies to assess a design drought – the worst drought on record for their company area. However, water companies in England are required to assess the resilience of their systems to droughts with a return period of 1 in 200-years and 1 in 500-years. As the River Dee catchment crosses into both England and Wales and is used as a source of water by English and Welsh companies, the river Dee system and thus supply to the Wrexham zone is assed with a view to accommodate the 1 in 500-year drought resilience target and adapt to the likely impacts of UKCP18 climate change projections.

As described in section A2 we have now completed stochastic modelling for our Wrexham zone. This modelling has enabled us to understand our deployable output and LoS for a full range of drought return periods including the 1 in 500 LoS. The guidance states that the expected level of 1 in 500 resilience should be achieved as early as possible, or by 2039 at the latest. Our assessments show that the water resources system in the Wrexham zone meets the 1 in 500 resilience from the start of the planning period (from 2025).

Level of Service Statement

Based on our current Levels of Service (1 in 40 years) we have calculated our annual percentage risk of a TUB over the 25-year planning period to be 2.5%; we do not expect this to change over the planning period.

Table A2.13 below presents the annual average risk of a Temporary Use Ban (TUB), Non-Essential Use Ban (NEUB) and Emergency Drought Orders (EDO).

Table A2.13: Annual average risk of drought restrictions for each AMP from 2025 to 2050

Annual Average Risk of Drought Restrictions for each AMP	DGD Stage	Our levels of services	2025-30	2030-35	2035-40	2040-45	2045-50
Temporary Water Use Ban	Stage 2 /3	1 in 40 years (2.5% annual risk)	2.5%	2.5%	2.5%	2.5%	2.5%
Ordinary Drought Orders (Non-Essential Use Restrictions)	Stage 3	1 in 40 years (2.5% annual risk)	2.5%	2.5%	2.5%	2.5%	2.5%
Emergency Drought Orders	NA	1 in 500 years (0.2% annual risk)	0.2%	0.2%	0.2%	0.2%	0.2%

Decisions to impose ordinary demand management restrictions (TUB and NEUB) in the event of droughts in our Wrexham zone are made based on availability of water in the Dee Storage System as stated in the Dee General Direction. We have carried out drought resilience modelling of the River Dee catchment using stochastically generated weather datasets. Modelling results have been analysed to determine return periods using the number of times the different Dee Storage System's triggers would have been crossed and/or demand restrictions would have been implemented over the whole number of stochastic years (19,200 years). These return periods have been used to inform estimation of annual risk of TUB and NEUB restrictions.

A2.2.3 Wider resilience

Our customers expect us to deliver a reliable service 24 hours a day, 365 days a year, and to plan and take decisions that mean we can do this reliably into the future at a price that is affordable to all.

Our PR19 Business plan includes aspects of resilience in the round. When developing the plan, we:

- Used our understanding of our assets and systems combined with external data and understanding of the broader challenges facing us and our communities over the long term, and. We have carried out hydraulic assessments of flood risk and drought risk.

- Embraced the requirements of the Well-being of Future Generations (Wales) Act and formed are forming relationships with organisations who all have a role to play in securing long-term resilience for the communities we serve.

- Talked to our existing and future customers about the biggest long term challenges and our plan reflects their views on how they expect us to balance these challenges with their bills today.

We also have built on many existing business as usual approaches to identify and evaluate risks and. We have applied good practice tools but made them specific to our business and region. In our PR19 business plan, we have set out the short, medium and long term developments – based on our analysis, discussions with colleagues, customers and stakeholders and inspired by Welsh policy ambition – to that will help us ensure long term resilience.

As part of our dWRMP and PR24 plans we have reviewed and developed our approach using the framework shown in Table A2.14.

Table A2.14: Source to tap resilience risk assessment

Drivers / Hazards		Strategic goal	Adapt and Transform
Asset wear and tear	increasing risk of ingress, process failure, system failure, harm to environment, customer disruption	Ensure our asset base continues to be able to anticipate, resist, absorb and recover from known hazards	**Base Plan investment (PR24)** • Increase efficiency and effectiveness of maintenance through analytics and innovation **Reservoir Safety (PR24)**
Government Policy / legislation	New standards (e.g. Reservoir Act)		
	Environmental Destination (including Environment Act Wales)	**Water always there:** Supplies that are resilient to long duration events and new environmental standards	**NEP water (PR24)** **Water Resource Management Plan** • Reduce leakage • Reduce customer demand (per capita consumption) • Provide support to private supplies
	Support communities with Private water supplies in times of drought		
Demographic / economic change	Population growth, household occupancy Levels of economic activity (respond to and promote)		
Climate change **(RCP8.5)**	increased risk of drought from reduced rainfall and increased evaporation		
	increased frequency of dry hot periods (customer demand) or freeze – thaw events (leakage)	**Water always there:** Supplies that are resilient to short duration events	**Water Resilience (PR24 plan)** • Improve system capacity and connectivity • Manage peak demand
	increased intensity and frequency of high rainfall events causing floods		
	increased severity of storm winds causing power outages		
	increased frequency and severity of ground movement, landslip and riverbank erosion		
	Increased run-off and temperature affecting treatability of raw water (e.g. chloride spikes, algae)	Supplies that continue to be **Good to drink**	**Raw water deterioration (PR24)** • Improve treatment or catchment management processes **Lead Free Wales (PR24)**
New legislation	New water quality standards		
Human activity	Unintended consequences: land use change, catchment deterioration (pesticide, fertiliser usage) and pollution events e.g. Dee		
	Malicious: cyber attacks and security breaches		**Cyber Security (PR24)** • keep pace with threats

As can be seen from Table A2.14 as well as the risk from drought we are seeking to understand all hazards across our water system from source to tap.

We have commissioned Stantec to help us bring together all these risks into one place to help inform the options for PR24.

Pollution events on the River Dee

Our bankside storage reservoir near Wrexham and treated water storage reservoirs at our Wrexham treatment works, provide us with sufficient storage should we have to cease abstraction in the event of a pollution event on the River Dee. We are members of the Dee Steering Committee which oversees the DEEPOL notification system, providing early warning to abstractors of pollution events in the Dee catchment. Through our catchment management programme, we have actively engaged with a wide range of businesses who have the potential to negatively impact waterbodies through their activities, to help them identify best practice and advise on pollution prevention techniques.

Catchment solutions for improved reservoir water quality

Our AMP8 investment plan proposes to deepen our current catchment management programme. One of the key components will be investigation and mitigation of algal blooms and taste and odour issues in our impounding reservoirs which in some locations restrict the volume of water available.

The processes installed at our water treatment works mean that we cannot use sources if algal blooms are significant. Our current solution is therefore to reduce abstraction from these reservoirs when issues arise. Whilst this option avoids the risks of increased water quality complaints, it restricts our flexibility and makes our raw water system less resilient.

This is especially true when these issues are in the summer months should use these reservoir sources to supplement our river abstractions that may be under low flow restrictions.

We are planning to carry out the first investigation, around Nant y Ffrith during AMP7, with further investigations being carried out in AMP8.

We are confident that there are viable solutions available at catchment level to remove the taste and odour issues. We therefore intend to investigate the cause of the water quality issues and address the issues at source.

A3. Imports and Exports

We operate a number of raw and treated water transfers and bulk supplies, most of which are externally to and from third parties. For the purposes of this dWRMP we only report on imports and exports that are of strategic importance using. We use a threshold of 1 Ml/d. Imports or exports below this threshold are not considered strategic as they have no material impact on our supply demand balance.

As we have described in section A1, our area is divided into four separate WRZs that are based on the WRZ definition set out in the Water Resources Planning Guideline (WRPG). As a result, our four WRZs are self-contained, but we do have some connectivity across our borders which allows us to import and export water. be strategic.

A3.1 Bulk supply agreements

We have bulk supply agreements in place with our neighbouring water companies, Severn Trent, United Utilities and Dŵr Cymru Welsh Water. Most of these are for emergency use only and are therefore not included in the supply demand balance calculations. However, we have sufficient supply surplus to ensure that these bulk supply agreements will be met.

The remaining supplies that are used regularly to supply single customers or very small supply areas account for less than 0.5 Ml/d. The most significant transfers are those between Hafren Dyfrdwy and Severn Trent, which are summarised in Table A3.1. Although some of these are less than the 1Ml/d threshold, we have reported all transfers between us for completeness. Since we published our WRMP19 we have installed metering across these bulk supplies, reviewed the metered data and used it to update the bulk supply agreement. The new metered data revealed that the Wrexham to Chester export was approximately 1Ml/d lower than calculated at WRMP19. This is reflected in our WRMP tables.

Table A3.1: Transfers of water between Hafren Dyfrdwy and Severn Trent

Direction of inter-company transfer	Exporting WRZ	Importing WRZ	Volume (Ml/d)
Hafren Dyfrdwy to Severn Trent	Llanfyllin	Shelton	0.15
	Llandinam and Llanwrin	Shelton	0.85
	Llandinam and Llanwrin	Bishops Castle	<0.1
	Wrexham	Chester	2.08
Severn Trent to Hafren Dyfrdwy	Shelton	Llanfyllin	7.24
	Mardy	Llanfyllin	0.02
	Chester	Saltney	4.73
	Mardy	Wrexham	0.04
	Shelton	Llandinam and Llanwrin	0.26
	Bishops Castle	Llandinam and Llanwrin	<0.1

We also supply non-potable water to the Wrexham Industrial Estate. We have discussed the potential growth of this major industrial site in our area with Wrexham Council. As part of the North Wales Growth deal a large expansion project, known as the Western Gateway is planned at the Wrexham Industrial Estate. The new development plan has zoned land for expansion of the Industrial Estate by a third of its existing size. Although at the planning stage, development is expected to start within the next three to five years and continue until around 2035. The quantity of water required by this new development is uncertain as it is dependent on the type of commercial development, for example a large warehouse would have minimal needs compared to Hi-tech manufacturing.

We have tested a one third increase in demand for water at the Wrexham Industrial Estate as a scenario in our supply demand balance. This scenario assumes that the expansion would contain the same mix of industries that are currently established.

As can be seen in Figure A3.1, we have sufficient surplus to cater for this potential additional supply requirement. We therefore do not feel it necessary to develop an adaptive pathway at this time but we will monitor progress of the development and include an updated assessment in our next WRMP in 2029.

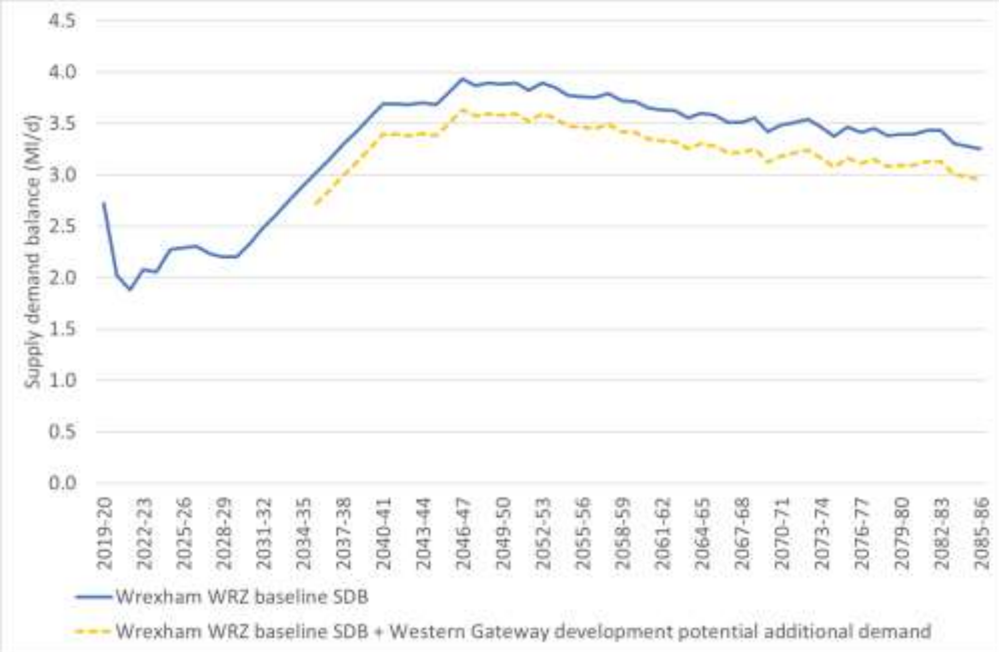

Figure A3.1: Baseline supply demand balance with and without additional Western Gateway development demand

A3.2 Water trading

We have replicated the approach we used at WRMP19 for our discussions with neighbouring companies. This three stage structured approach identifies potential needs for both parties for third party water resource options. The approach covered both the potential imports and exports.

In preparing for this dWRMP we adopted the same approach, the stages of which are outlined below.

Stage 1 - communicate need and opportunities

We approached potential third party suppliers inside and outside our region to inform them of the opportunity. The scope of the discussions covered resilience as well as water resource options.

To do this we used multiple channels to ensure the broadest involvement, for example:

a. through our pre-consultation letter;
b. by invitation to water resource management plan stakeholder engagement session;
c. by invitation to meet on an individual basis

Stage 2 - develop technically viable options

d. We met with all interested parties on a one to one basis to understand each other's specific needs and capability. These parties were: Dŵr Cymru, United Utilities and Severn Trent
e. We worked up options separately and then reviewed jointly to confirm the option was feasible and to understand risks.
f. We then sought to confirm if the party was interested in pursuing an option and if so agreed to carry out further feasibility to determine the outline costs and benefits.
g. Screen the third party options in the same way as internally generated options.

Stage 3 - Agree which options to pursue and outline commercial and pricing arrangements

We started this water trading engagement process in 2020 and completed the end of stage 2 by May 2021. Although we have a small supply surplus in all zones under the most extreme climate change scenario. Having discussed the needs of our neighbouring companies (Dŵr Cymru Welsh Water, United Utilities and Severn Trent) these small surpluses are not sufficient to provide a viable water transfer.

The outcome of this process was that:

- Imports - as all our water resource zones are in surplus we did not progress any option beyond stage 2e
- Exports – also did not progress beyond stage 2e because Dŵr Cymru did not want to progress any of the small options that we presented. United Utilities did not have any requirement and our options along the border with Severn Trent are severely limited due to the topography

The options discussed are shown in Table A3.2.

Table A3.2: Summary of options discussed with other water companies

	Imports (resilience only)	Exports	Status
Dŵr Cymru	Expansion of the Bretton connection	• Expand the existing connection at Corris near Machyntlleth • Use of the existing Montgomery connection at Clywedog dam to support supplies in mid Wales	Not progressed
United Utilities	Connection to the Vyrnwy Aqueduct to		Discussions continuing for PR24
Severn Trent	No viable transfers identified	• Clywedog [1]	

1 Note: We own and operate two large dams at Clywedog reservoir and Lake Vyrnwy, whose abstraction licences are controlled by the Environment Agency and United Utilities respectively to supply large areas of the Midlands and northern England. At Clywedog reservoir, we are investigating whether the dam could be enhanced to provide greater resilience to our customers, help mitigate some of the local flood issues, provide water for onward transfer, whilst bringing an overall improvement to the environment and local wellbeing. This scoping study may lead to a proposal for more detailed feasibility work if endorsed by regulators and the Welsh Government.

We will review our position in five years time as part of the water resources management plan cycle.

A4. Outage

Our water supply planning projections include an assessment of the likelihood of source outages occurring in our supply system. The water resources planning guideline supplementary guidance – outage from Natural Resources Wales and the Environment Agency (2020, p. 1) define an outage as a "*temporary short-term loss in deployable output*". Outage can be planned, where the outage is foreseen and pre-planned, or unplanned, where the outage is caused by an unforeseen or unavoidable event. It can result in either partially reduced output of a source or complete closure. Outages include events which affect the "Water Available For Use" (WAFU), by restricting our ability to supply our customers and also events which do not affect the WAFU but pose a potential risk to supply and can last for longer than 3 months. However, careful consideration needs to be given to events lasting longer than 3 months as it may be more suitable to reflect these restrictions/closures as part of the source deployable output if the loss of output is not recoverable. In accordance with NRW and the EA Water Resource Planning Guideline supplementary guidance (2020) we have considered our outage allowance outside of our target headroom assessment and ensured that we have not double-counted outage.

Outage in Saltney and Llanfyllin is zero as both WRZs are bulk import zones. We have assumed that bulk supplies will be maintained in line with bulk supply agreements, and any outage allowance relating to the water supplied by bulk supplies should lie with the exporting zone.

A4.1 Wrexham WRZ outage modelling approach

Between WRMP09 and WRMP14, we developed a complex 'source to tap' model which calculated the loss of supply in hours per year for each District Metered Area (DMA). The components included in the model depicted the process that water is supplied through. All critical components are modelled and comprise, for example, a raw water source, an aqueduct or a single stage in a treatment works. Failure data was assigned to each and every component and Monte Carlo simulations were then carried out to determine the risk of loss of supply for each DMA.

The models were constructed using data and parameters from the following sources:

- industry standard failure rates (e.g. loss of power)
- company specific rates (e.g. for pipe failure)
- expert judgement (e.g. one in ten years for an algal bloom).

The models were calibrated against observed failure rates and a good correlation was achieved between the observed loss of supply and the model predictions.

Interdependencies and redundancies within the system were assessed by modelling different supply scenarios, e.g. from different treatment works. The results from the models were used to determine the loss of supply caused by a failure in the route from the source to the outlet from the treatment works in hours per year (hrs/yr). The outputs from the models showed that the 'source to treatment works systems' are inherently reliable. We have continued with this DMA approach since WRMP19, with the updates including adjustment of the treatment works capacity. The outages for Wrexham WRZ have been recalculated[5] to take account of capacity changes and the results are shown in Table A4.1.

Table A4.1: Summary of outage allowances adopted for dWRMP24 for Wrexham WRZ

Treatment Works	Capacity (Ml/d)	Unavailability (hrs)	% Unavailability	Outage (Ml/d)
Pendinas	3.40	0.57	0.0065	0.0002
Llwyn Onn	45.50	0.22	0.0025	0.0011
Oerog	2.47	4.82	0.0550	0.0014
Wrexham WRZ				**0.0027**

We calculated our outage using an approach consistent with that used in WRMP19. However, with the creation of Hafren Dyfrdwy we look to align our outage calculation methods for all of our WRZs. We assessed aligning the Wrexham outage methodology with that of Llandinam and Llanwrin but due to the resilience and relatively short period of outage record in Wrexham (2019–2022) this would have resulted in a smaller outage allowance. Thus, we have continued with the Wrexham WRMP19 methodology.

[5] Treatment works capacity multiplied by % unavailable, divided by 100.

A4.2 Llandinam and Llanwrin outage modelling approach

We have used a risk-based approach which follows the best practice principles set out in the UKWIR report *Outage Allowances for water resources planning* (UKWIR, 1995). This method uses Monte-Carlo analysis to assess the “allowable” outage (the probability distribution of the combined risks of the legitimate planned and unplanned outages occurring), with the output of the analysis enabling us to adopt a suitable level of risk.

Our outage model allows us to use a “bottom up” approach which utilises the operational outage data and information collated in our database for individual sources in each water resource zone. This is the same approach that was used for WRMP19. We believe the use of site-specific outage records results in a more appropriate assessment of future outage risk. Our outage allowance models use data which is processed in our specially developed “Event Tracker” tool to generate the outage events and consolidate them into suitable distributions which are required to perform the Monte Carlo simulations in the outage allowance models. The outage allowance model uses triangular distributions for assessing the magnitude and duration of outage risks and a Poisson distribution for event frequency.

We have used this database to inform our latest assessment of future outage risk. The database records the following information:

- The source(s) that is affected,
- The cause of the outage (quality issue, process maintenance etc.),
- Whether the outage was planned or unplanned,
- Whether the source was fully offline or partially restricted,
- The duration of the event,
- How much of the capacity of the source could not be deployed as a result of the outage.

Our outage allowance models have been developed with a user interface which enables a thorough audit trail to be maintained. The user interface captures key pieces of information, including a full set of input data and output data for the model run.

The outage allowance model has an additional function built in, which allows us to assess the impact of the outage in two ways:

- The outage is included in the model as a proportion of the full source deployable output.
- The outage event is only recognised by the model if the severity of the event exceeds the buffer between the source deployable output and the maximum capacity of the source. Furthermore, when an outage event does exceed this buffer, its calculated magnitude takes this buffer into account. As a result, outage severity for a source is reduced when calculated against capacity (unless deployable output is equal to maximum capacity, in which case it will be equal).

We have used the second option in our modelling. In most cases, the deployable output of our sources is constrained by a factor other than the maximum treatment capacity of the treatment works, such as licence or infrastructure. Applying the outage impact to the full source deployable output in the modelling would result in a higher Outage Allowance. Adopting the second option enables us to assess the impact the outage events would have on our dry year deployable output.

The following is a summary of the approach used to select which issues are to be included in the outage assessment:

- If an actual event has been identified by the Event Tracker then it has been included in the outage assessment unless it was an operational choice such as ‘preserving raw storage’ or ‘works control’.
- Generic pump or valve issues have been included for groundwater sources where events have not been observed in this category or their magnitude is lower than the generic issue.

- Any outage event that was removed during the WRMP14 and WRMP19 process was also removed for our dWRMP24 outage assessment as the issues had been resolved.
- Only 'legitimate' events have been included in the outage assessment. These events were identified through internal stakeholder consultation.
- Following the UKWIR 1995 guidance, any outage event that lasted longer than 90 days either needed to be removed (as this counts as a long term loss of deployable output) or treated with caution. We decided to cap the duration to 90 days as the updated deployable output assessment has taken these into account.

We have used the recorded data in our assessment where available. We now have approximately 12 years of historic outage data for our Llandinam and Llanwrin sources. In line with our outage assessment for WRMP19, we have considered both planned and unplanned events in our analysis.

Planned outages

We have an ongoing programme of planned maintenance and capital enhancement activities at our water production sites in order to maintain the long-term serviceability of our assets. To minimise the loss of output from maintenance activities we schedule work to be carried out in a way that limits risks to customers' supplies. Planned maintenance is avoided at peak demand periods and this is reflected in very low numbers of planned outages between June and August. Outages due to repair and maintenance activities will only affect average deployable outputs and are not expected to influence our ability to supply our customers during peak demand periods. Furthermore, where possible, planned maintenance is planned so that works may be brought back into production at short notice if required.

For our groundwater sources, we have used actual data of the impacts of planned maintenance of our boreholes wherever it is available. Most of our water resource zone assessments include an element of planned outage due to process maintenance and capital improvement.

Unplanned outages

The UKWIR (1995, p. 4) methodology defines an unplanned outage as being "an outage caused by an unforeseen or unavoidable legitimate outage event affecting any part of the sourceworks and which occurs with sufficient regularity that the probability of occurrence and severity of effect may be predicted from previous events or perceived risk". Their definitive list of unplanned events are:

- Pollution of source
- Turbidity
- Nitrate
- Algae
- Power failure
- System failure.

The main unplanned outage issues for groundwater sources are pump failures and power failures. There are also issues of flooding at some sources and occasional periodic quality problems, principally turbidity after heavy rain. Where unplanned outages have occurred and have been recorded on our groundwater outage database, we have used actual recorded data to inform the outage assessment. The types of issues included in the assessment are summarised below:

- Burst/leak on the site (leading to a system failure)
- Electrical issues on site (leading to a system failure or caused by power failure)
- Flooding on site (leading to a system failure)
- Mechanical issues on site (leading to a system failure)

- Pump/valve issues on site (leading to a system failure)
- Quality issues (including pollution of source, turbidity problems).

Although our detailed site outage record for groundwater sources extends back to 2008, several of our sources have not been affected by pump/valve outage events during this time. Therefore, for groundwater sources we have included allowances for pump/valve issues with the following distribution: frequency of 0.4 events per source per year; and a duration average of three days, between a minimum and maximum of one and five days respectively.

Annual average outage allowances to 2085

The output from the probabilistic analysis of outage risks we have undertaken is summarised in Table A4.2. The table shows the likelihood of different outage quantities occurring in the year. For example, our assessment shows that there is a 80% certainty (20% risk) that in any given year, up to 0.02 Ml/d will be lost due to outage, and a 90% certainty (10% risk) that up to 5.54 Ml/d will be lost due to outage in the Llandinam and Llanwrin zone.

Table A4.2: Range of outage allowances at different levels of risk

WRZ Name	DO (Ml/d)	Outage (Ml/d)				
		60% (40% risk)	70% (30% risk)	80% (20% risk)	90% (10% risk)	100% (0% risk)
Llandinam and Llanwrin	18.73	0.00	0.00	0.02	0.24	5.54

For our Llandinam and Llanwrin zone, few outage events have been recorded in part because this zone is highly resilient so rarely goes out of supply. To this effect we have maintained the same assumptions that are consistent with WRMP19. The outage allowance for this zone has therefore remained constant from WRMP19.

As shown in Table A4.2 there is a large difference between the 80th percentile outage value and the 90th and 100th percentile outage values, but the difference between the 80th percentile and the 60th and 70th percentile values is relatively small. This is due to the probabilistic methodology; when selecting a percentile closer to the tails of the distribution the change for each percentile change is typically greater than the same percentile change closer to the centre of the distribution. Consistent with WRMP19 we have therefore used the 80th percentile values of the cumulative frequency distribution of outage probabilities in our water resources planning.

Components of Outage Allowance

For the final plan, the overall outage risk for Llandinam and Llanwrin will be broken down into categories so that their relative contribution can be estimated. The outage categories are quality, process maintenance, burst/leak, capital improvement, electrical, and pumps/valves. This will be achieved by running the outage model multiple times with only issues from a single category enabled and other issues excluded each time. The proportional contribution of each category of outage issue will be used to estimate the proportion of the total outage for each WRZ that is attributable to each category. It should be noted that because a probabilistic model is used, the results from this analysis should be regarded as indicative rather than definitive.

A4.3 Outage Allowance summary

Table A4.3 shows the outage allowances we have adopted with the percentage of the zonal deployable output that is affected. Overall, the outage allowance is low as a percentage of total DO at both a company level and at the individual zone level, being a maximum of 0.11% of DO in the Llandinam and Llanwrin zone. At a company level, the outage allowance is 0.03% of our total DO.

Table A4.3: Summary of outage allowances adopted for dWRMP24

WRZ Name	Outage Allowance (Ml/d)	Percentage of Deployable Output (%)
Llandinam and Llanwrin	0.02	0.11
Llanfyllin	NA	NA
Saltney	NA	NA
Wrexham	0.0027	0.01

We have not included any outage allowance for Llanfyllin and Saltney as previously discussed as these water resource zones are supplied by bulk supplies and we assume that supplies will be maintained in accordance with our bulk supply agreements.

A5. Drinking Water Quality

Providing a safe, wholesome supply of drinking water to our customers is our primary duty. We must ensure that the water we provide meets the standards set out by the EU Drinking Water Directive, plus any additional UK requirements and ensure the necessary protection is in place to prevent deterioration in the water quality, with a view to reducing the level of treatment required. In particular when developing our dWRMP, we must consider how we will support the objectives for any drinking water protected areas within our supply area.

Drinking water protected areas or 'safeguard zones' are designated zones in which the use of certain substances must be carefully managed in order to prevent pollution of raw water sources that are used for drinking water. There are no safeguard zones within our supply area. However, the River Dee catchment from Snowdonia to the weir in Chester is designated under the Water Resources Act 1991 as a Water Protection Zone. This means that a consent is required where certain substances are used or stored at specific sites anywhere within this part of north east Wales. It helps prevent water pollution arising from activities that cannot be controlled using other permits. Although this designation is driven by environmental concerns, it also provides a level of protection for our abstractions from the River Dee. We have a number of Dee Protection Zone (DPZ) consents ourselves and have worked with NRW, through the Dee Catchment Protection Group (see below) to raise awareness with local businesses about the DPZ consent requirement.

All of our water treatment works are designed to address the challenges of the raw water from the relevant sources, to ensure a consistent wholesome supply. We use a Water Safety Plan7 approach to proactively address risks and where unacceptable risks are identified, we agree legal programmes of work with the Drinking Water Inspectorate (DWI) to resolve them.

The River Dee is the most highly regulated water body in the UK. As such, there are a range of protections in place to prevent deterioration in the water quality including a proactive monitoring regime - which is part funded by the water companies who abstract from the Dee – and associated 'early warning system' which provides notification of any significant pollution events to key abstractors. The monitoring regime is managed by the Dee Steering Committee (DSC). In May 2017 the DSC sanctioned the setting up of a Dee Catchment Protection Group, a working group with representatives from Hafren Dyfrdwy, Severn Trent Water, United Utilities, Dwr Cymru Welsh Water, Natural Resources Wales and Environment Agency. The aim of the group is to coordinate catchment activities in supporting the objectives of the Dee Steering Committee with specific objectives around providing intelligence from catchment teams regarding potential risks to abstraction which require monitoring; coordinating catchment activities in response to abstraction risks highlighted through incidents and routine sampling undertaken, and coordinating promotion of the River Dee as a drinking water source and some of the challenges to quality from activities within the catchment.

The NRW guidance requires us to consider measures to protect our supplies against long term risks of pollution. We believe that contributing to the work of the Dee Catchment Protection group, along with continued support of the DSC and wider catchment management programmes within the Dee catchment, will enable us to pro-actively manage any risks of pollution through collaborative working with other abstractors and engagement with key land and water users in the catchment on the wider benefits of good water management practices.