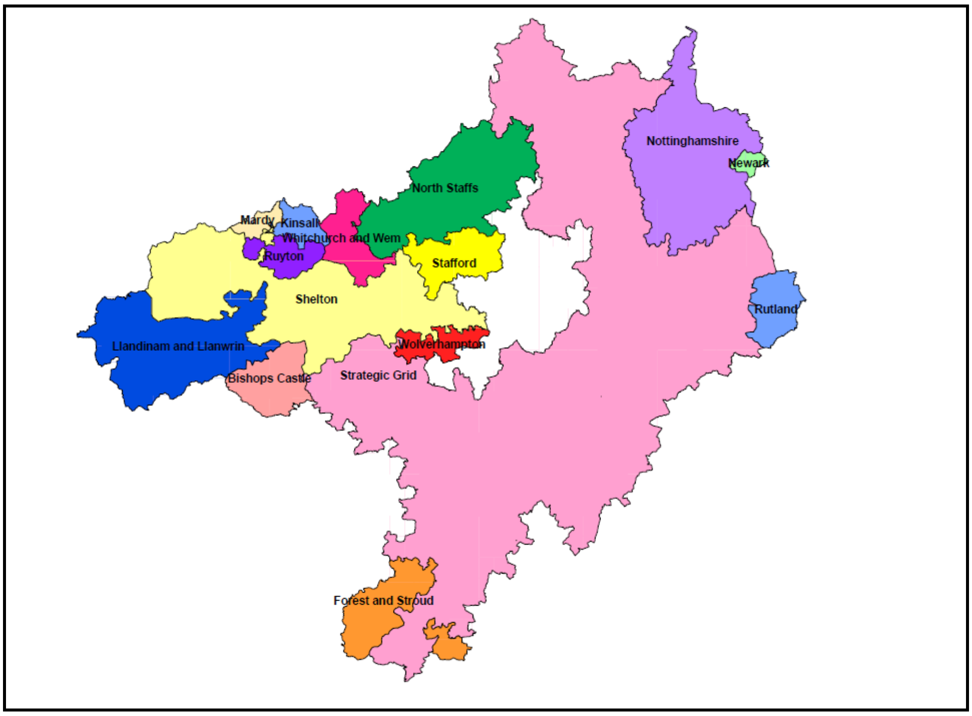
A1 Water Resource Zones

Following the 2009 Water Resources Management Plan, we informed Defra of our plan to review the structure of our six water resources zones in time for the 2014 WRMP. The purpose of the review was to ensure that we comply with the EA definition of a water resource zone being the "largest possible zone in which customers share the same risk of a resource shortfall".

We completed our review of resource zones in 2009-10 and shared the results and supporting evidence to Defra and the EA in June 2010. Our review took into consideration the supply and distribution enhancements we are undertaking during AMP5 and resulted in 15 water resource zones, as illustrated in figure A1.1 below. The new zones provide a more accurate representation of how customers will be served by our network at the end of AMP5, and meet the EA's resource zone definition. Our 2011 and 2012 WRMP annual reviews have included a summary of the outturn water supply and demand position for each of these new zones.

Figure A1.1: Severn Trent Water's new Water Resource Zones



Defining our Water Resource Zones

Our review of water resource zones used a combination of the best available company asset configuration records along with operational expert judgement. Following this review, we have also reconfigured the water demand and supply models used for our water resources planning.

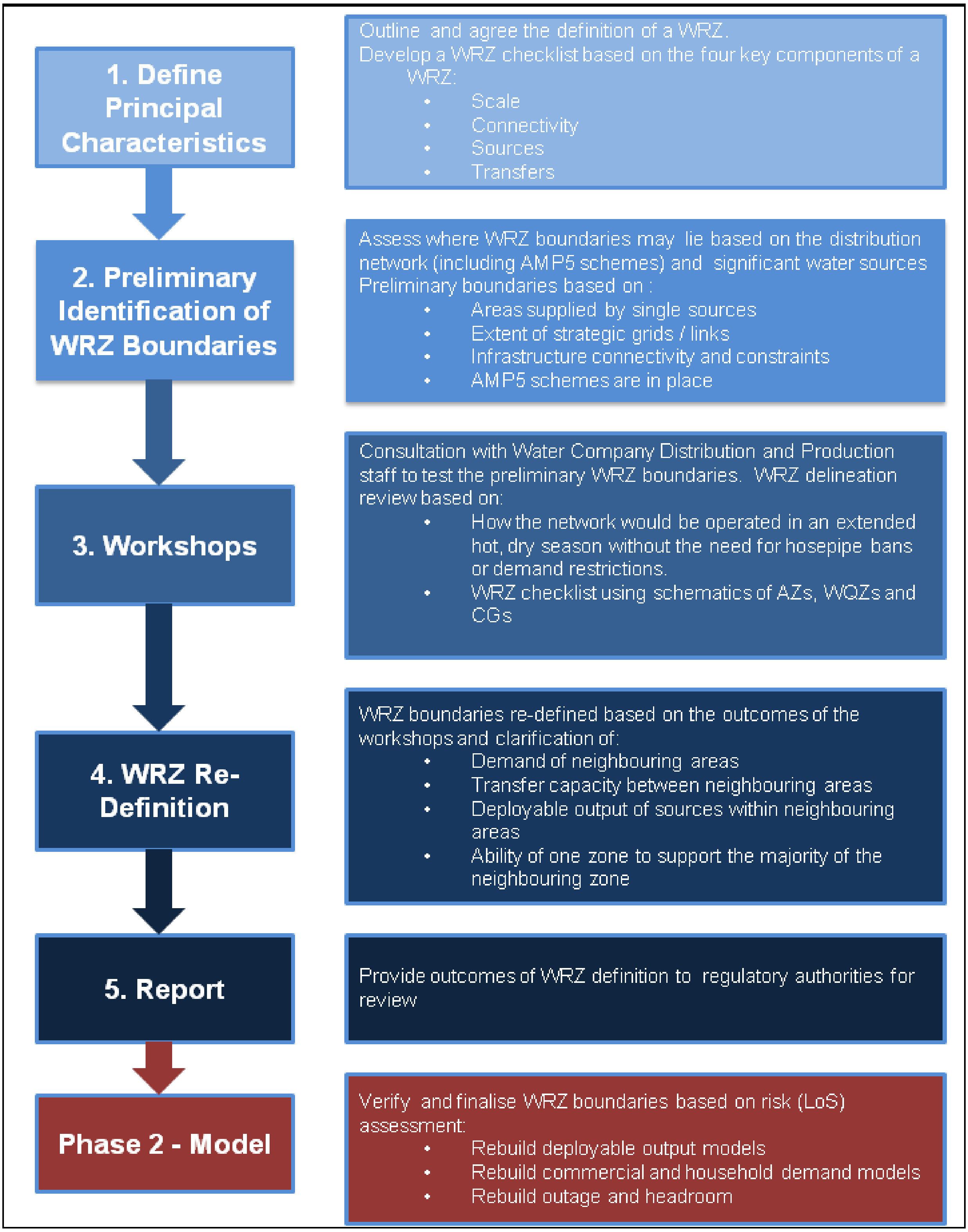
Our approach to reviewing the structure of our existing water resource zones was agreed with the EA in January 2010, and can be summarised as follows:

Appendix A - How much water do we have available?

- We have reviewed our major strategic sources and assessed how the connectivity of our supply system allows them to support our smaller sources of water.
- For supply / demand investment planning, our scenario is an extended hot, dry season (eg summer / autumn 2003).
- We have considered to what extent the conjunctive supply system can meet demand without the need for hosepipe bans / restrictions.
- Where the distribution network constrains our ability to share water between sources to meet demand, this forms a “cleavage line” between zones.
- Our assessment is based on delivery of the AMP5 supply resilience schemes.
- Our assessment did not include short term emergency risks due to engineering failure or ‘peak day’ demands as these are not relevant to the definition of a water resource zone. They are covered by our resilience and isolated communities investment plans and our local distribution investment plans.

The key steps in our approach to reviewing our Water Resource Zones are summarised in Figure A1.2 below.

Figure A1.2: The process of defining Water Resource Zones



Characteristics of our Water Resource Zones

The new zones vary widely in scale, from the Strategic Grid zone which supplies the majority of our customers, to the small zones of Mardy and Bishops Castle which supply much smaller populated areas. These zones have very different water resources challenges, with some requiring significant investment in the long term to ensure secure supplies, while others require minimal investment to maintain the current assets and infrastructure. These future pressures are explained throughout Appendices A, B and C of this WRMP, while chapter 3 sets out our long term plans to ensure sufficient supplies are available in each of these zones.

The 2011-12 characteristics of our 15 water resource zones are summarised in Table A1.1.

Table A1.1: Water Resource Zone 2011-12 characteristics

Name	Deployable Output (Ml/d)	WAFU (Ml/d)	Number of households	Population served	Leakage (Ml/d)	Distribution Input (Ml/d)
Bishops Castle	4.67	4.57	2,762	7,530	1.32	2.74
Forest & Stroud	44.99	42.05	54,907	130,387	14.52	41.79
Kinsall	5.00	4.81	4,907	11,938	1.42	4.58
Llandinam & Llanwrin	19.85	19.17	17,981	42,309	5.43	14.58
Mardy	3.65	3.54	3,138	8,119	1.02	2.68
Newark	15.5	15.03	20,190	46,080	2.14	11.70
North Staffordshire	149.99	147.50	229,241	523,241	29.53	126.17
Nottinghamshire	269.87	263.77	443,809	1,048,927	49.29	237.32
Rutland	0.00	10.00	11,874	32,376	2.07	8.20
Ruyton	5.32	5.10	4,503	12,428	1.79	4.42
Shelton	142.99	140.5	196,206	470,743	27.07	109.50
Stafford	28.00	27.03	38,976	93,567	6.07	24.43
Strategic Grid	1469.56	1319.58	2,092,597	5,061,528	304.94	1244.19
Whitchurch & Wem	10.90	10.79	12,192	30,398	3.30	9.41
Wolverhampton	66.00	65.4	99,850	232,280	18.92	64.16

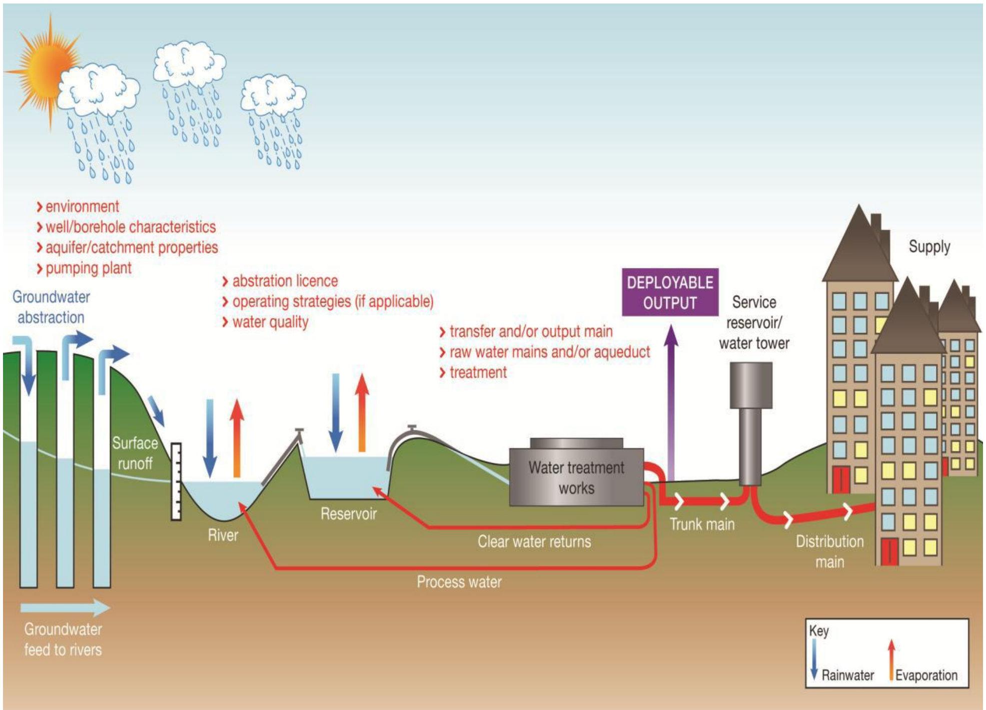
A2 Calculating Deployable Output

Deployable Output (DO) is defined in the Environment Agency's Water Resources Planning Guidelines as:

"the output for specified conditions and demands of a commissioned source, group of sources or water resources system as constrained by; hydrological yield, licensed quantities, environment (represented through licence constraints), pumping plant and/or well/aquifer properties, raw water mains and/or aqueducts, transfer and/or output mains, treatment, water quality and levels of service."

As a concept it is described in the below figure from *UKWIR WR27 Water Resources Planning Tools 2012 guidance* (Akande *et al*., 2011).

Figure A2.1: Deployable Output Concept



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We have 15 water resource zones, these are split between conjunctive use zones and groundwater only zones. The deployable output for the zones is calculated differently depending on which type of zone they are. The zones and methods used are tabulated below.

Appendix A - How much water do we have available?

Table A2.1: Deployable Output Methodologies Used

Resource Zone	Type	Method	Reason
Strategic Grid	Conjunctive Use	Aquator Modelling	Both groundwater and surface water supplies with a complex network.
Nottinghamshire	Conjunctive Use	Aquator Modelling	Both groundwater with surface water imports from Strategic Grid zone.
Shelton	Conjunctive Use	Aquator Modelling	Both groundwater and surface water supplies.
Wolverhampton	Conjunctive Use	Aquator Modelling	Both groundwater and surface water supplies.
Forest and Stroud	Conjunctive Use	Aquator Modelling	Both groundwater and surface water supplies.
North Staffordshire	Conjunctive Use	Aquator Modelling	Both groundwater and surface water supplies
Newark	Conjunctive Use	Aquator Modelling	Groundwater with imports from the Nottinghamshire zone.
Stafford	Ground Water Only	Aquator Modelling	Historically part of the Aquator Model
Bishops Castle	Ground Water Only	UKWIR Assessment	Groundwater Only
Mardy	Ground Water Only	UKWIR Assessment	Groundwater Only
Llandinam and Llanwrin	Ground Water Only	UKWIR Assessment	Groundwater Only
Kinsall	Ground Water Only	UKWIR Assessment	Groundwater Only
Whitchurch and Wem	Ground Water Only	UKWIR Assessment	Groundwater Only
Ruyton	Ground Water Only	UKWIR Assessment	Groundwater Only
Rutland	Bulk Import	Agreed Import amount	Import from Anglian Water.

In the following sections we explain how we have derived the deployable output for our zones, firstly for groundwater and then for the conjunctive use zones.

A2.1 Groundwater Deployable Output Method

The deployable output of all of our operational groundwater sources was assessed in 2006 in accordance with the *UKWIR methodology* (UKWIR, 1995 and UKWIR, 2000) to inform our WRMP09. During 2011-12, we have again reviewed and updated the deployable output of our groundwater sources in accordance with the guidance in the UKWIR methodologies. This has included a review of groundwater output capacity in relation to all constraints (licence limitations, infrastructure limitations, aquifer limitations and distribution limitations), and review of nitrate and water quality, climate change and EA sustainability changes impacts on groundwater DO.

Source Performance Diagrams (SPDs) were derived for each borehole source in order to determine the drought year average deployable yield and the peak week deployable yield. In this document the drought year average DO will be referred to as “average DO” and the drought year peak week DO as ”peak week DO”.

For the assessment, we have updated all available groundwater datasets to mid 2012, and our assessment of groundwater DO incorporates the recent 2011/12 drought, which represented some of the lowest groundwater levels recorded across our resource area.

The review of groundwater DO was carried out in eight stages:

Stage 1: Review of previous DO assessment
The first stage of the process reviewed the groundwater source information reported in our WRMP09. This forms part of the audit trail for this WRMP.

Stage 2: Source Licence verification
This stage of the process verified the average and peak licence details reported in our WRMP09 assessment. Several sites were identified to have minor licence changes since the WRMP09 assessment.

Stage 3: Review of network constraints
This stage of the process identified any network constraints up to the first Distribution Storage Reservoir (DSR). Several additional constraints to those identified in 2009 were recorded.

Stage 4: Review of geological / borehole construction logs
This stage of the process re-reviewed the geological and borehole construction logs on a site by site basis, to determine any additional constraints to those identified in 2009. No additional constraints were identified.

Stage 5: Operational verification
This stage of the process captured expert judgement from our operational staff on the deployable output of our groundwater sources. Information on site infrastructure and processes (pump capacities, pump depths, treatment and booster capacities, operational interlocks and Programmable Logic Controls) was captured and reviewed and recent actual

production data was also examined. This gave an indication of average and peak DO capability.

Stage 6: Review, collation and update of manual and telemetry groundwater level data and spring flow data
This stage of the process reviewed groundwater level and flow data collated as part of the WRMP09 assessment. Where applicable, manual groundwater dips and telemetry water level and flow data were collated to mid 2012 and records updated on a source by source basis. In addition, available EA regional groundwater level data were collated and records updated to mid 2012.

Stage 7: Source Performance Diagrams update
This stage of the process undertook a systematic update of the SPDs on a site by site basis, by compiling the data collated from the previous stages and creating new performance curves. As part of this process the SPDs were updated with: source licence data (from Stage 2), network constraints (from Stage 3), geological constraints and Deepest Advisable Pumping Water Level (DAPWL) (from Stage 4), pump depth and capacity (and treatment and booster capacity where applicable) (from Stage 5) and water level data (Stage 6).

This data was then utilised to create a series of updated performance curves, and determine the average and peak DO on a source by source basis.

Stage 8: Nitrate assessments
This stage of the process comprised a review of nitrate concentrations and trends, and the consequent impact on source DO up to 2040. A series of nitrate blend scenarios were evaluated to determine the impact that rising nitrate concentrations would have on source DO over this period without interventions.

Other quality issues have not been explicitly included in the DO review. It has been assumed that any other water quality problems are resolved by treatment or other solutions being implemented through the company business plan, and that there will therefore be no impact on DO.

Other groundwater considerations

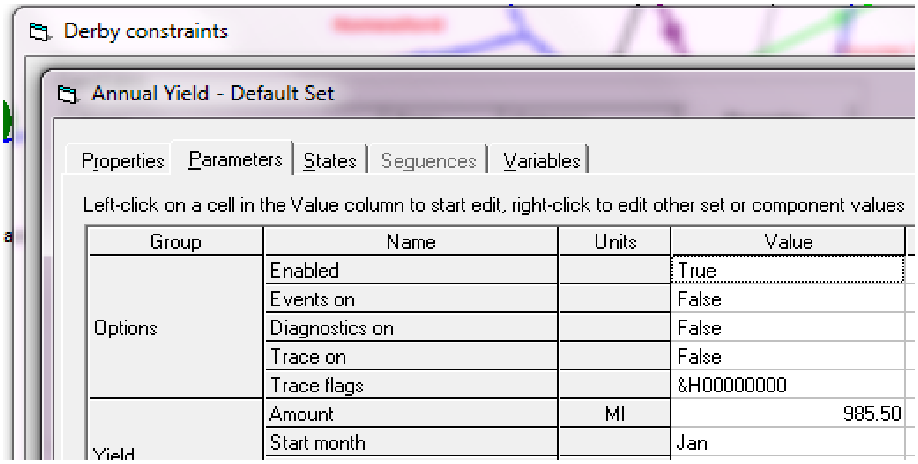
- Groundwater Treatment Losses: a number of new nitrate, water hardness and cryptosporidium plants have been or are being installed. Currently, where DO is constrained by treatment pumping capacity or throughput through the water treatment works, this loss is accounted for in the DO values reported. No process water losses have been accounted for in the DO numbers reported. Analysis of a sample set of groundwater treatment works indicates that process losses are small in comparison with the groundwater output (generally <1%, but up to 4.5%). For the small number of sites where process losses are applicable, we do not consider process losses to be significant on a zonal scale.

- Time Limited Licences: the Environment Agency has stated (e.g. in the CAMS Stakeholder Group meetings, Water Resources Planning guideline) that it has a policy of presumption of renewal for the majority of existing time limited licences. We have assumed this in our planning process.

Groundwater Source Inputs to Aquator

For conjunctive use zones, groundwater annual average and peak day yields have been updated as part of the overall groundwater deployable output review discussed above. These updated yields have been incorporated into the Aquator model as annual yield constraints and daily maximum capacities respectively. An example of this is shown in Figure A2.2.

Figure A2.2: Updating Annual Yields in Aquator



For spring sources the monthly profile of yield during the drought year has been input into Aquator as a "monthly" daily maximum capacity, as the effective DO of these sources changes across the year.

A2.2 Deployable Output Method for conjunctive use zones

For our conjunctive use zones, we derive zonal DO in line with the best practice guidance found in *UKWIR WR27 Water Resources Planning Tools 2012 (*Akande *et al*., 2011*).* To do this we use the Aquator water resources simulation model. Aquator is a powerful application for developing and running simulation models of natural river and water supply systems. The simulation package facilitates the construction of models comprising a range of components to represent sources, demand centres and their linkages. These components can then be customised so that simulations can be produced over a wide range of scenarios and operating rules.

We use Aquator to model the complex nature of our water resources system. Our model includes the following components and constraints:

- Surface water raw water sources: The raw water sources, or groups of sources, are represented within each zone. Input data includes their output capacities and details of any limitations due to abstraction licence, resource availability, pump capacity, treatment capacity or transfer capacity. Where a source is supplied by a reservoir, the control rules for that reservoir are used to define the safe output from the source over the year. For run-of-river sources any abstraction licence or prescribed flow limitations are taken into account in the model. Each reservoir and river on the model has catchments associated with it, these each have daily inflow series ascribed to them that cover a simulation period of 91 years starting in 1920.

- Groundwater sources: The source yield of each of our operational groundwater sources are included as an individual source or a group of sources. This process of assessing individual groundwater source DO is summarised in Section A2.1 above. This method provides the basis of the assessment framework for groundwater sources as advocated in the *UKWIR WR27 Water Resources Planning Tools 2012 guidance (*Akande *et al*., 2011*).* For groundwater sources drought year average and peak deployable output yield have been calculated and included in the groundwater aquator component. For the majority of our groundwater sources the limiting factor is the abstraction licence, although there are hydraulic or operational restrictions at some sources. The abstraction licence can have daily, annual or multi-year conditions; these are represented in the Aquator model as appropriate. Additionally, some blending requirements for water quality purposes in multi-source locations are incorporated into the model as operating controls.

- Aqueducts and distribution linkages: Aqueducts and distribution linkages are included between sources and demand centres and their maximum capacities are entered. The model allows us to identify where distribution constraints limit our ability to deploy water to where it is needed.

- Imports and exports: These operational import and export transfers are represented between zones and for bulk supplies to/from other companies.

- Demand centres: There may be one or many demand centres represented in a zone. These represent areas where both our domestic and industrial customers exist and use water.

The deployable output of the conjunctive use water resources zones are derived within one model. Therefore where the DO of one zone can affect the DO of another, consideration is taken as to which zone is modelled first.

To analyse deployable output we use Aquator's inbuilt DO analyser. This incrementally increases demand across a water resource zone in small steps; for example for the Strategic Grid zone we use 5Ml/d increments. The analyser runs the model in daily steps across the full 91 years of our catchment inflow series, until either there is a failure to supply a demand centre or until there are more than three crossings of the Temporary Use Ban (TUB) line across the zone. Aquator calculates the deployable output as the average output across the 91 year record.

For modelling purposes the demand in the surrounding zones is kept static while the demand in the zone being analysed is increased. Once the deployable output of the first zone has been derived, this is then set as its DO level and the next zone is analysed and so on.

Appendix A - How much water do we have available?

Due to the connected nature of the zones, the order in which the DO is modelled can have an effect on the DO of the individual zones. We have modelled the zones in the following order.

- Firstly North Staffordshire and Stafford are modelled as these are not currently connected to any other zone.
- We then model the Shelton zone as this abstracts from the upper river Severn above the abstraction points for the other zones affected by the River Severn.
- After this we then model the Wolverhampton zone as this is again above other abstractions on the river Severn.
- Following this the Strategic Grid zone is modelled as this is the largest zone,
- Nottinghamshire, Newark and Forest & Stroud zones are then modelled, as these are dependant on the Strategic Grid zone.
- Finally a DO run is carried out with all zones at their DO level, this ensures that zonal transfers are correct and that running all zones at their maximum DO does not cause any further failures.

For each of the conjunctive use zones that are modelled in Aquator, transfers between zones are as listed in Chapter A5. Treatment losses are incorporated within the model for all surface water treatment works.

Water Resource Zones and Model Structure

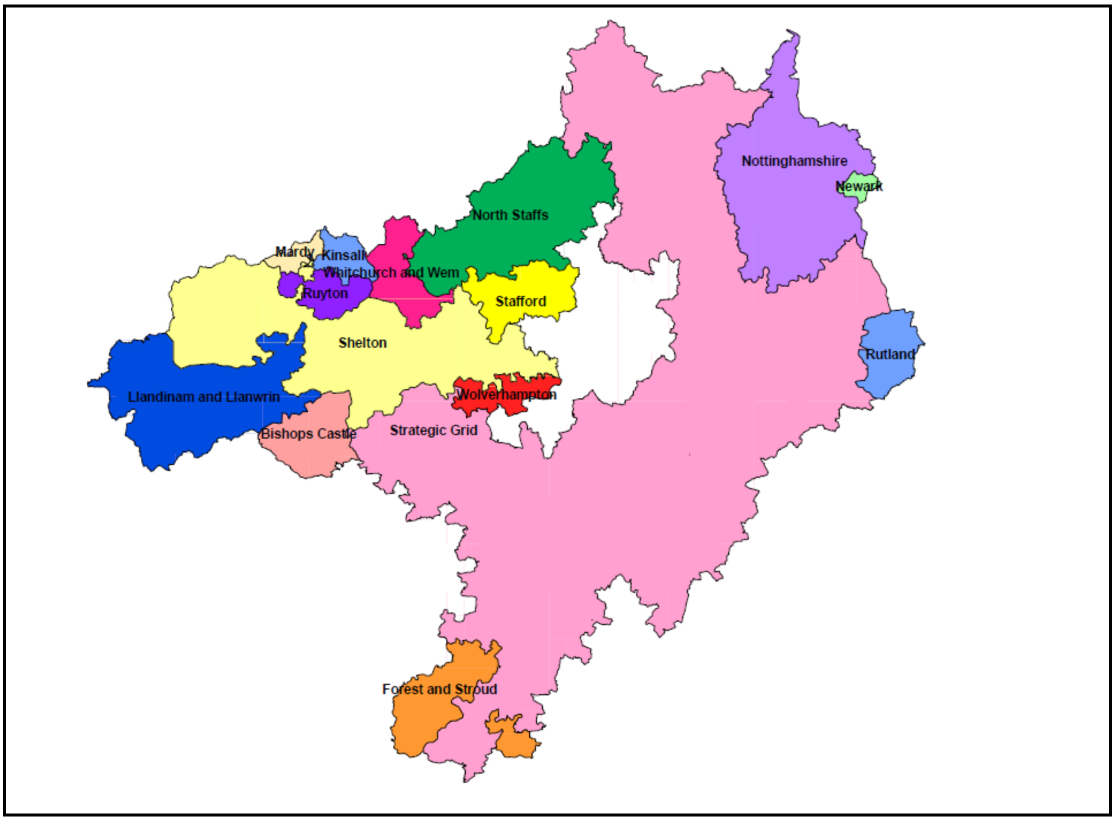
Chapter A1 explains that since WRMP09 we have made considerable changes to the structure of our water resources zones. In 2010 we reconfigured our water resource zones (WRZ) to ensure compliance with the Environment Agency's (EA's) definition of a WRZ:

"*largest possible zone in which customers share the same risk of a resource shortfall*"

Previously we had based our Water Resources Planning on six water resource zones. For this WRMP, our region has now been divided into 15 water resource zones, as shown in Figure A2.3. Under stressed conditions, resources within each zone can be configured to meet demand within these boundaries. Customers within these zones share the same risk of a resource shortfall.

We have derived and reviewed the structure of the new zones using a bottom up approach, looking at local and strategic constraints in our network. The deployable output in eight of the new zones is constrained by local groundwater yields or local network constraints. The remaining zones are conjunctive use zones, which use a mixture of groundwater and surface water, and these tend to be constrained by reservoir yields and large strategic linkages with other zones. For example the Nottinghamshire zone is supplied by a large amount of groundwater as well as a number of links to the surface water in the Strategic Grid zone, meaning the two zones are well integrated. However in times of water stress in the Strategic Grid zone, any spare resource in the Nottinghamshire zones groundwater sources cannot be used to feed back into the Strategic Grid.

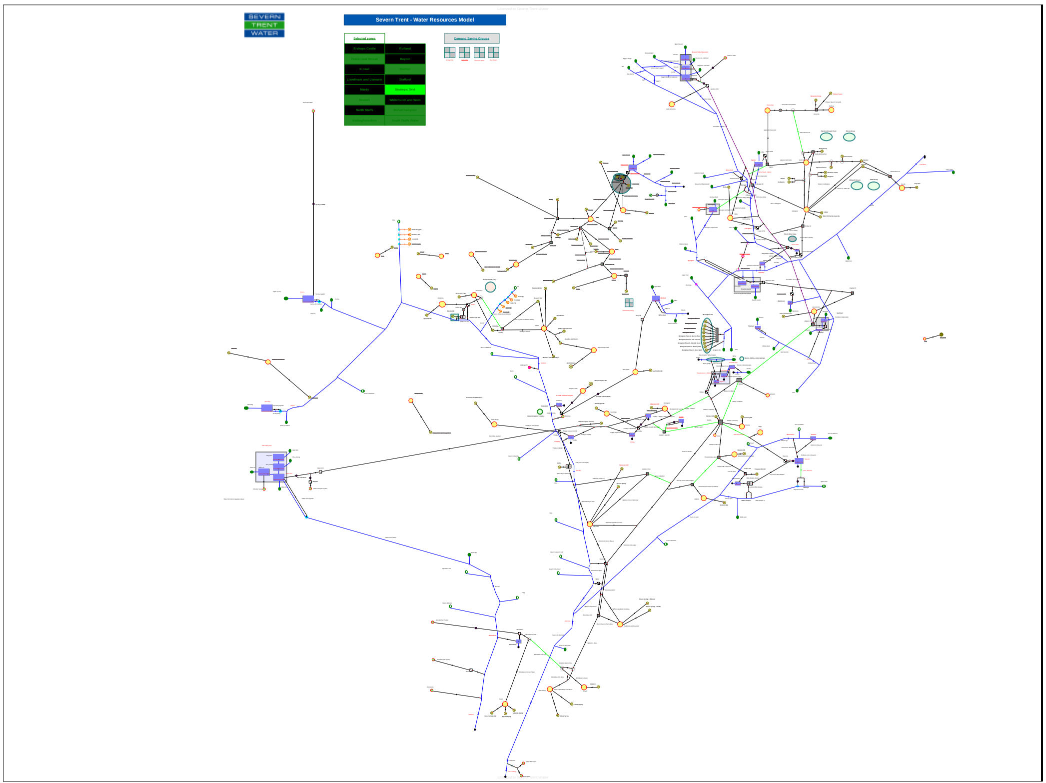
Figure A2.3: Severn Trent Water's new Water Resource Zones



The changes to our water resource zones have been fully shared with Defra, the Environment Agency and Ofwat following our review in 2010. More explanation of our water resource zones can be found in Chapter A1.

Due to the changes in the water resource zones structure it was considered that our water resources models in Aquator would also need to be fully rebuilt and the inputs updated. As part of the model rebuild we decided to combine all the sources and assets into one company wide model which encompasses all of our conjunctive use zones. This is because all of our conjunctive use zones are linked either by use of the same rivers for abstraction (River Severn for Shelton, Wolverhampton and Strategic Grid) or by strategic network linkages (Strategic Grid and Nottinghamshire) or both of these. Our updated model schematic is shown in Figure A2.4.

Figure A2.4: New Severn Trent Water Resources Model



The reasons for following the single model approach are shown in Table A2.2.

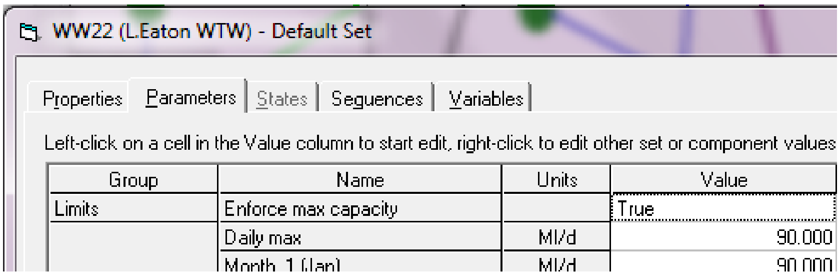
Table A2.2: Pro's and Con's of using a single model

Pro's	Con's
The effect of abstractions taken upstream on downstream abstractions, can be modelled correctly	The time taken to run the model is significantly increased.
Linkage / transfers between WRZs are easily modelled.	
There is the ability to prove future linkages and abstractions and their effects on other zones.	

A2.3 Aquator Model Updates since WRMP09

We have taken the opportunity of the rebuild to fully update and review many of the components/data within the model. These include a full review of the surface and groundwater licences used as constraints in the model, as well as a review of the water treatment works maximum capacities, an example of which we have shown in Figure A2.5.

Figure A2.5: Maximum works capacity updates



Strategic Linkages

We have reviewed the maximum capacities of a number of key pipelines and aqueducts that act as constraints within the model using both historic flow data and hydraulic modelling to establish the maximum potential flow along the pipelines. As a result a number of key changes have been made since the modelling used to inform the WRMP09.

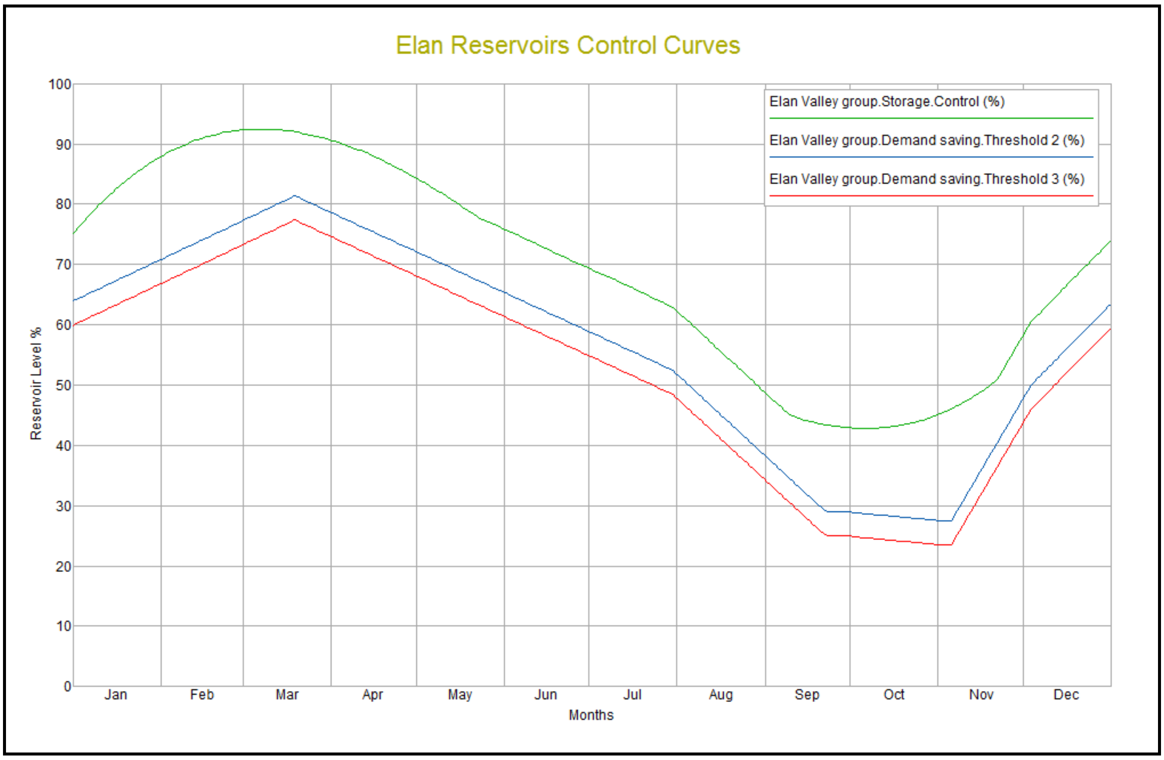
A number of supply areas in the model have been split out to improve the definition and granularity of the model in particularly complex areas. An example of this is the Nottinghamshire area, which has a number of group licences covering a large number of groundwater sources. The configuration of sources and group licences in this area are now better represented in the model.

Reservoir Control Curves

We have reviewed the control of our key reservoirs as part of the update we carried out to produce our 2014 drought plan. This has included updating the storage alert line control curve which Aquator uses to determine when and how to use the reservoirs, the temporary use ban line and non-essential use restriction line as the level 2 and 3 thresholds for demand saving; helping the model to calculate level of service.

Figure A2.5 is a graph of the updated control lines for Elan Valley Reservoirs. Shown are the storage alert line and the level 2 and level 3 threshold curves that the model uses to simulate the timing and effects of imposing demand restrictions.

Figure A2.5: Aquator output graph of Elan Valley Reservoir Control Curves



Demand Saving Groups

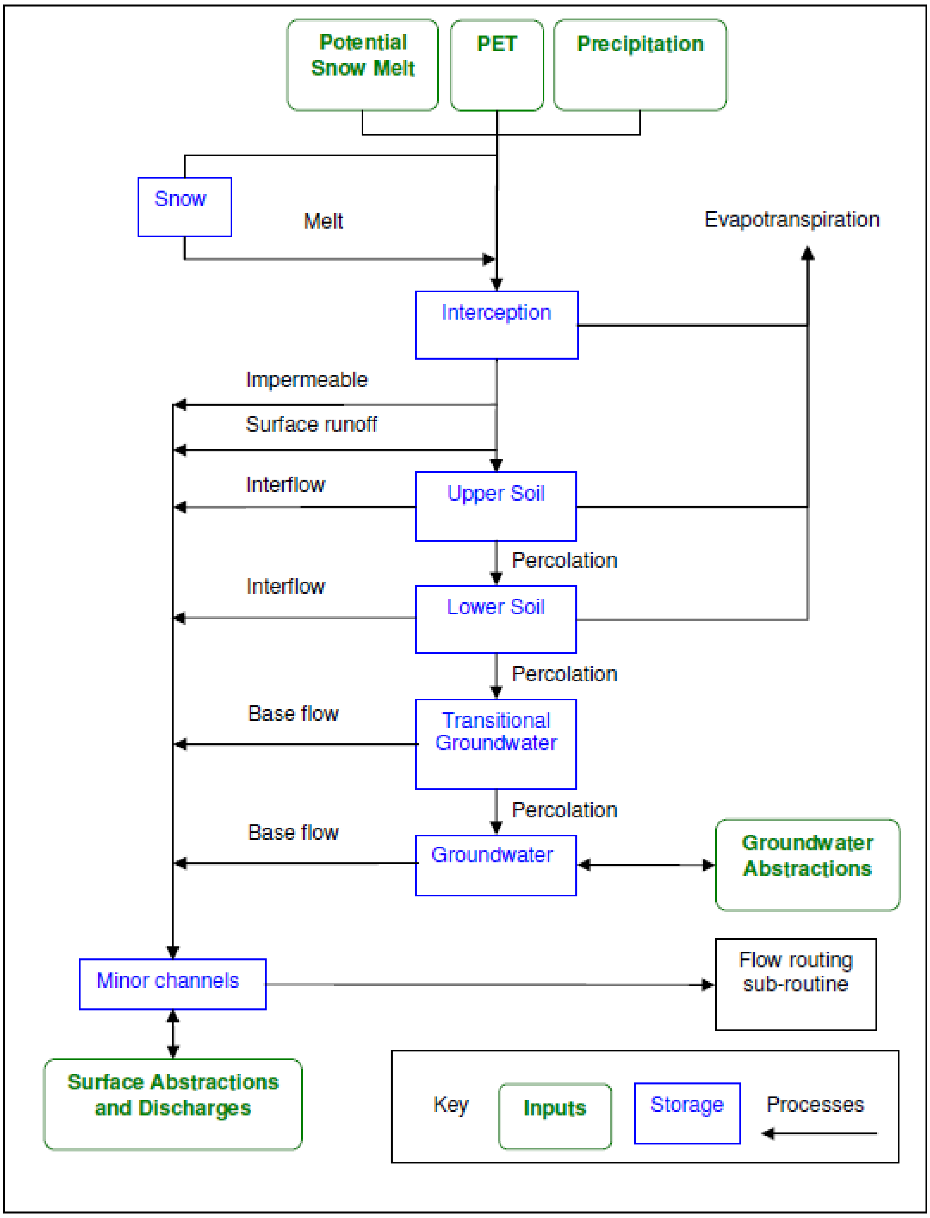
The rebuilt Aquator model has been adapted to model the zonal level of service within Aquator, which we previously calculated outside of the model using output spreadsheets. We can now derive level of service using the Aquator "Demand Saving Group" component, which allows us to model "Demand Savings", such as Temporary Use Bans (TUB) and Non-Essential Use Bans (NEUB) for a selection of demand centres, and therefore a set water resource zone.

We have set up demand saving groups in the model for the Strategic Grid Zone (using Elan Valley reservoirs, Derwent Valley reservoirs, Carsington/Ogston and Draycote reservoir), the Forest and Stroud Zone (using the Elan Valley reservoirs) and the North Staffordshire zone (using Tittesworth reservoir). Each of these reservoirs has both a TUB trigger line and a NEUB trigger line. These trigger lines are set on the model to activate demand savings. If the reservoir storage drops below the TUB line for 7 days or more between April and the end of October, a 5% demand reduction is introduced across the zone. If reservoir storage continues to fall and drops through the NEUB line for 7 days or more between April and the end of October, a further reduction of 5% is introduced giving a total demand reduction of 10%. The highest level of reduction reached will stay in place in the model for up to 180 days. These simulate the effects that imposing TUBs or NEUBs would have on demand in a real life situation.

Inflow Series Update

A key update we have undertaken since WRMP09 is on the historic catchment inflow sequences used in Aquator which are calculated using the HYSIM rainfall-runoff model, HYSIM calculates runoff in a catchment or group of catchments using data such as rainfall and potential evapo-transpiration. A flow chart showing how HYSIM works is shown in Figure A2.6.

Figure A2.6 HYSIM configuration



Source: R E Manley and Water Resource Associates Ltd (2006) A Guide to Using HYSIM

For WRMP09 our flow series was extended up to 2006. As part of the Aquator model update for WRMP14 we have brought the flow series as up to date as possible. The initial objective of the update was to extend all the flow series to December 2010. However during the course of the update project, a number of limitations were identified with the data used in the previous HYSIM modelling. This included inconsistencies between the historic rainfall data supplied by the Met Office for the WRMP09 flow extension project and the updated datasets provided in 2011, problems in the scaling method used to combine the original and updated Met Office gridded rainfall data in the previous studies and disparity in the data.

Following identification of the various data issues the initial project objectives were expanded to include an additional data review and recreation of rainfall and PET series for use in the HYSIM rainfall-runoff model for 79 catchments for the full 91 year record. All of the existing HYSIM models were recalibrated. In addition new Environment Agency (EA) naturalised data was incorporated and a joint calibration and verification process introduced. Therefore a full update and restating of the entire 91 year flow series has been carried out, bringing all the flow series up to December 2010.

In addition to the flow data extension, the study has led to further improvements in the consistency and reliability of the data sets. In most catchments the revised models show an improved fit between simulated and recorded flows. A thorough review of the flow series has been undertaken in order to identify the confidence levels associated with each of the series.

As mentioned we have updated flow series to include the dry summer of 2010, however we have not included data for the drought of 2011. This is because at the time of the update, data was not yet available for the whole of 2011. During 2011 we did not introduce restrictions therefore we feel that the drought period is not worse in terms of surface water than those already in the time series.

Further information on Calibration and Verification of the HYSIM flows

The following text gives further explanation of how we have calibrated and validated the Hysim flow datasets used in our Aquator model, along with our model outputs. This additional explanation is in response to queries raised during consultation on our draft WRMP by Natural Resources Wales regarding the steps we have taken to validate our water resources modelling.

The Hysim flow series were calibrated using a joint period of calibration (generally 2001 to 2010) and verification (1991 to 2000). Where a good calibration but poor verification results were achieved, we gave further consideration to the modelling. Where possible, the verification period results were improved without detracting from the calibration period results.

The goodness of fit and adequacy of a given simulation was measured using the following criteria:

1. Examination of the daily flow chart to confirm if the model matches the low flow periods, has a similar rate of recession and matches summer and winter storm peaks. Not every feature can be replicated with a model, but this assessment provides an adequate representation of the hydrograph shape and how this might vary in key years or stages in the calibration period.

2. Examination of the flow duration curve (FDC) to help identify how good the fit is for lower flows and higher flows. Although the aim is to achieve a good fit over the whole record, the fit at lower flows is almost always most important for water resource assessments. The use of a log scale to display FDCs accentuates the lower part of the FDC allowing, at a glance, assessment of the goodness of the fit at low flows.

3. Comparison of the mean flows, Q50 and Q95 statistics provide further evidence as to the goodness of fit both over the whole record and at low flows. These statistics alone are not enough to determine a good fit and it is important that these statistics support the above two assessments.

4. The root mean squared error (RMSE) is a good statistical measure that was used in assessing the performance of simulations. It is calculated as the square root of the mean of the squared difference between the observed (Oi) and simulated (Pi) flows. This was calculated separately for the full range of flows and the low (Q50-Q95) flows. To standardise comparisons of RMSE, this was calculated as a percentage of Q50. Broadly speaking both RMSE statistics follow the same trend.

Table A8.1 gives an over view of the type of reference flows used for the HYSIM modelling on the Severn, Wye and Upper Trent.

Table A8.1 Overview of HYSIM calibration requirements

Group	HYSIM Catchment		Reference Flow Series
	Severn		
Upper Severn	CL-RES	Clywedog Reservoir	Naturalised
	SE-ABE	Severn at Abermule	Naturalised
	VY-RES	Vyrnwy Reservoir	Naturalised
	CO-CON	Cownwy at Cownwy	Recorded
	VY-LLA	Vyrnwy at Llanymynech	Naturalised
	SE-MON	Severn at Montford	Naturalised
	PE-YEA	Perry at Yeaton	Naturalised
	TE-WAL	Tern at Walcot	Naturalised
	SE-BUI	Severn at Buildwas	Naturalised
	WO-TOT	Worfe at Burcote	Recorded
	SE-BEW	Severn at Bewdley	Naturalised
Avon	AV-STA	Avon at Stareton	Recorded
	SO-STO	Sowe at Stoneleigh	Recorded
	LE-PRI	Leam at Prince's Drive Weir	Recorded
	DE-WEL	Dene at Wellesbourne	Recorded
	AR-BRO	Arrow at Broom	Recorded
	AV-EVE	Avon at Evesham	Recorded
Lower Severn	ST-KID	Stour at Kidderminster	Recorded
	TE-TEN	Teme at Tenbury	Recorded
	TE-KNI	Teme at Knightsford Bridge	Recorded
	SE-SAX	Severn at Saxons Lode	Naturalised
	SE-HAW	Severn at Haw Bridge	Naturalised (partially)
	SE-GLO	Severn at Gloucester Docks	Naturalised (partially)
	Wye		
Wye	EL-RES	Elan Reservoirs	Naturalised
	IT-DIS	Ithon at Disserth	Recorded
	IR-CIL	Irfon at Cilmery	Recorded
	WY-ERW	Wye at Erwood	Naturalised
	WY-BEL	Wye at Belmont	Naturalised
	LU-BUT	Lugg at Butts Bridge	Naturalised
	LU-LUG	Lugg at Lugwardine	Naturalised
	MO-GRO	Monnow at Grosmont	Recorded
	WY-RED	Wye at Redbrook	Naturalised
	Trent		
Upper Trent	TR-DAR	Trent at Darlaston	Recorded
	SO-GTB	Sow at Great Bridgeford	Recorded

(Table produced by Mott Macdonald, 2011)

The statistical output from HYSIM includes the “Correlation Coefficient” and “Percentage of the explained variance” as two measures of the accuracy of the rainfall-runoff models. These measures are sensitive to high flows and outliers and are not necessarily appropriate for examining how well the model fits at low flows. We found that a reasonable correlation coefficient may give a model with a good fit at high flows but a poor fit at low flows. As a result, we have not used these statistical measures. We used these measures for assessing the quality of the calibration alongside physical catchment characteristics from previous experience and the CEH Hydrometric Register and Statistics. This informed our decisions on parameter values required in simulation and guided their optimisation.

The main emphasis in HYSIM model calibration was achieving a close agreement between simulated and recorded flows in terms of the flow duration curve (FDC), particularly the lower part since high flows are generally not as important in water resources assessment. Whilst the FDC provides a good overall estimate of the calibration the performance of the model varies from year to year. We therefore include an element of uncertainty around the accuracy of the flow series in our target headroom analysis for our Water Resources Planning.

The Wye Basin

Our interest in the Wye basin is primarily the Elan Valley reservoir system which meets most of the demand from Birmingham. There is also an abstraction at Mitcheldean a short distance upstream of Redbrook. The following discussion concentrates on the recalibration and verification of the existing HYSIM models focusing on these two locations of primary interest. EA Wales (now Natural Resources Wales/ Cyfoeth Naturiol Cymru) provided us with the naturalised flow series for the six locations shown in Table A8.2.

The 2008 model for the Elan Reservoirs produced a good fit against the naturalised flow series.

Incorporation of updated data required recalibration of this model, and comparison against updated naturalised flow data to 2010 has resulted in similar results. The new FDC shows a good fit, particularly at high and low flows, but slightly over-estimates mid range flows (Figure A8.1). Whilst visual comparison to the previous FDC may suggest a poorer fit, the RMSE as a % of Q50 statistics remain approximately the same; though the mean flows have been more closely matched. The performance of the most recent simulations are comparable to those undertaken in 2008, but have more robust water balance parameters with the improved input data.

We undertook recalibration of the Ithon at Disserth and Irfon at Cilmery against recorded flow, with comparable RMSE statistics to the Elan Reservoirs calibration. With significant improvement of the Irfon at Cilmery compared to that in 2008, we achieved a good fit and statistical performance at Erwood, as demonstrated in Table A8.2. Since 2008 we received naturalised flows for the Lugg at Butts Bridge and at Lugwardine. At Lugwardine there was not enough flow data to perform any verification due to the short record and high flows were truncated in the reference flow series, preventing an effective comparison of the means.

In addition to various changes to the hydrological parameters for upstream catchments the hydraulic parameters were revised for the Wye at Belmont and Redbrook catchments in order to improve fit and statistical performance. These adjustments have contributed to an overall good fit at Redbrook (Figure A8.2).

The statistical measures summarised in Table 3.2 indicate that the RMSE as a % of Q50 is 61% for all flows and 19% for low flows (Q50 to Q95). This is a significant improvement on equivalent statistics from the 2008 calibrations which gave 107% and 32% respectively. A large part of this calibration improvement will be a result of the revised input data. (Mott Macdonald, 2011)

Table A8.2 Wye catchment calibration statistics

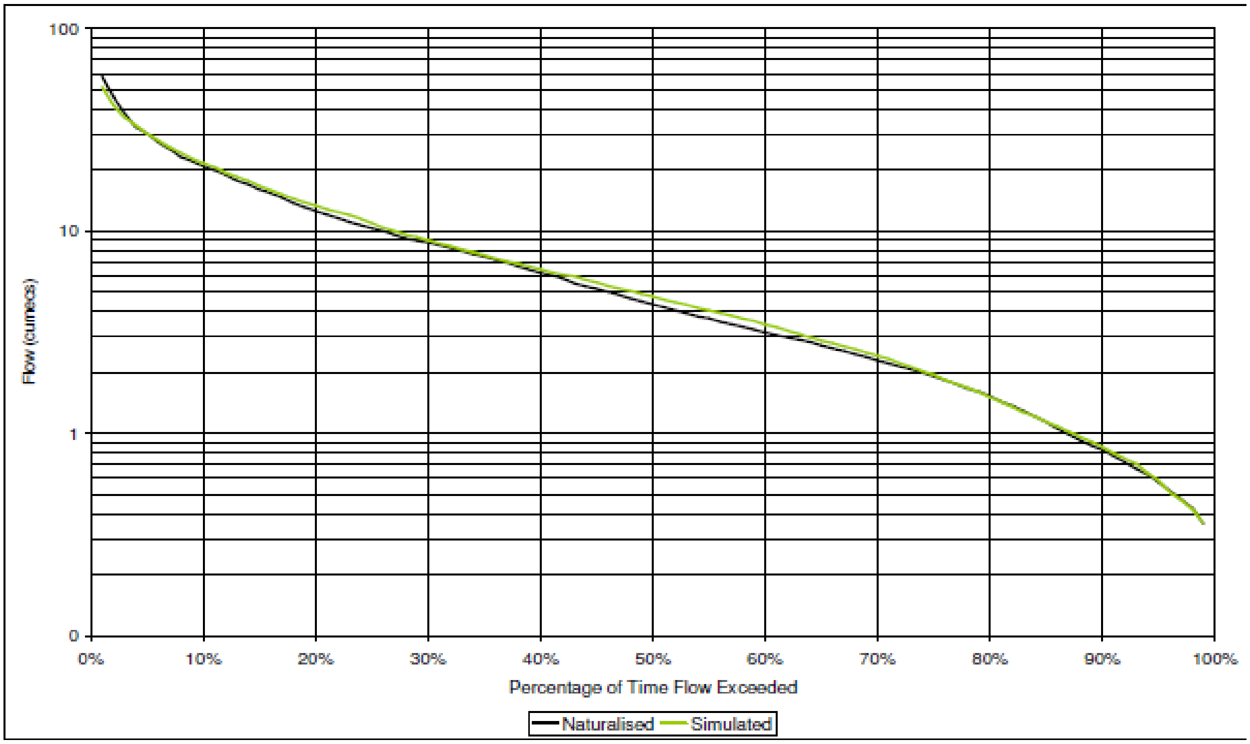
Catchment	Reference flow	Period	Mean flow (m^3/s) Reference	Mean flow (m^3/s) Simulated	% Difference	RMSE as a % of Q50 All flows	RMSE as a % of Q50 Q50-Q95	Comments
Elan Reservoirs	Naturalised	2001-2010	8.57	8.60	0.4	128	39	Good fit attained across majority of flows with Q40-Q70 slightly over-estimated. Low flows well matched in almost all years.
		1991-2000	*9.86*	*9.66*	*-2.0*	*110*	*37*	*Excellent fit attained across Q1-Q75 flows. Q75-Q100 slightly under-estimated. Low flows in 1996 and 1997 under-estimated. Naturalised low flows in 1999 are lower than 1996 and 1997 indicating questionable data.*
Ithon at Disserth	Recorded	2001-2010	8.05	8.15	1.2	114	41	Excellent fit across majority of flows.
		1991-2000	*8.66*	*9.06*	*5.4*	*132*	*42*	*Q10-Q50 over-estimated.*
Irfon at Cilmery	Recorded	2001-2010	9.94	9.96	0.2	119	30	Excellent fit across majority of flows. Q10- Q35 over-estimated.
		1991-2000	*11.25*	*11.17*	*-0.7*	*132*	*40*	*Good fit attained across majority of flows, Q80-Q100 under-estimated.*
Wye at Erwood	Naturalised	1999-2007	45.16	45.06	-0.2	76	25	Good fit attained for majority of flows, Q65-Q100 slightly over-estimated.
		1990-1998	*42.89*	*42.99*	*0.2*	*81*	*28*	*Excellent fit achieved across majority of flows. Low flows well matched in almost all years.*
Wye at Belmont	Naturalised	1999-2007	58.43	58.22	-0.4	81	32	Excellent fit attained across majority of flows. Mid flows slightly over-estimated.
		1990-1998	*54.90*	*55.04*	*0.3*	*80*	*29*	*Excellent fit attained across majority of flows. Q70-Q93 under-estimated.*
Lugg at Butts Bridge	Naturalised	1999-2007	6.32	6.31	-0.2	48	24	Good fit attained for majority of flows. Mid flows slightly over-estimated with Q85-Q98 slightly under-estimated.
		1990-1998	*5.97*	*5.98*	*0.2*	*72*	*43*	*Good fit across majority of flows with Q90-Q100 slightly over-estimated.*
Lugg at Lugwardine	Naturalised	1999-2007	10.92	12.58	-	117	23	High peaks in reference flow series truncated. Mean flows not comparable. Good fit attained across rest of flows.
				N/A				*Verification not possible as naturalised flow series too short to sensibly split between calibration and verification.*
Monnow at Grosmont	Recorded	2001-2010	5.23	5.37	2.7	146	27	Reasonable fit attained across mid and low flows. Q5-Q45 and Q75-Q95 over-estimated.
		1991-2000	*6.60*	*6.07*	*-8.0*	*136*	*33*	*Good fit attained across majority of flows. Q80-Q95 slightly over-estimated.*
Wye at Redbrook	Naturalised	1999-2008	91.42	91.70	0.3	61	19	Good fit attained across majority of flows with Q15-Q50 slightly over-estimated. Low flows well matched in almost all years.
		1990-1998	*84.19*	*84.82*	*0.7*	*63*	*23*	*Excellent fit attained across majority of flows. Q95-Q100 over-estimated. Naturalised series shows questionable decline from Q95. Low flows in 1990 are lower than other years in both periods.*

Verification statistics and comments listed in italics below calibration statistics.

(Table produced by Mott Macdonald, 2011)

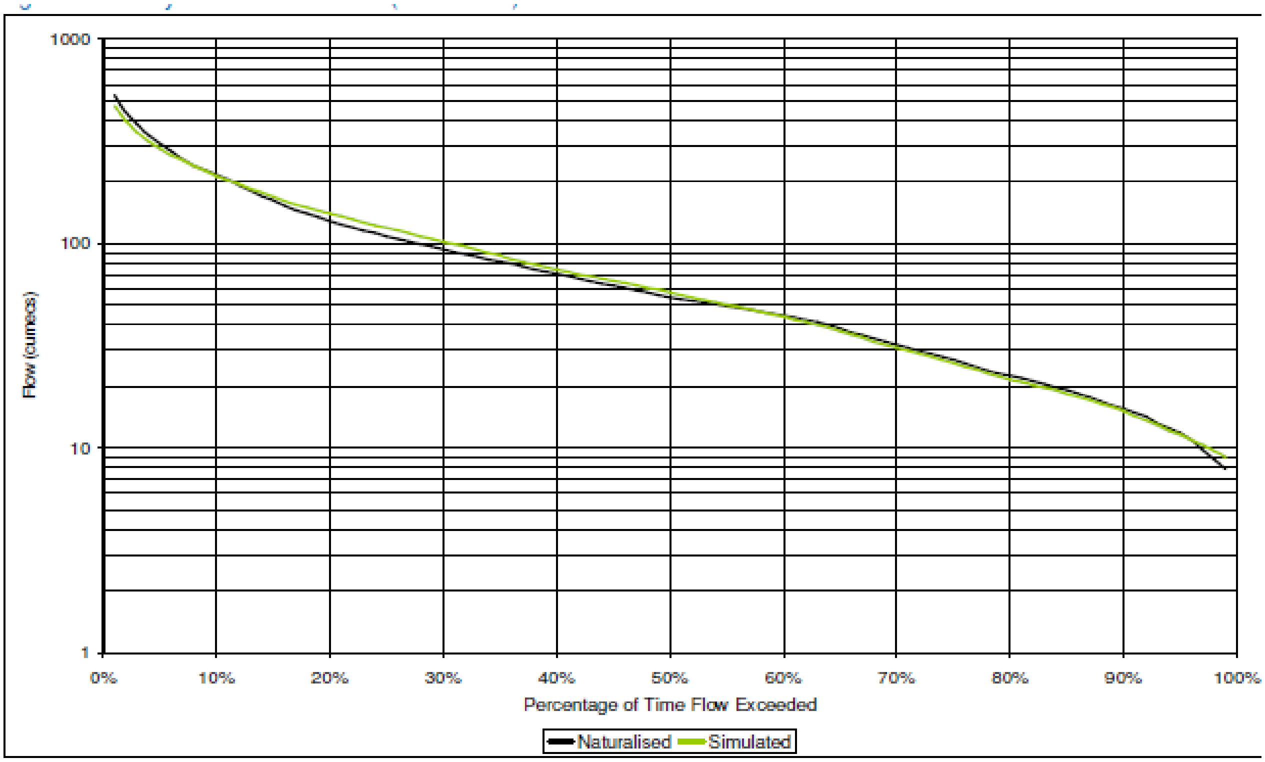
Appendix A: How much water do we have available?

Figure A8.1 Elan Reservoirs FDC (2001-2010)



(Graph produced by Mott MacDonald, 2011)

Figure A8.2 Redbrook FDC (1999-2008)



(Graph produced by Mott Macdonald, 2011)

Aquator Output Validation

We derive deployable output (DO) at a resource zone level for our conjunctive use water resource zones. This is in accordance with the relevant guidance (including the "*Unified Methodology for the determination of Deployable Output from Water Sources, Project 00/WR/18/2", UKWIR, 2000*). We have seven conjunctive use water resource zones, all of which we model using Aquator.

Our model is built to represent the current (and end AMP 5) supply network using the inputs as described in section A2.2. It then calculates a Deployable Output using the full 91 year inflow series and based on the company stated levels of service.

We do not expect the model outputs to exactly match historical flows or actual abstraction for the following reasons:

- it uses a set monthly demand profile which does not vary year to year.
- we have not modelled the actual outages that occurred in 2006.
- the model incorporates sources that are available now and may not have existed/been in operation throughout the whole flow record period. For example, it includes AMP5 schemes such as the DVA duplication as well as reservoirs such as Carsington that did not exist more than 20 years ago.
- the operational control curves on our strategic reservoir sources have been revised and optimised to fit the current supply network and demand assumptions. Historically we used different curves on these reservoirs. The model uses the current controls curves and rules.
- River Severn regulation is modelled within Aquator using VBA code. Regulation is carried out throughout the 91 year period. Lyn Clywedog was built in 1964 and completed in 1966. The EA began regulating the river in 1968.

In validating the outputs of our Aquator model, we have to take all of this into consideration.

We have derived the demand data and demand profiles in Aquator using actual data for 2006/07. In order to validate the model outputs, we are therefore able to use actual data for 2006/07 and compare this against Aquator model outputs for that year. We have created a state set on Aquator which enables us to set all the reservoir storage levels to start on 1st January 2006 at the actual storage levels recorded on that day. The inflow series have been calibrated over a period that includes 2006/07. This means that the model can then decide which sources to use and when based on actual resource states and demand and the model outputs should therefore be a reasonable representation of what happened that year.

Reservoir drawdown

We have compared actual reservoir drawdown for 2006/07 with the modelled reservoir drawdown. The results are shown in Figures A8.3 to ##. The error bars are set to +/- 5%, which represents a level of relatively high accuracy (equivalent to accuracy band 2 when using the Ofwat accuracy rating).   Actual reservoir drawdown is recorded weekly which accounts for the stepping in the actual data.

Figure A8.3 Derwent Valley reservoir actual vs modelled drawdown

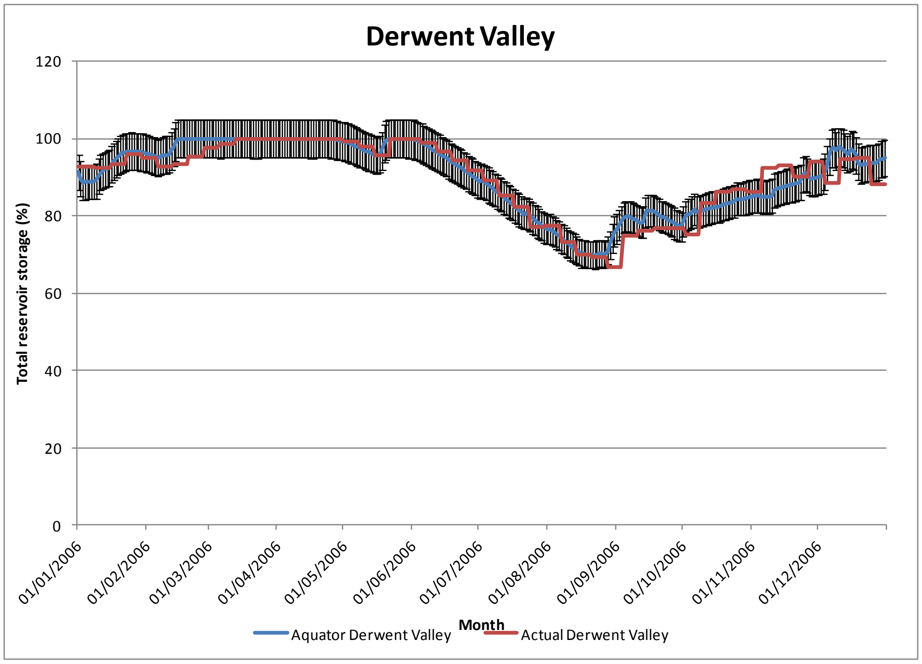
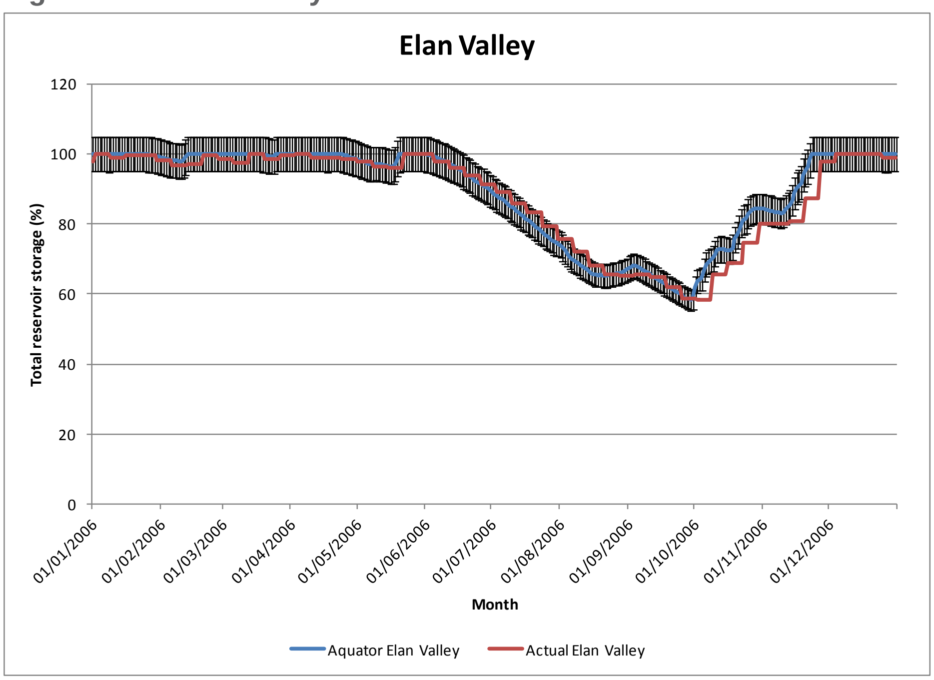
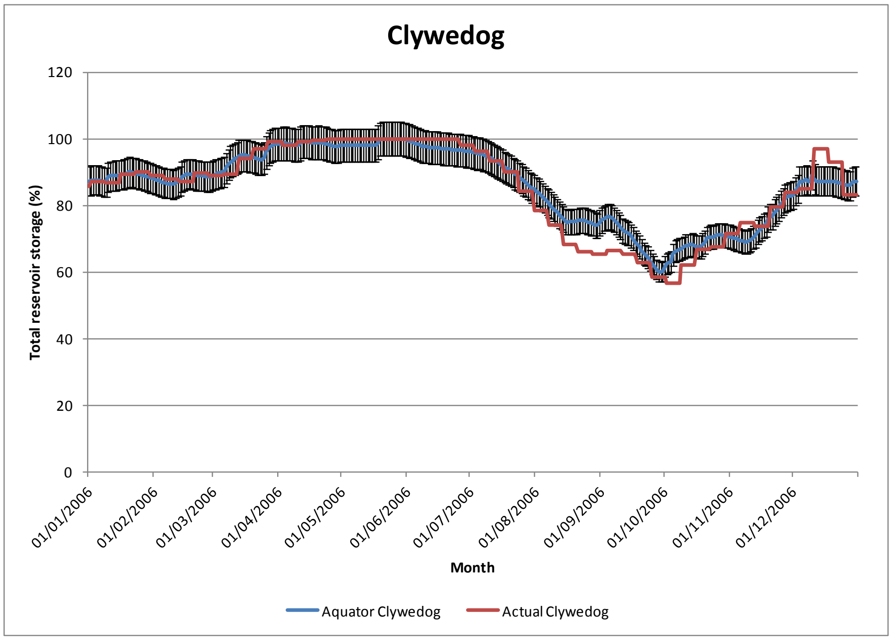


Figure A8.4 Elan Valley reservoir actual vs modelled drawdown



As can be seen from the figures above, the modelled drawdown for the naturally refilling reservoirs Derwent Valley and Elan Valley shows a good fit, with the length of the drawdown period and the refill period matching closely the actual reservoir drawdown during 2006.

Figure A8.5 Clywedog reservoir actual vs modelled drawdown

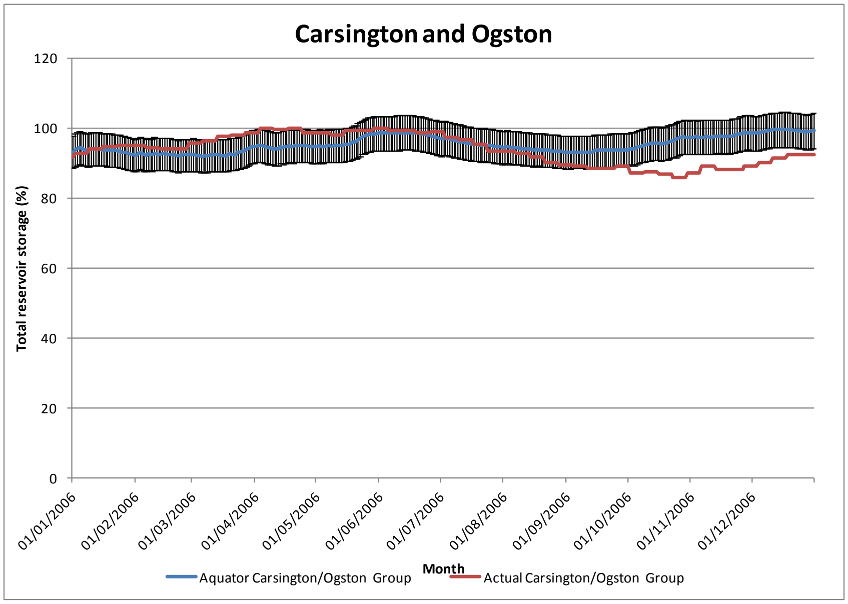


Clywedog is also a good fit considering the man-made influences on the reservoir drawdown through the river regulation releases.   The number of regulation days triggered on the model is very close to the number of actual regulation days during the summer of 2006.

Table A8.3 River Severn regulation statistics

	2006 Actual	2006 Modelled
ber of regulation days	82	83
ılation start date	21st June	21st June
ılation end date	30th September	29th September

Figure A8.6 Carsington and Ogston reservoirs combined actual vs modelled drawdown

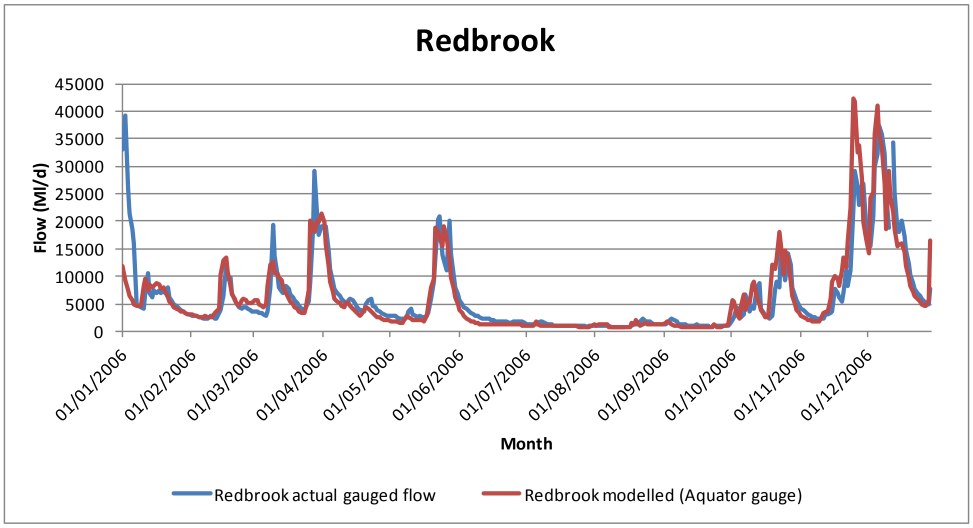


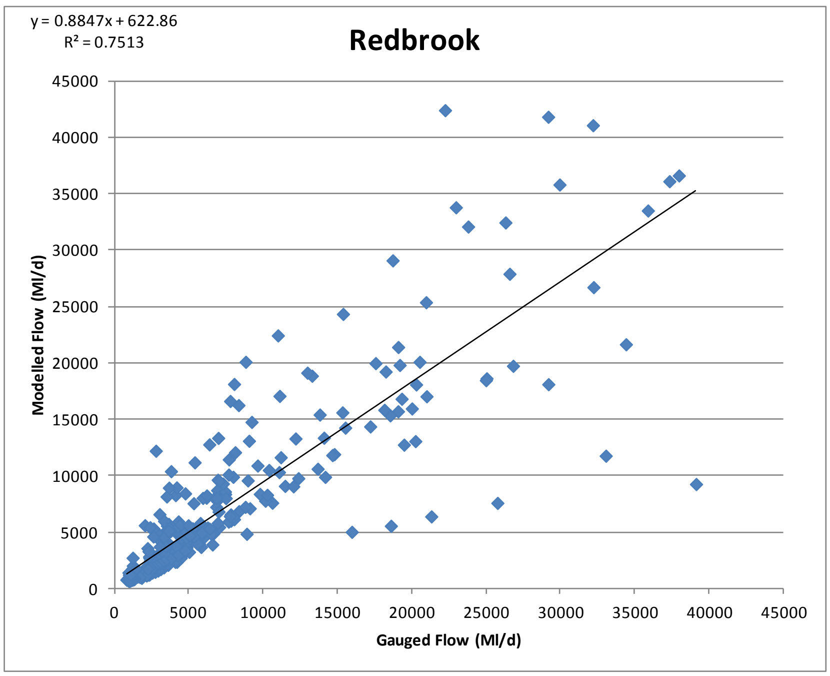
Carsington and Ogston are pumped storage reservoirs. The representation on the model shows what the reservoir drawdown would have been like had we operated the system exactly as per the licence rules and optimising for cost and resource. It can be seen that this shows a slightly less good fit than the naturally filled reservoirs. It is likely that this could be due to outage/restrictions on the pumps at that time.

River flows

We have compared actual river flows for key gauges in the region to the modelled gauge data derived during the validation model run. For each gauge we have plotted actual gauged flow against the Aquator modelled gauge flow to produce a graph, flow duration curve and flow statistics. On the whole the model replicates the low flows very well, with peaks occurring at the correct time.

Figure A8.7 Redbrook flow analysis





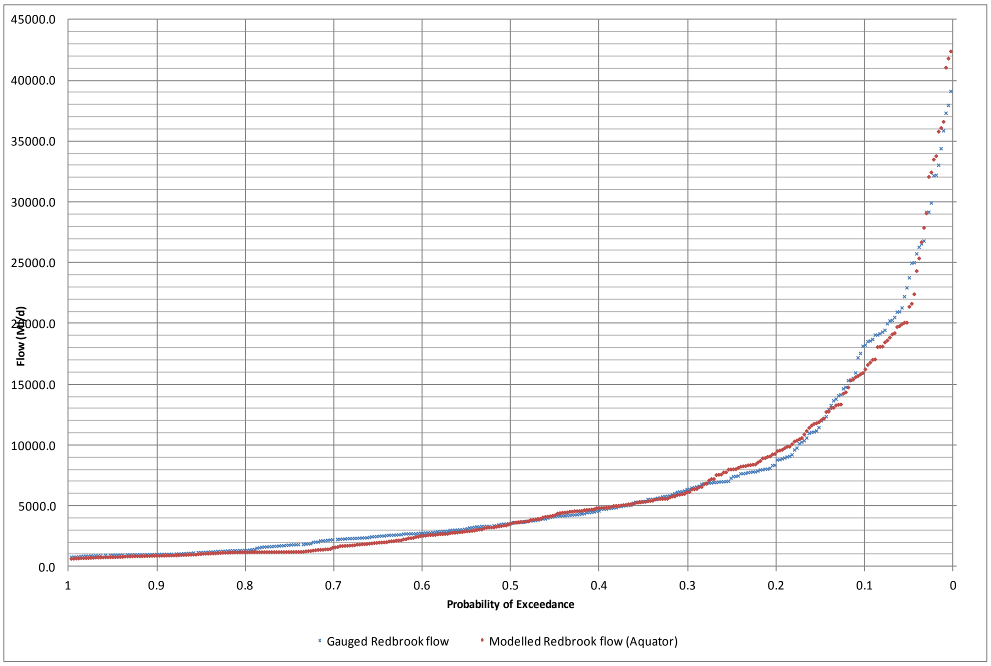
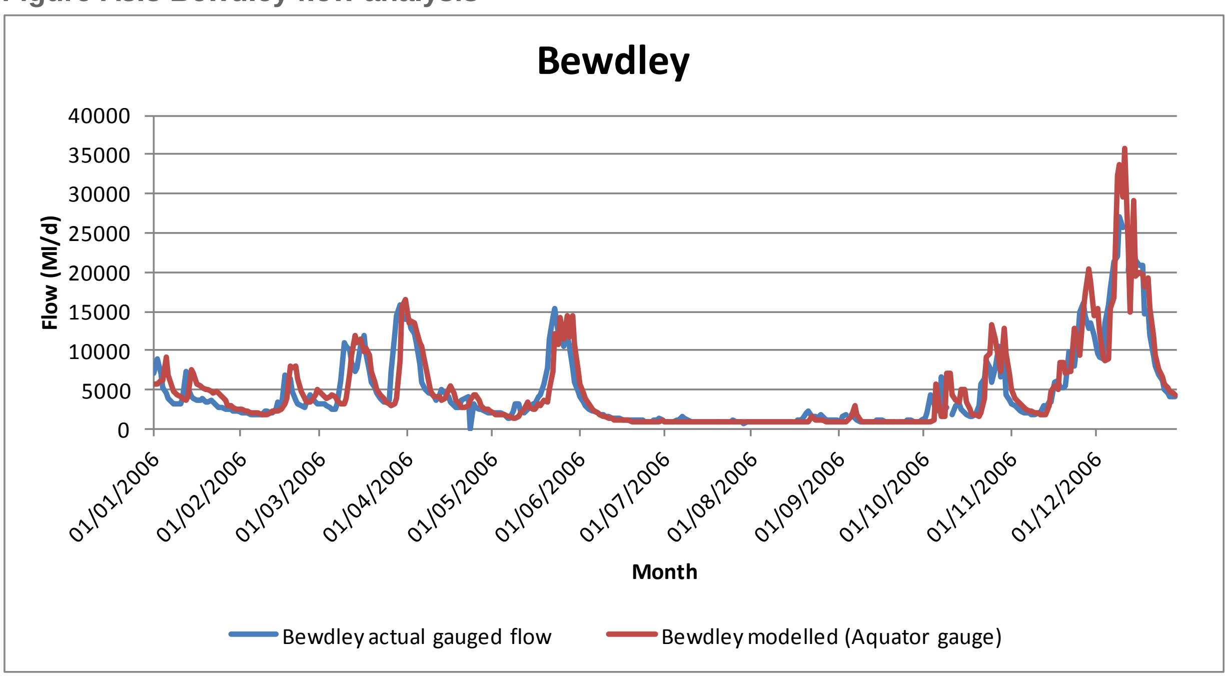
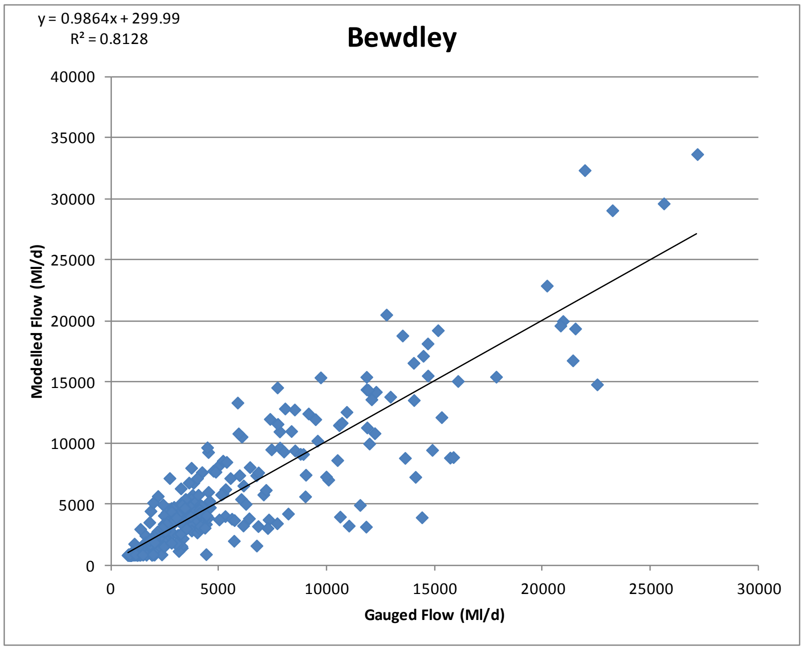
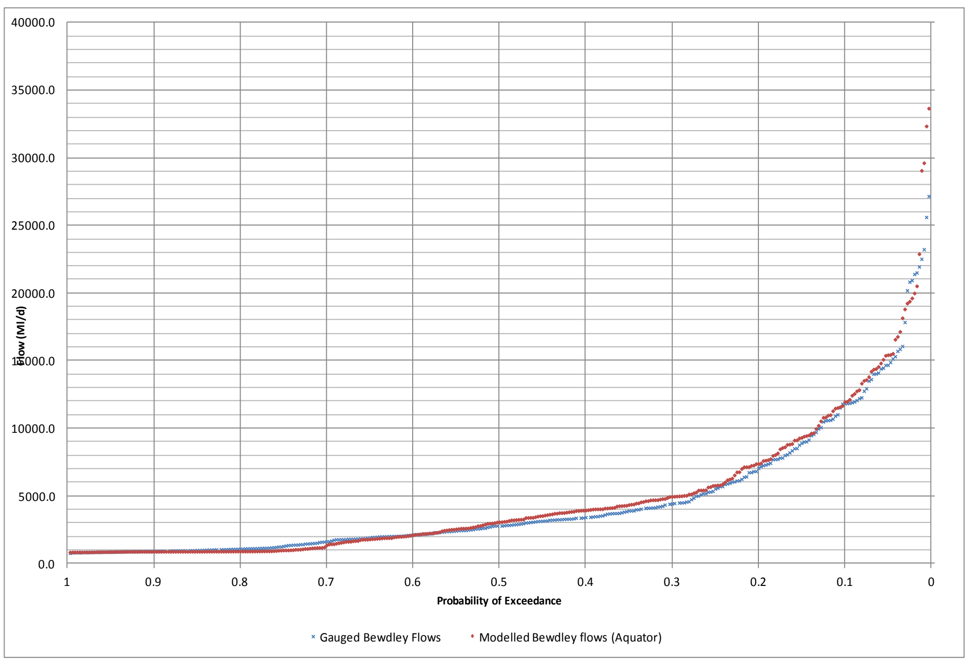


Figure A8.8 Bewdley flow analysis



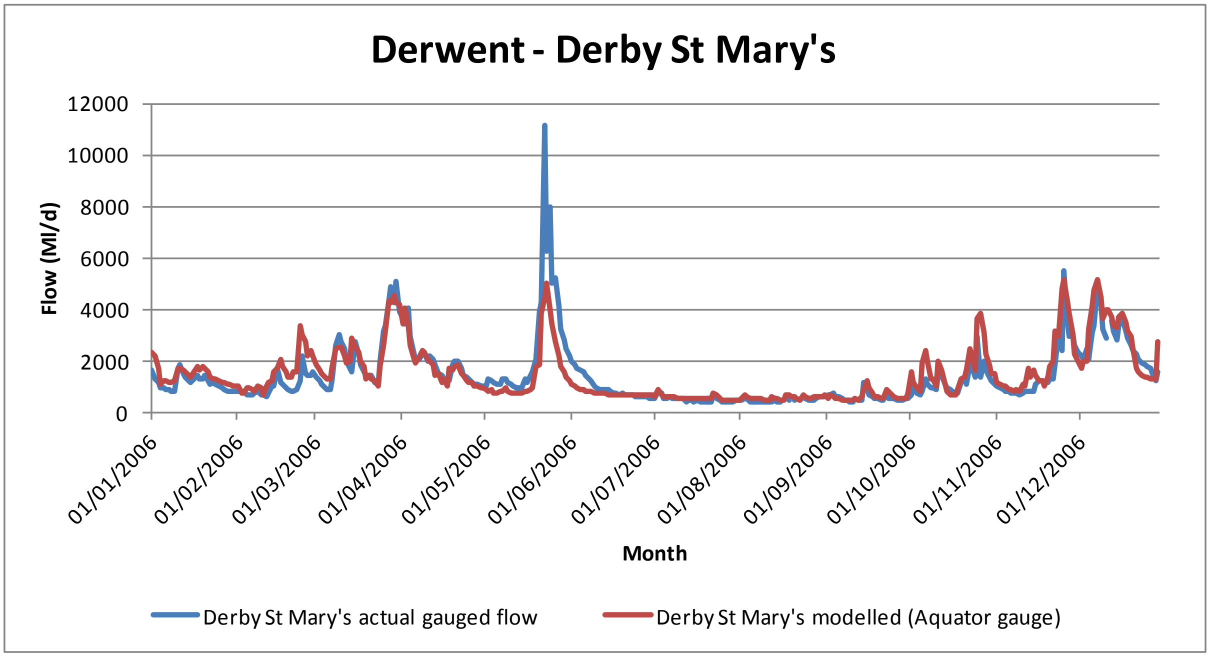
Appendix A: How much water do we have available?

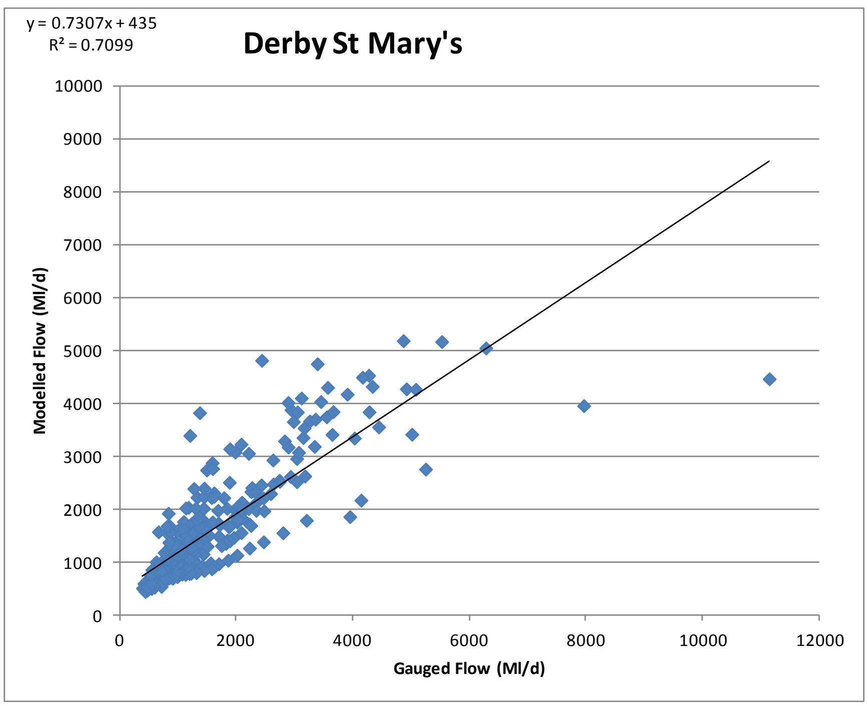




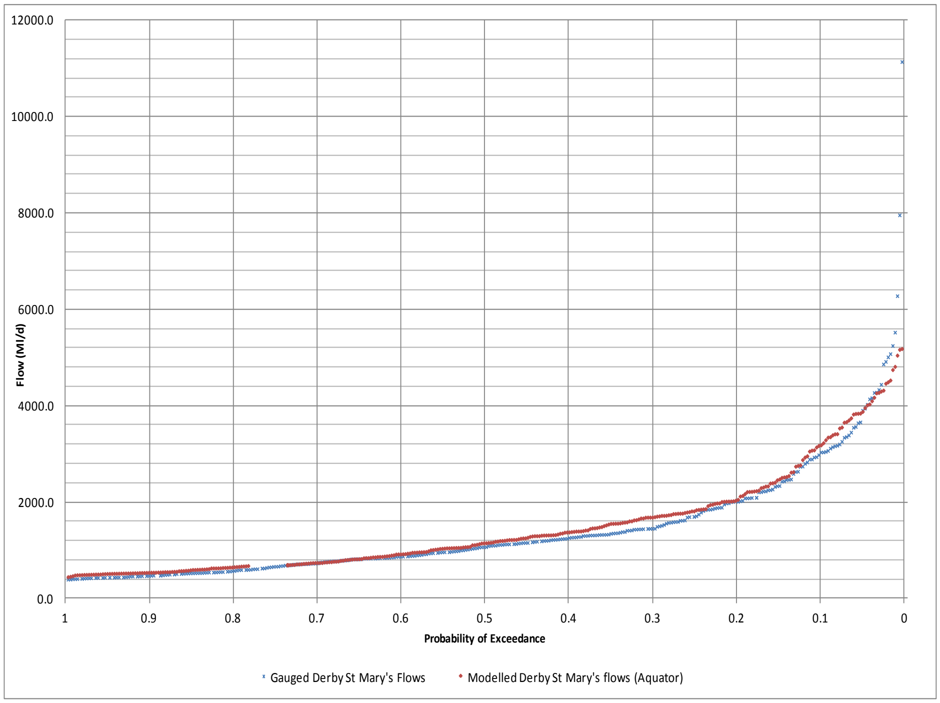
The timings in the model at Bewdley are out by 1 day. This is due to the time of travel assumptions for how long it would take for releases made at Clywedog to reach the gauge at Bewdley which are correct at low flows. In reality, the releases are often made at a slightly higher flow and therefore reach Bewdley earlier. In other words the way that the releases are made in reality can be more precautionary than is the case in Aquator. Overall this slight misalignment does not impact the modelling as they are correct at lower flows.

Figure A8.9 Derby St Mary's flow analysis





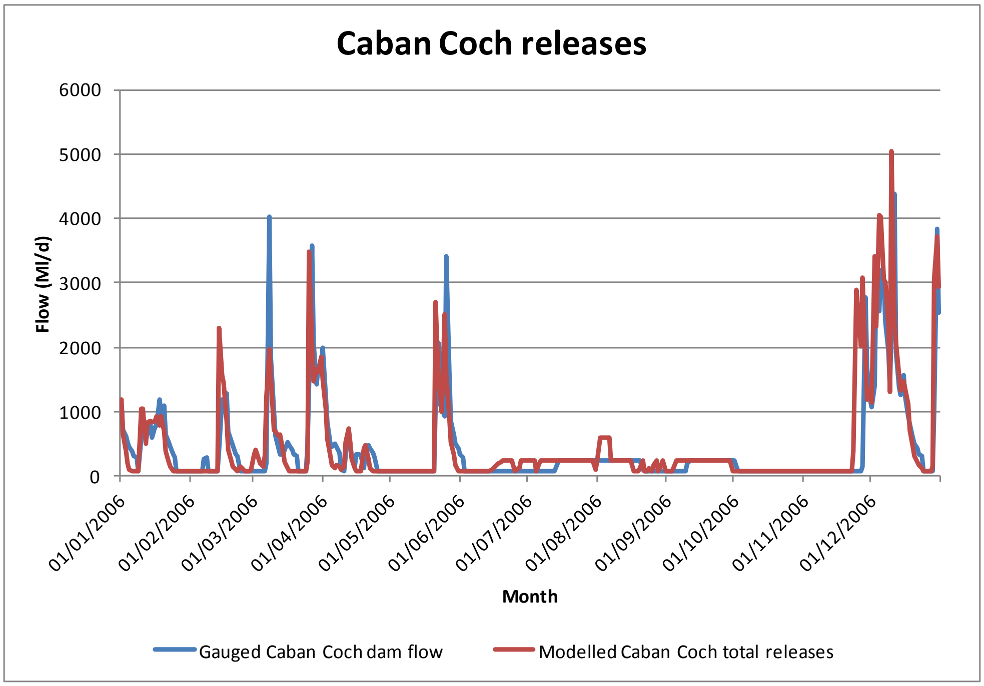
Appendix A: How much water do we have available?

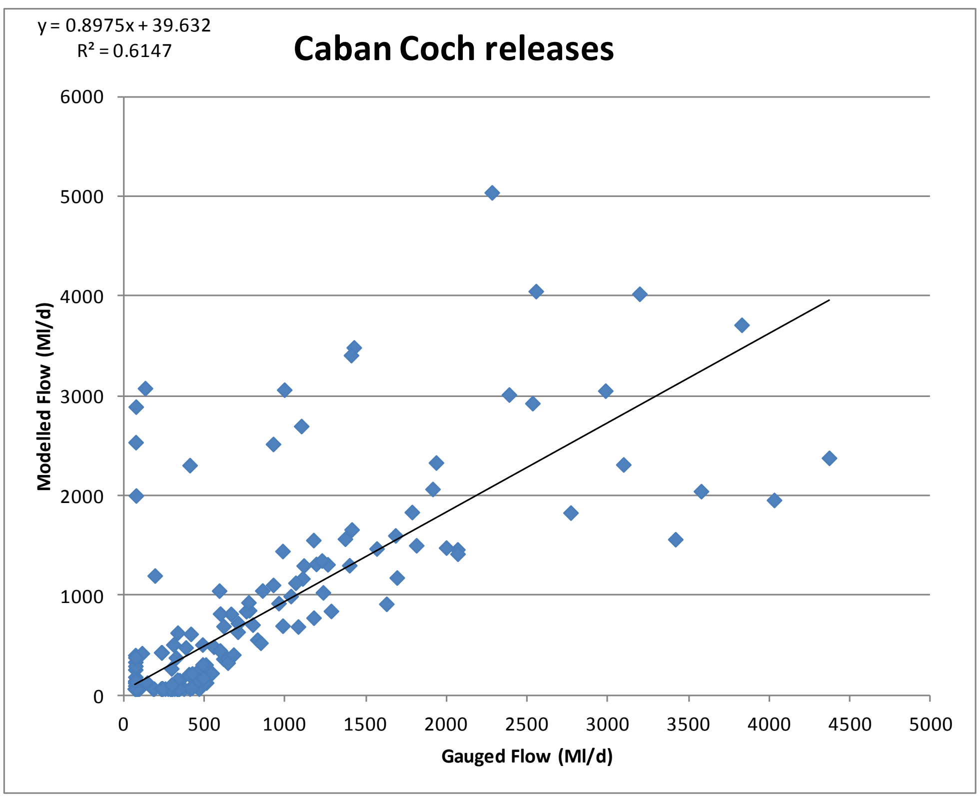


Releases from Caban Coch

We have also compared the actual releases made from Caban Coch reservoir against the modelled releases on Aquator. The modelled releases are the sum of the Aquator components "Caban Coch before regulation release" (which includes spill) and "Caban Coch regulator" (which ensures the regulation and compensation releases are made).

Figure A8.10 Caban Coch flow analysis





Overall the fit between the gauged flow and modelled flow is relatively good. The key difference is that the model ensures releases are made exactly as the licence instructs. In reality, compensation releases are often a little higher than the licence requires; ensuring that the licence is not breached due to meter error or due to human error.

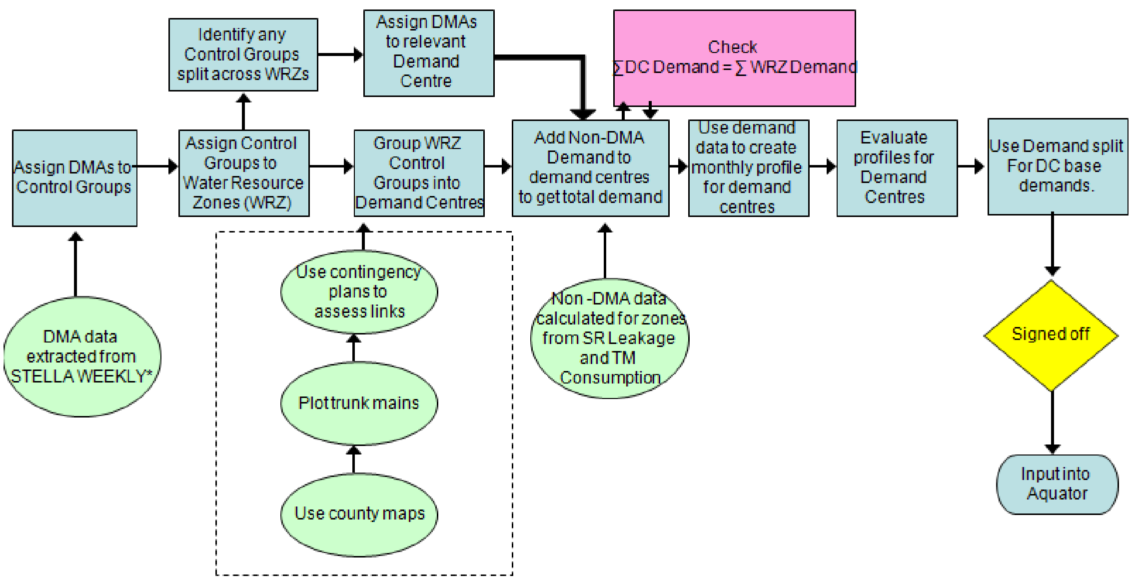
Demand Centres and Demand Profiles

We have fully reviewed and updated the demand data that is used in our Aquator modelling. To better represent the spread of demand across the water resource zones we have used a bottom up approach to build a more granular assessment of the location and usage profiles of the demand centres.

We used demand data at district metered area (DMA) and control group levels to build our demand centres. The grouping of DMAs and control groups is based on the sources of water supplied to that demand area. To do this we used information from a number of our company databases, such as the distribution contingency plans, control group overview documents, county schematics and water resource zone technical notes.

The method we used is described in Figure A2.7.

Figure A2.7: Demand Centre Review Flow Diagram



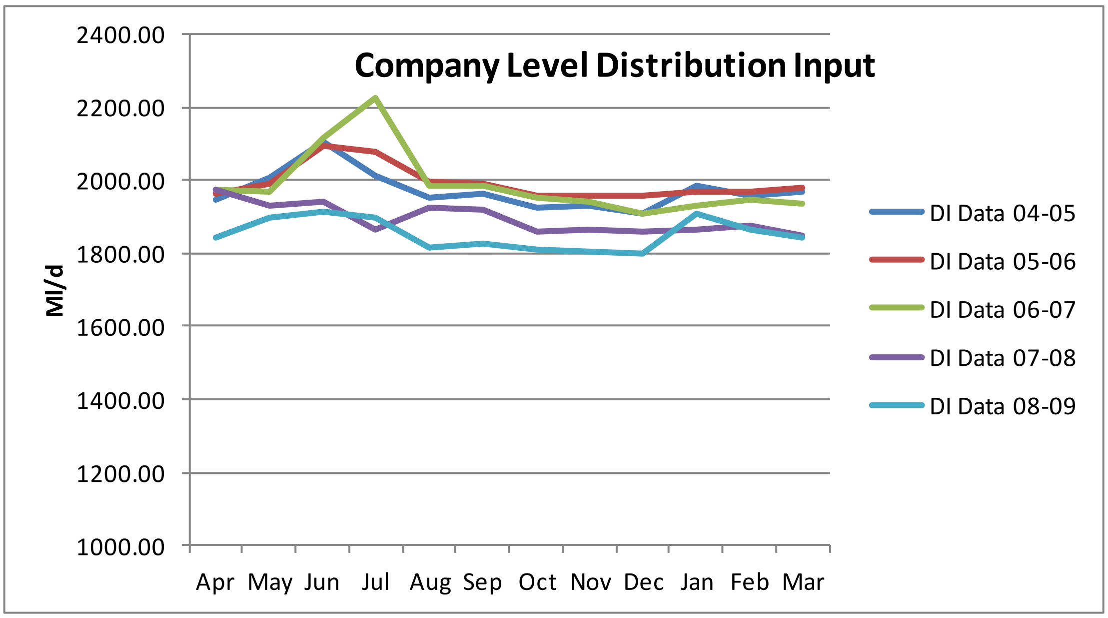
* Demand for 06/07 used for demand profiles as this has the highest recent summer peak out of the dma data that is available.

An audit trail showing how each demand centre is built and the information used to create the demand centres has been created including sections on the data sources used to derive the demand centres and an explanation of the sources that feed them.

Once the configuration of the demand centres had been completed we looked at which years of data to use from the DMA demand dataset. We have a good quality DMA data record that goes back as far as the end of 2003. For a base level demand we chose the 2006/07 financial year as this was a year with a pronounced summer peak, but was not a drought year. It is worth noting that our water treatment works distribution input data has an enhanced audit trail post 2000.

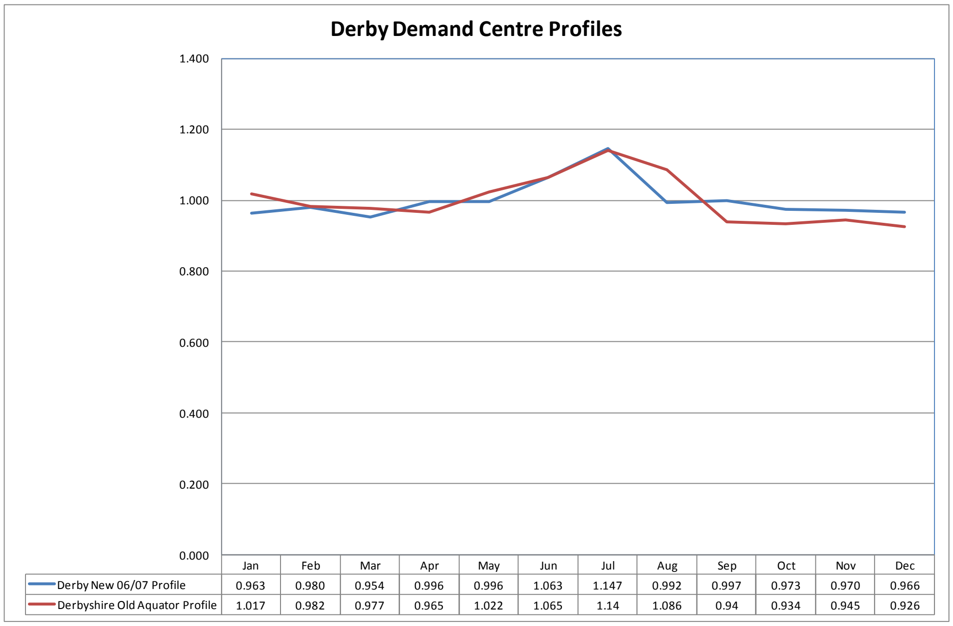
In Figure A2.8 which shows distribution input, it can seen that of the years of data we have DMA level available, the summer with the highest in-year peak is 2006.

Figure A2.8: Distribution input data at a company level from 2004-2009



As part of this review we also updated the monthly demand profiles allocated to the demand centres. For this we also used the peak to base ratio for the 2006/07 year. As well as giving a good summer peak this also means that we can easily calibrate the model against this year. As a result of the demand centre review and update, we now have greater confidence in the new profiles for which we have a full audit trail and a known methodology. Furthermore we now have an individual profile for each demand centre, based on historic demand data for that area. We have shown an example of the old and new profiles in Figure A2.9.

Figure A2.9: Demand Centre profile comparison



Surface Water Treatment Works Losses

For all of our zones with surface water treatment works (WTWs), the process losses for these WTWs have been calculated in the Aquator model. We have derived the process losses using information from our 2012 annual return to apply a percentage loss to each WTWs. This allows the model to take account of the process loss within the DO analysis. Table A2.3 shows the percentage process loss for each WTW.

Table A2.3: Surface Water Treatment Works Losses

Water Treatment Works	Losses (%)
Bamford	2
Campion Hills	8
Church Wilne	2
Cropston	3
Draycote	7
Frankley	1
Little Eaton	1
Melbourne	2
Mitcheldean	1
Mythe	3
Ogston	1
Shelton	7
Strensham	4
Tittesworth	8

Appendix A: How much water do we have available?

Water Treatment Works	Losses (%)
Trimpley	1
Whitacre	2

New AMP5 assets included in our DO Analysis

The baseline deployable output numbers for this plan include a number of planned schemes that were included in our WRMP09 and which will be in place by 2015. These are schemes that were identified in the WRMP09 as having both resilience and a deployable output benefit. The two key schemes are the Derwent Valley Aqueduct (DVA) duplication and the Edgbaston borehole scheme, these are described below.

Derwent Valley Aqueduct Duplication

The scheme is designed to increase the capacity of the DVA at a pinch point identified between Ambergate reservoir and Hallgates reservoir. The capacity will be increased from 55Ml/d to 117Ml/d above Sawley valve house and from 85Ml/d to 130Ml/d between Sawley and Hallgates.

The DVA duplication scheme was identified as having both a resilience benefit and a deployable output benefit. The resilience benefit enables the north of the Strategic Grid WRZ to supply water to Leicester and Warwickshire in the case of water treatment works outages. The scheme also allows “locked-up” deployable output in the north of the Strategic Grid WRZ to be used across the zone.

Edgbaston Borehole

The Edgbaston borehole scheme is designed to be available both for resilience, in the event of a works outage affecting Birmingham, but also to have DO benefit, giving increased overall output into the Strategic Grid zone. The scheme has been modelled with a peak and average daily licence of 10Ml/d.

Discussions with the Environment Agency

We have briefed the EA on our updated water resources model and new deployable output assessment at a number of meetings in 2012. In these meetings we took the EA through the changes and improvements we have made to the Aquator model. This included the model rebuild project, flow series update, model parameter review (demand centres, component parameter review, key linkages review) and our updated control curves. We have also discussed our updated groundwater baseline DO and our conjunctive use zone baseline DO.

The EA commented that the benefits of these meetings were:

- EA better understand the Aquator model and sources of DO information.
- Familiarised the EA with modelling assumptions.
- Transparent audit trail demonstrated.
- Strengthening working relationships and consultation process.

A2.4 Baseline Deployable Output

The baseline deployable output (DO) for each zone is presented in Tables A2.4 to A2.6. This is the DO provided by our current supply system at our current level of service of customers not experiencing a Temporary Use Ban (TUB) more frequently than 3 times in 100 years and does not include the potential impacts of future climate change or sustainability changes. The deployable output with no level of service restrictions and for the reference scenario level of service is discussed in section A2.5.

Groundwater Only Zones

For each of our groundwater only zones, the modelled zonal deployable output is equal to the sum of the individual source deployable output as we have shown in Table A2.4.

Table A2.4: Deployable output of groundwater only zones

WRZ	WRMP14 DO (Ml/d)	Constraint
Bishops Castle	4.7	Groundwater Yield
Kinsall	5.0	Groundwater Yield
Llandinam & Llanwrin	19.9	Groundwater Yield
Mardy	3.7	Groundwater Yield
Ruyton	5.3	Groundwater Yield
Whitchurch & Wem	10.9	Groundwater Yield
Stafford	25.5	Groundwater Yield and Network Linkage

Surface Water Only Zones

We do not currently have any water resource zones that are purely surface water fed. Our zones are either groundwater only or conjunctive use; where the surface water and groundwater sources in a zone are used together to give an improved overall deployable output.

We do however have one zone which is completely fed by an import from Anglian Water which is shown in Table A2.5. Our bulk supply agreement is for up to 18Ml/d, 8Ml/d of this is an import to the Strategic Grid zone

Table A2.5: Deployable output of our surface water zone

WRZ	WRMP14 DO (Ml/d)	Constraint
Rutland	10	Bulk Supply Agreement

Conjunctive Use Zones

For each of our conjunctive use zones the modelled deployable output of each source is based on the deployable output of the whole zone, therefore we do not have any zones where the individual deployable outputs shown in the WRMP tables do not aggregate to the water resource zone deployable output which is shown in Table A2.6.

Table A2.6: Deployable output of our conjunctive use zones

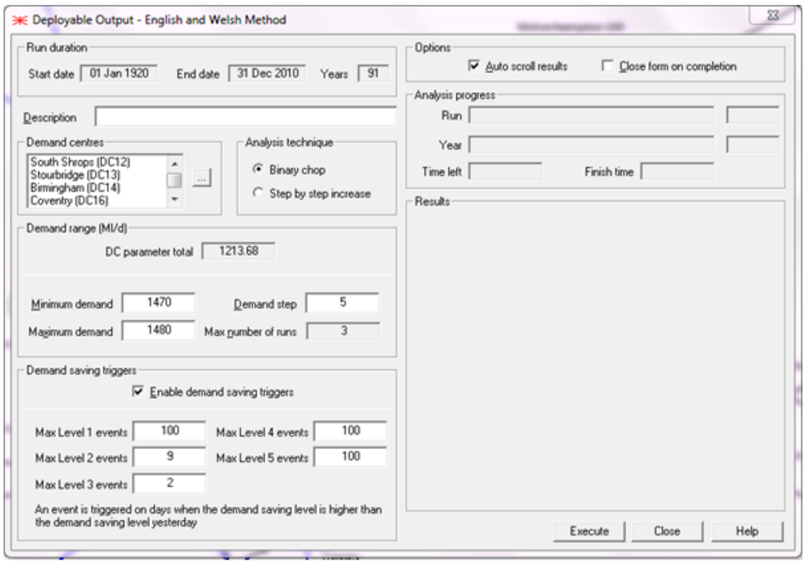
WRZ	WRMP14 DO (Ml/d)	Constraint
Strategic Grid	1465.8	Zonal Constraint. Constrained by Elan Reservoir and other surface and ground water sources at full capacity in 1976. Linkages to bring further water from north of grid zone are also at maximum capacity.
Nottinghamshire	269.9	Zonal Constraint. Constrained by groundwater yields/ group licence and imports from the Strategic Grid (SG) zone. Above this DO failures occur in the SG zone.
Newark	15.5	Zonal Constraint. Constrained by groundwater yield of local source, and available import from Nottinghamshire zone.
Shelton	143.0	Zonal constraint. Failure point is Shrewsbury; constraint is based on restricted groundwater yield in the zone.
Wolverhampton	65.0	Zonal Constraint. Constrained by groundwater yields and available supply from River Severn.
Forest and Stroud	45.0	Zonal Constraint. Constraint based on groundwater yields and regulated river abstraction on River Wye.
North Staffs	148.0	Zonal Constraint. Failure at higher DO occurs in Stone area. Constraint due to groundwater yield and network linkages.

A2.5 Deployable Output and Level of Service

As discussed in Appendix D6 our level of service (LOS) of no more than three Temporary Use Bans (TUBs) in 100 years and not more than 3 Non-essential Use Bans (NEUBs) in 100 years, is met in all of our water resource zones. This LOS is set in our Aquator modelling as a requirement for our base deployable output (DO) assessment.

We have tested the sensitivity of the link between DO and LOS by carrying out modelling at other levels of service as indicated in the WRMP Guidelines. We have tested the reference LOS of 1 in 10 years for TUBs and 1 in 40 for NEUBs. We set this in the model by allowing only 9 crossings of the TUB line and 2 crossings of the NEUB line in our 91 year model run. We also tested the “No Restrictions” DO. We simulated this in the model by removing the TUB and NEUB control lines, therefore allowing the model to calculate the DO level without implementing any restrictions.

Figure A2.10: Example model set up for reference LOS



In the below Table A2.7 we show the DO for the three different LOS scenarios for each of the conjunctive use zones.

Table A2.7: Conjunctive Use WRZs DO and LOS

WRZ	DO at Company LOS	DO Reference LOS	DO with No LOS restrictions in place
Strategic Grid	1465.8	1468.7	1450.0
Nottinghamshire	269.9	269.9	269.9
Newark	15.5	15.5	15.5
Shelton	143.0	143.0	143.0
Wolverhampton	65.0	65.0	65.0
Forest and Stroud	45.0	45.0	45.0
North Stafford	148.0	148.0	148.0

It can be seen that for a number of our WRZs there is no change in baseline DO as a result of changing LOS.

There are a number of reasons for this;

- For zones such as Shelton that are conjunctive use between a run of river abstraction and groundwater supplies, we have not linked the zone to any levels of service control curve on a reservoir. This is because the DO and LOS of the zone would not be affected by storage in any of our reservoirs. We tested the sensitivity of linking the Shelton zone to Clywedog reservoir, but this showed no difference in DO. It is worth also noting that for Shelton in particular as the river abstraction is towards the upper reaches of the river, it is not likely that linking LOS to a certain river level would have any benefit;

- The Nottinghamshire zone DO is based on the groundwater in the zone and a number of imports from the Strategic Grid zone, therefore we have not currently linked the zone to any LOS control curves on any reservoir. This therefore gives a flat profile of DO against LOS. We have checked the sensitivity of linking the Nottinghamshire LOS to the Derwent Valley reservoirs in the Strategic Grid zone and it has been found that this shows no increase in DO of the Nottinghamshire zone.

- The Forest and Stroud zone LOS has been linked to the Elan Valley reservoirs, because the regulation of the River Wye is linked to the levels at Elan. However this is only part of the constraint on the Forest and Stroud zone and the groundwater and Spring sources in the zone also of effect the DO. Therefore there is little effect of LOS on DO in this zone.

- Newark DO is based on Groundwater and its link with Nottinghamshire zone only so is not affected by LOS.

- The LOS trigger in North Stafford zone is based on the level in Tittesworth reservoir. However the zone’s DO is constrained by groundwater and network capacity.

Figures A2.10 and A2.11 are graphical examples of the relationship between deployable output and level of service, included are the graph for the Strategic Grid zone and North Staffordshire zone.

Figure A2.10: Graph of Baseline Deployable Output versus Level of Service – Strategic Grid zone

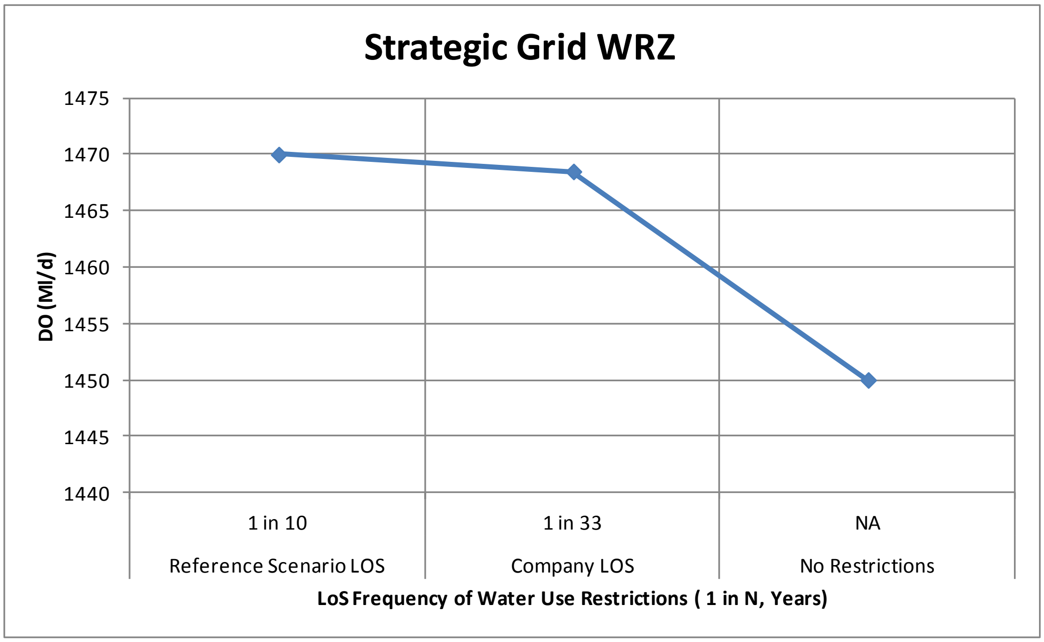
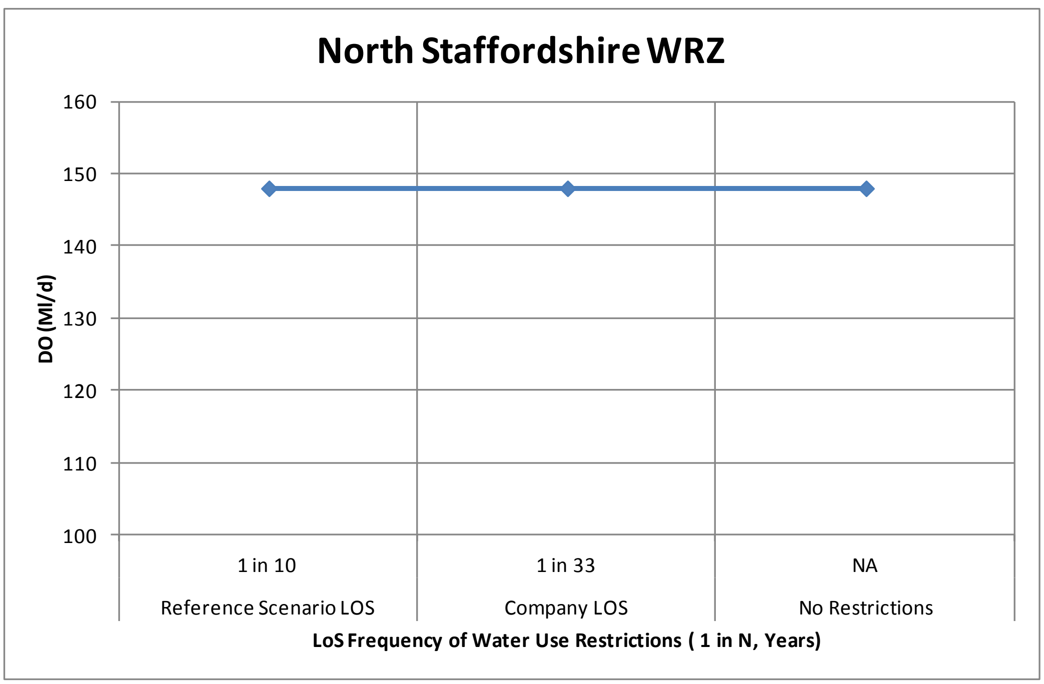


Figure A2.11: Graph of Baseline Deployable Output versus Level of Service – North Staffordshire



It can be seen that for the Strategic Grid zone at base DO level, although there is a definite benefit of introducing restrictions 3 times in 100 years, there is only a very small benefit to increasing the number of LOS events further. This is because for this zone above this

Deployable Output level there is a critical failure in 1976, which occurs even with both a TUB and NEUB in place. In that year, Elan Valley reservoir storage drops to just above emergency storage and there is insufficient capacity across the rest of the Strategic Grid zone to make up this shortfall. This is caused by a number of factors including fully utilised licences and restrictions in capacity between the north and south of the grid.

In our groundwater only zones, the sources of supply are all constrained by either abstraction licence or infrastructure. As such, alternative levels of service will have no effect on the deployable output in these zones.

- The Stafford water resource zone is supplied by five groundwater sources. The sources of supply are all constrained by infrastructure.
- The Bishops Castle water resource zone is supplied by two groundwater sources. The sources of supply are constrained by abstraction licence and infrastructure, respectively.
- The Mardy water water resource zone is supplied by a single groundwater source. The source of supply is constrained by infrastructure.
- The Llandinam and Llanwrin water resource zone is supplied by two groundwater sources. The sources of supply are constrained by abstraction licence and infrastructure, respectively.
- The Kinsall water resource zone is supplied by two groundwater sources. Individually, the sources of supply are constrained by abstraction licence and infrastructure, respectively. When abstracting together the two sources of supply are further constrained by an overarching group abstraction licence.
- The Whitchurch and Wem water resource zone is supplied by three groundwater sources. Two of the sources of supply are constrained by abstraction licence. One of the sources of supply is currently out of supply, and has no deployable output attributed to it.
- The Ruyton water resource zone is supplied by a single groundwater source. The source of supply is constrained by abstraction licence.

A2.6 Confidence Label Grading of Deployable Output

Following the guidelines for confidence labelling of DO assessments in the *UKWIR WR27 Water Resources Planning Tools 2012 guidance* (Akande *et al*., 2011) we have assigned a confidence label to each water resource zone. The considerations we have used for this are summarised in Table A2.8. The confidence labels are based on the length of hydrological data and the availability and consistency of the constraints data used in the DO assessment. Figure A2.12 shows the matrix that is used in the assessment of the confidence label.

Figure A2.12: Confidence Label Outcomes Matrix taken from UKWIR WR27 (2012)

			LENGTH of Hydrological and/or hydrogeological data sets			
			> 99 years	71 – 99 years	< 70 years	
			A	B	C	
AVAILABILITY (and consistency) of Constraints Data	Available and of consistent quality	A	AA	AB	AC	HIGH
	Mostly available but of variable quality	B	BA	BB	BC	
	Not available	C	CA	CB	CC	LOW
			HIGH		LOW	

Table A2.8: Confidence Label and Basis

Water Resource Zone	Zone Classification and degree of constraints on output	Confidence Label	Basis
Strategic Grid	Conjunctive use zone, including surface water (reservoir / river) sources and groundwater sources, with inter and intra-zonal transfers and complex constraints Degree of constraints is assessed as medium to high.	AB	Constraints include treatment works capacity (based on pump capacity, infrastructure, treatment capacity), abstraction licences, groundwater yields, river regulation, pipeline capacities. Constraints data is readily available and is of consistent quality. DO assessment carried out using 91 years of Hydrological data, using HYSIM rainfall/ runoff modelling to create the flow series. Hydro-geological data is for a shorter period, but makes up a small proportion of this zone.
Nottinghamshire	Conjunctive use network, including large transfers from surface water sources in the Strategic Grid zone and a complex network of groundwater sources and constraints Degree of constraints is assessed as medium to high.	AC	Constraints include abstraction licences (including a number of complex group licences) groundwater yields, pipeline capacities and transfers from the Strategic Grid zone. Constraints data is readily available and is of consistent quality. DO assessment carried out using 91 years of Hydrological data (Strategic Grid Zone), using HYSIM rainfall/ runoff modelling to create the flow series. Site specific hydro-geological data, which is used for a large proportion of this zone, generally has a 14 year record. Regional observation level data has a 43 year record.
Newark	Single groundwater source with a transfer from the Nottinghamshire zone. Degree of constraints Low to Medium.	AC	Constraints include abstraction licence, groundwater yield and a transfer from the Nottinghamshire zone. Site specific hydro-geological data for this zone has a 15 year record. Regional observation level data has a 43 year record.
Shelton	Conjunctive use zone, including direct river abstraction and groundwater sources, with intra-zonal transfers and constraints Degree of constraints is assessed as medium to high.	AC	Constraints include treatment works capacity, abstraction licences, groundwater yields, pipeline capacities. Constraints data is readily available and is of consistent quality. DO assessment carried out using 91 years of Hydrological data, using HYSIM rainfall/ runoff modelling to create the flow series. Site specific hydro-geological data for this zone has an average of 19 year record. Regional observation level data has a 41 year record.

Appendix A: How much water do we have available?

Water Resource Zone	Zone Classification and degree of constraints on output	Confidence Label	Basis
Wolverhampton	Conjunctive use zone, including large bulk supply transfer from South Staffs Water and a number of groundwater sources and constraints Degree of constraints is assessed as medium to high.	BC	Constraints include treatment works capacity, abstraction licences, groundwater yields. Constraints data is mostly available, but some constraints are based on the exporting company, we are therefore not aware of their quality. DO assessment carried out using 91 years of Hydrological data, using HYSIM rainfall/ runoff modelling to create the flow series. Site specific hydro-geological data for this zone has an average of 18 year record. Regional observation level data has a 41 year record.
Forest and Stroud	Conjunctive use zone, including surface water river source and groundwater sources, with inter and intra-zonal transfers and complex constraints Degree of constraints is assessed as medium to high.	AB	Constraints include treatment works capacity (based on pump capacity, infrastructure, treatment capacity), abstraction licences, groundwater yields, river regulation, pipeline capacities. Constraints data is readily available and is of consistent quality. DO assessment carried out using 91 years of Hydrological data, using HYSIM rainfall/ runoff modelling to create the flow series. Site specific hydro-geological data for this zone has an average of 42 year record. Regional observation level data has a 54 year record.
North Staffordshire	Conjunctive use zone, including surface water reservoir source and groundwater sources, with intra-zonal transfers and complex constraints Degree of constraints is assessed as medium to high.	AB	Constraints include treatment works capacity (based on pump capacity, infrastructure, treatment capacity), abstraction licences, groundwater yields, river regulation, pipeline capacities. Constraints data is readily available and is of consistent quality. DO assessment carried out using 91 years of Hydrological data, using HYSIM rainfall/ runoff modelling to create the flow series. Site specific hydro-geological data for this zone has an average of 24 year record. Regional observation level data has a 41 year record.
Stafford	Group of five groundwater sources with intra-zonal transfers. Degree of constraints is assessed as Low to Medium.	AC	Constraints include abstraction licence, groundwater yield and a number of intra-zonal linkages. Site specific hydro-geological data for this zone has an average of 14 year record. Regional observation level data has a 41 year record.

Appendix A: How much water do we have available?

Water Resource Zone	Zone Classification and degree of constraints on output	Confidence Label	Basis
Bishops Castle	Groundwater only zone comprising two sources. Degree of constraints is assessed as Low to Medium.	AC	Constraints data is available and consistent. Constraints are simple; determined by infrastructure and licence. Site specific hydro-geological data for this zone has a 16 year record. Regional observation level data has a 41 year record.
Kinsall	Groundwater only zone comprising two sources. Degree of constraints is assessed as Low to Medium.	AC	Constraints data is available and consistent. Constraints are simple; controlled by group licence. Site specific hydro-geological data for this zone has a15 year record. Regional observation level data has a 41 year record.
Llandinam & Llanwrin	Groundwater only zone comprising two sources. Degree of constraints is assessed as Low to Medium.	AC	Constraints data is available and consistent. Constraints are simple; determined by infrastructure and licence. Site specific hydro-geological data for this zone has an average of 17 year record. Regional observation level data has a 41 year record.
Mardy	Groundwater only zone comprising one source. Degree of constraints is assessed as Low to Medium.	AC	Constraints data is available and consistent. The constraint is simple; determined by infrastructure. Site specific hydro-geological data for this zone has a 19 year record. Regional observation level data has a 41 year record.
Ruyton	Groundwater only zone comprising one source. Degree of constraints is assessed as Low to Medium.	AC	Constraints data is available and consistent. The constraint is simple; controlled by licence. Site specific hydro-geological data for this zone has a 15 year record. Regional observation level data has a 41 year record.
Whitchurch & Wem	Groundwater only zone comprising three sources. Degree of constraints is assessed as Low to Medium.	AC	Constraints data is available and consistent. Constraints are simple; determined by infrastructure and licence. Site specific hydro-geological data for this zone has a 16 year record. Regional observation level data has a 41 year record.
Rutland	Zone is based on bulk supply imports from Anglian Water.	AA	Constraint is based on the full amount of bulk supply being available when required as per our bulk supply agreement.

A3 Future changes to deployable output

Our baseline projections of future deployable output include our assessment of the impacts on supply of the EA's Restoring Sustainable Abstraction programme and of climate change. This chapter explains how we have assessed these impacts and how they have been incorporated into our baseline deployable output projections.

A3.1 Restoring Sustainable Abstraction

Some of our existing water abstractions may be having a detrimental effect on the environment, particularly during dry weather periods when river flows are low. Throughout AMP5 we are investigating the impacts of those abstractions identified by the EA as possibly causing harm to the environment. Through our investigation work we are gathering site specific evidence of the extent of damage being caused, and whether our activities are the main cause, or just part of the problem.

Where our abstractions are identified as 'confirmed' or 'likely' to be the cause of the problem, the EA requires us to find and implement solutions. These solutions might include revoking or reducing our abstraction licences at the affected sites and possibly finding an alternative source of supply. These sustainability reductions to licences may be required to protect international or national designated conservation sites (Habitats Directive, Sites of Special Scientific Interest or Biodiversity 2020 sites), to protect locally important sites or to deliver Water Framework Directive (WFD) objectives.

In preparing our WRMP, we have worked with the EA to find workable solutions to the 'confirmed' and 'likely' sites, ranging from local environmental mitigation measures to alternative sources of supply. The reductions to our baseline deployable output projections include the impacts of any reduced or revoked abstraction licences at sites where we are likely to be required to change our abstractions.

The extent of the 'confirmed' and 'likely' sustainability changes to abstraction licences included in our final WRMP are summarised below. We then explain the impacts that these will have on the deployable output of our water resource zones.

Confirmed and Likely Changes

In August 2012 the EA issued phase 1 of their National Environmental Programme (NEP), which included the list of sustainability changes to abstraction licences that they require us to included in our final WRMP. The EA provided a list of 'confirmed' and 'likely' sustainability changes plus other 'non-licence change solutions' required to mitigate local environmental concerns. The changes identified were based on our current AMP5 investigations, some of which were inconclusive at that stage, and on schemes identified from our previous AMP4 work.

A second notification was issued in Phase 2 of the NEP in February 2013. This included the addition of a new site at Batchley Brook and Stanford Reservoir plus the removal of the Croxden Brook site from the original likely list. The timing of the Phase 2 list means that these changes have not been able to be included in the final WRMP.

The final formal notification of the sustainability changes required by the EA was issued in Phase 3 of the NEP in August 2013. However as the final Impact Assessment reports were completed by the end of December 2013 (as a regulatory delivery date) a further revision was made in Phase 4 in December 2013, and we believe there will be a further revision to be made in Phase 5. Changes to the Implementation list include the addition of Dover Beck, Meece Brook and River Greet, and the removal of Aldford Brook. There are also changes made in the 'Investigation and Options Appraisal' list and 'Ongoing' list. We are also in discussion with the EA about dates for delivery of schemes and Options Appraisal .

The Table below outlines the confirmed and likely sustainability reductions provided by the EA in the August 2012 Phase 1 NEP and which we have included in our WRMP.

Table A3.1: Confirmed and Likely sustainability changes for groundwater

EA RSA Site Name	STWL Source Licence Name	Current Daily Average (Ml/d)	New Daily Average (Ml/d)	Type
GROUNDWATER SOURCES				
River Blithe	Sheepwash	4.54	0.00	Licence Revoked
River Sherbourne	Brownshill Green	2.50	0.00	Licence Varied - Change of use to Compensation
Swynnerton Pools	Swynnerton	10.25	9.75	Licence Reduction
Rainworth Water	Rainworth	9.00	0.00	Licence Revoked
	Normans Hollow	5.00	0.00	Licence Revoked
	Rushley	4.00	0.00	Licence Revoked
Battlefield Brook	Washingstocks	4.49	0.35	Licence Reduction
	Whitford	4.50	0.35	Licence Reduction
	Wildmoor	8.17	0.00	Licence Revoked
Upper Worfe	Sherrifhales	5.12	0.00	Licence Revoked
	Lizard Mill & Shifnal	15.92	0.00	Licence Revoked
	Cosford & Neachley	20.46	10.10	Licence Reduction
Glynch Brook	Bromsberrow	6.00	3.00	Licence Reduction
Aldford Brook	Peckforton	5.85	13.70	Licence Reduction
	Tattenhall	6.81		Licence Reduction
	Tower Wood	5.67		Licence Reduction
Merryhill Brook	Dimmingsdale	No Change	No Change	Local Scheme
	The Bratch	No Change	No Change	Local Scheme
Croxden Brook	Greatgate	No Change	No Change	Local Scheme
Pinnock Springs	Pinnock Pumping Station	No Change	No Change	Local Scheme
Worcestershire Middle Severn Sandstone - Hartlebury Common SSSI	Astley & Green Street	No Change	No Change	Local Scheme
Worcestershire Middle Severn Sandstone - Puxton & Stourvale Marsh SSSI	Green Street	No Change	No Change	Local Scheme
Worcestershire Middle Severn Sandstone - Hurcott & Podmore Pools SSSI	Green Street & Bellington	No Change	No Change	Local Scheme

Table A3.2: Confirmed and Likely sustainability reductions for surface water

EA RSA Site Name	STWL Source Licence Name	Current Daily Average (Ml/d)	New Daily Average (Ml/d)	Type
SURFACE WATER SOURCES				
Rivers Blythe and Bourne	Whitacre	50.68	Not known	Hands off Flow change & Local Solution
Middle Derwent	Ambergate	No Change	No Change	Potential Reduction
	Little Eaton to Little Eaton WTW	No Change	No Change	Potential Reduction
	Little Eaton to Church Wilne WTW	No Change	No Change	Potential Reduction
River Wye SAC HD RoC	Wyelands to Mitcheldean WTW	No Change	No Change	Licence change (HOF and Regulation)
Carsington Reservoir & Henmore Brook	Carsington Reservoir	No Change	No Change	Operational Change Compensation Flow Variation
Tittesworth Reservoir	Tittesworth	No Change	No Change	Operational Change Compensation Flow Variation
Charnwood Reservoirs	Blackbrook Reservoir	No Change	No Change	Operational Change Water Level Management
Charnwood Reservoirs	Cropston and Swithland Reservoirs	No Change	No Change	Operational Change Water Level Management
River Ashop	Derwent Reservoirs (Ashop Diversion)	No Change	No Change	Operational Change Additional Compensation Flow
River Noe	Derwent Reservoirs (Noe Diversion)	No Change	No Change	Operational Change Additional Compensation Flow

We have incorporated these abstraction licence changes into our Aquator model to allow us to demonstrate the impact on water resource zone deployable output. Several of the groundwater licence changes are at sources that are largely underutilised. As a result, while the quantity of licensed volume would be reduced by around 81Ml/d, this translates into a loss of around 37Ml/d in our total deployable output.

For our surface water sources, many of the changes being sought will affect the operating rules and daily operation for these sources. The changes will alter the flow regime of these surface water bodies, often by requiring us to provide more flows. Quantifying the impacts of these changes on deployable output is more complex and requires the changes to the operating rules to be clarified. We have not completed our assessment of the deployable output impact of these changes at this stage and we will continue to work with the EA to understand how these changes should be translated into operational rules. For example, we will be actively participating in the EA's forthcoming Significant Water Management Issues (SWMI) consultation. The EA will be running this consultation from June to December 2013. One of the issues that we expect this to cover is how best to align this plan with the River Basin Management Plans (RBMPs) that are due in 2015.

In addition to these 'confirmed' and 'likely' sustainability changes to our abstraction licences, we are also affected by the changes required by the Welsh EA to Dwr Cymru Welsh Water's (DCWW) abstraction licence at the Elan Valley Reservoirs in the upper River Wye catchment. As required under the Habitats Directive, Natural Resources Wales have undertaken a review of consents (ROC) on the River Wye. This has concluded that a number of licence changes are required to reduce the impact of abstractions on the river. These changes include DCWW's licence at Elan Valley Reservoir, which will affect the discharges from the reservoir for river compensation and regulation.

DCWW provide us with a major bulk supply of water from Elan Valley Reservoirs to our Strategic Grid zone. Our Aquator modelling indicates that it is the changes to the Elan Valley Reservoir operation that will have the single biggest impact on deployable output in that zone. Our final WRMP assessment showed that up to 75Ml/d of deployable output could be lost in the Strategic Grid zone due to the changes to the reservoir operation.

Since we published the draft WRMP, we have continued to work with Natural Resources Wales (NRW) to identify ways to minimise the impacts of these changes to the River Wye and Elan Valley operation.

We have carried out further Aquator modelling, to ensure that the control curves at Elan that effect the abstraction at Trimpley are optimised, we have explored ways in which we would reduce the flow from Elan to Birmingham earlier in the summer during dry years based on the reservoir level at Elan

Through this work we have reduced the impacts of these changes to around 40Ml/d loss of deployable output.

However this change increases the use of River Severn water (Trimpley Abstraction) which will have an Opex cost implication due to the extra pumping required from Trimpley to Frankley.

The impacts on deployable output in those zones affected by the RSA 'confirmed' and 'likely' changes are explained below.

Strategic Grid zone

The Phase 1 NEP includes likely licence changes in the Bromsgrove area, impacting our Washingstocks, Wildmoor and Whitford sources, in the Malvern area at Bromsberrow, and the Coventry area at Brownshill Green, which total a possible 22Ml/d of licence reductions. There is also a new "hands off flow" on the River Blythe proposed, which could affect the abstraction to Whitacre water treatment works. In the latest NEP Bromsberrow is no longer at risk and the Blythe HOF will be the subject of further investigation before any changes are made

The combined effect of these changes on the deployable output of the Strategic Grid is a reduction of 5Ml/d across the zone. The changes would also impact on the security of supplies in the area supplied by the Bromsgrove groundwater sources and would effectively isolate this supply area from the rest of the Strategic Grid water resource zone.

When these licence changes are combined with the changes to DCWW's licence at Elan Valley there is a much larger deployable output reduction in the Strategic Grid zone of 45Ml/d. In summary, the changes at Elan Valley mean that regulation and compensation releases to the river from the reservoirs are required at much higher flows in the River Wye than currently. Also, the maximum combined discharges to the river are higher at all times.

The impacts on Strategic Grid deployable output are show in Table A3.3.

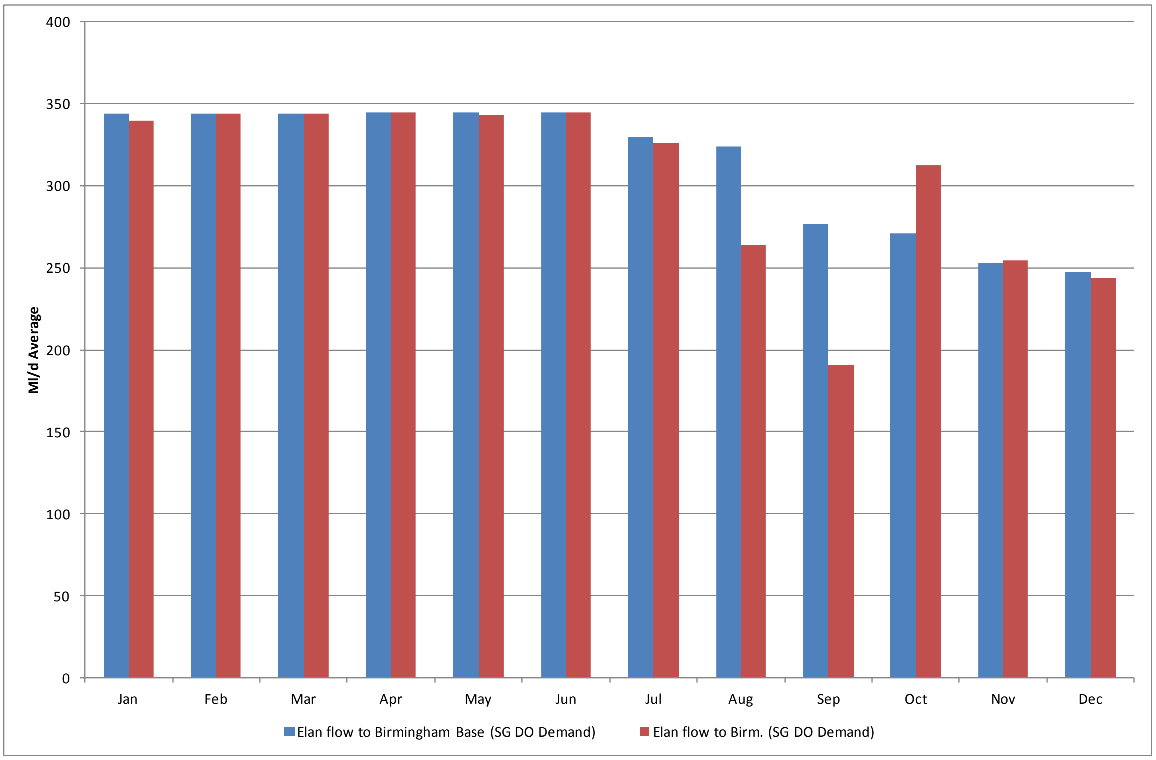
Table A3.3: Impacts of sustainability changes on Strategic Grid zone

Scenario	Base DO (Ml/d)	DO with Sustainability Changes (Ml/d)	Reduction (Ml/d)
Sustainability changes only	1465	1460	5
Sustainability changes with Wye HD (ROC) changes	1465	1420	45

The large reduction in zonal deployable output resulting from the licence changes is caused primarily by the increased regulation and compensation releases from Elan Valley Reservoirs, reducing the amount of water available to send to the Strategic Grid zone. Our modelling shows that under the proposed new reservoir operating rules, during dry years much less water is available for supply from Elan Valley to the Strategic Grid zone.

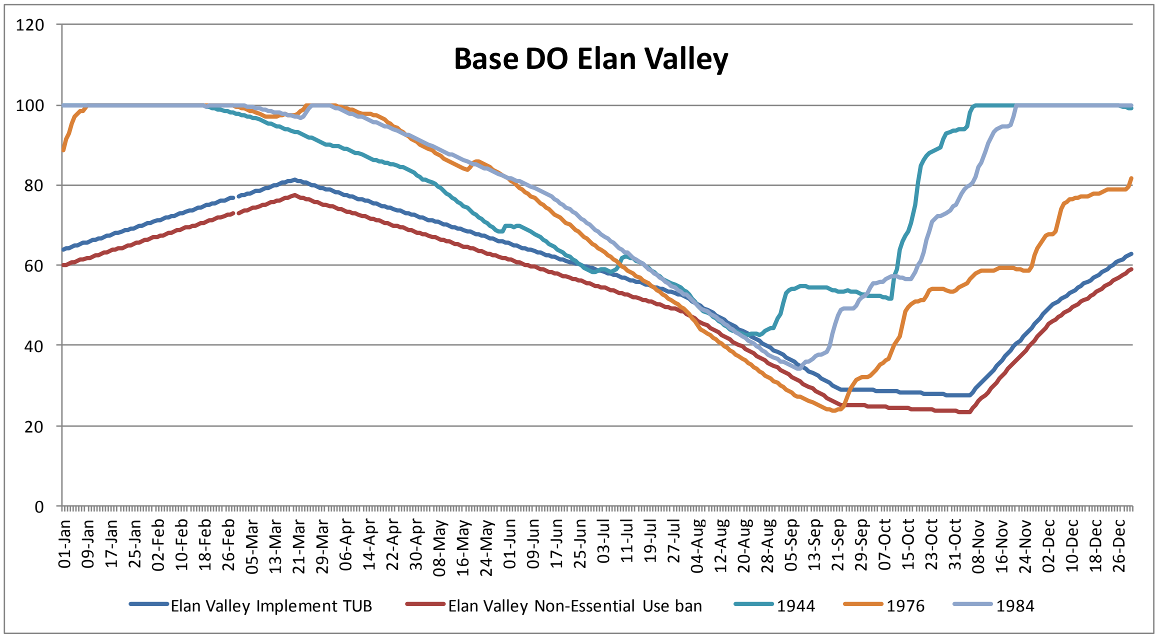
For example, our modelling shows that during the summer of 1976 (Apr-Sept) 4800Ml more water would have been released from the reservoir to the River Wye and 4600Ml less would have been available to the Strategic Grid zone. In the model this causes a large reduction in the flow to the Strategic Grid in September 1976, as we have shown in Figure A3.1.

Figure A3.1: Reduction in Elan Valley flow to the Strategic Grid



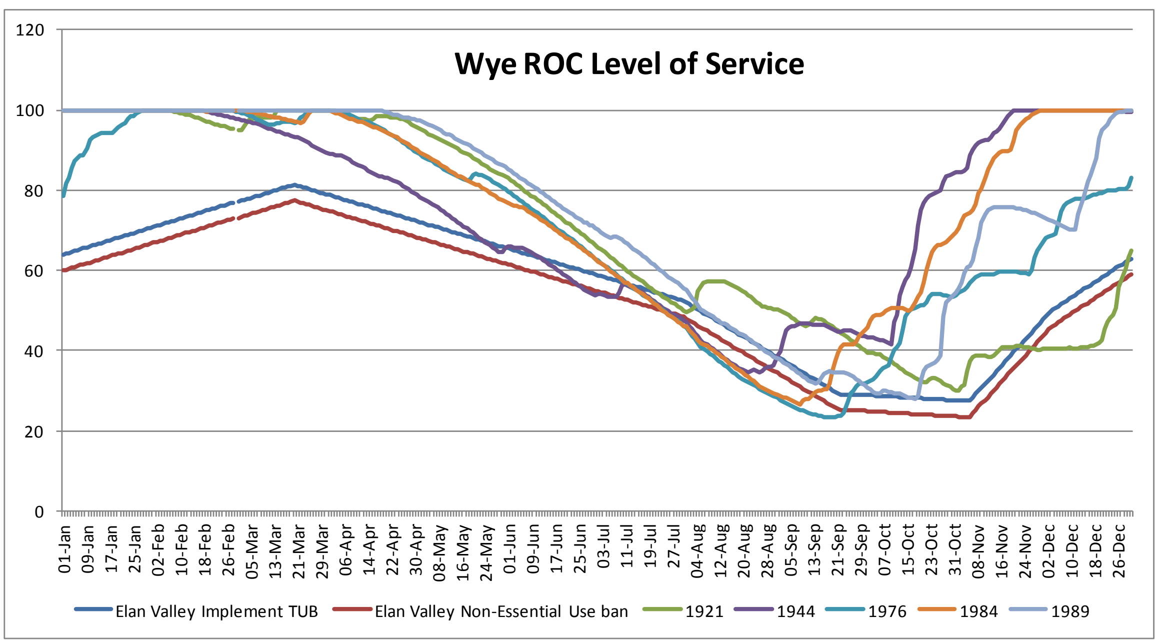
The increased discharges to the river also cause the reservoirs to draw down more sharply and more often, making less severe drought events more critical to our zonal deployable output. As a result, the Elan Valley changes mean there would also be a deterioration in our level of service around hosepipe ban frequency under the base level DO. Figure A3.2 shows that under the baseline scenario we have three crossing of the TUB line and one crossing of the NEUB line over the 91 year model run.

Figure A3.2: Baseline DO – Crossings of Elan Valley TUB and NEUB Lines



However with the River Wye HD licence changes if we run the model at the same DO demand level we would have five crossings of the TUB line and three crossings of the NEUB line, as illustrated in Figure A3.3.

Figure A3.3: Wye HD (ROC) – Crossings of Elan Valley TUB and NEUB Lines



Forest and Stroud zone

There are no 'likely' sustainability changes in the Phase 1 NEP list that affect the groundwater licences in the Forest and Stroud zone, however this zone is affected by the licence changes required on the River Wye. The EA's Review of Consents on the River Wye concluded that changes are required to our Wyelands (Lydbrook) abstraction licence, which supplies Mitcheldean WTW This is our only confirmed licence change in the Phase 1 NEP list.

Table A3.4: Impacts of sustainability changes on Forest and Stroud zone

Base DO (Ml/d)	DO with Sustainability Changes (Ml/d)	Reduction (Ml/d)
45	45	0

Under the new Lydbrook licence conditions, our maximum daily and annual average abstraction quantities are unchanged. However, the frequency and duration of when the maximum quantities would be reduced will be greatly increased because the licence threshold will be linked to a much higher minimum river flow condition. Also there is no longer a mid-level abstraction rate allowed, and abstraction would be reduced straight from 55Ml/d to 39.8Ml/d, depending on river flows.

The effect of the Lydbrook licence changes do not impact on the deployable output of the zone, because this is already constrained by the drought output from spring-flow sources elsewhere in the zone combined with the Lydbrook minimum licence condition during dry years.

However, Mitcheldean is the largest source of supply in the Forest and Stroud zone, and provides supply support to the groundwater / spring sources in the area. The licence change will put wider supply resilience at risk as the alternative supply plans for the neighbouring groundwater sources will not be operable without the current full Mitcheldean licensed quantities available to support them.

The risk is that Mitcheldean will not be available to support outages at our groundwater sources in future because its output will more frequently be restricted to minimum abstraction. This can be seen clearly in the below two figures which compare the frequency and duration of the Mitcheldean abstraction being restricted under the current and proposed new licences.

Figure A3.4: Graph of modelled abstraction constraint days per year current licence

Appendix A: How much water do we have available?

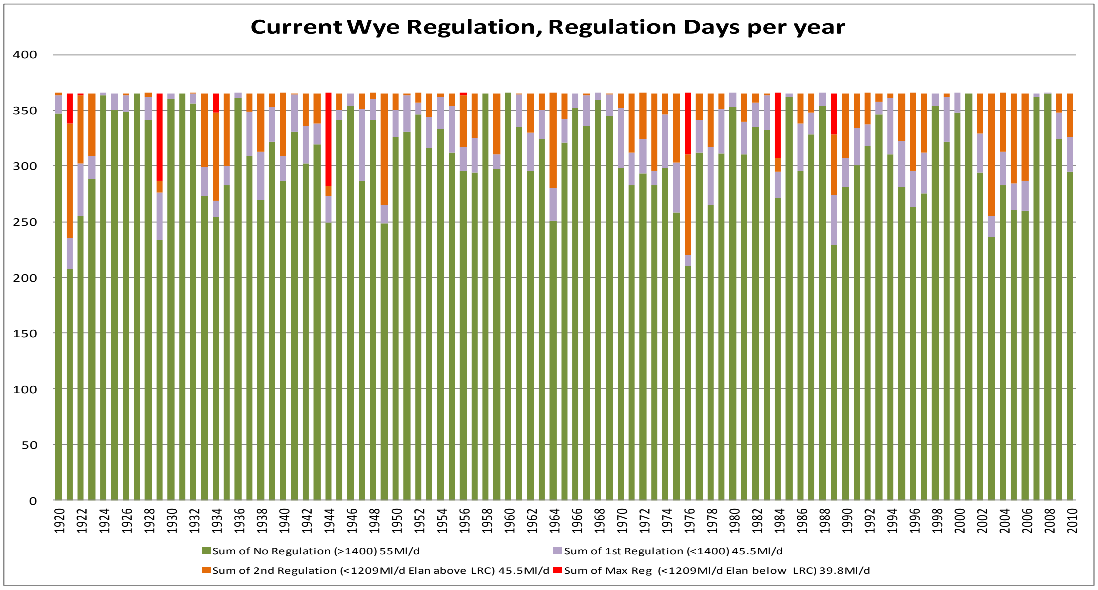
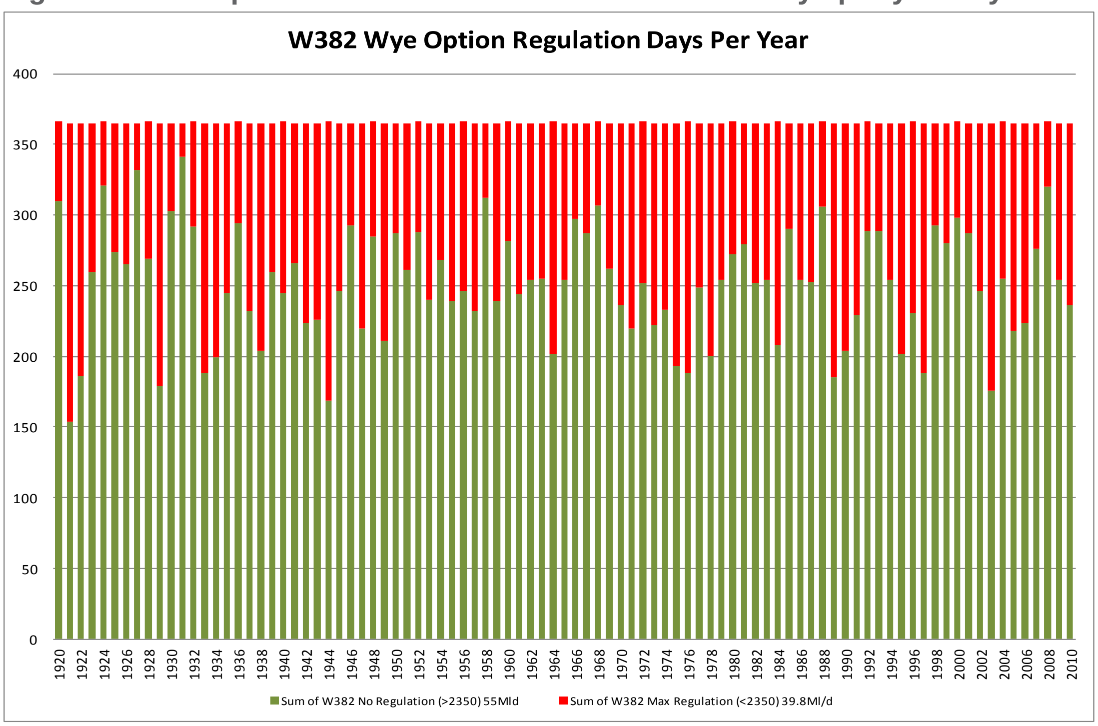


Figure A3.5: Graph of modelled abstraction constraint days per year Wye ROC



Key: Max abstraction: Green = 55Ml/d, orange / purple 45.5Ml/d, Red 39.9Ml/d

It can be seen from these graphs that with the new abstraction licence conditions, Mitcheldean will be on minimum abstraction for many more days each year, and what has historically been an unusual event will become an annual occurrence.

Shelton zone

The Phase 1 NEP included a total of 31.4Ml/d 'likely' sustainability reductions in the Shelton zone, targeted on our River Worfe sources at Sherrifhales, Lizard Mill, Shifnal, Cosford, and Neachley groundwater sources.

Table A3.5: Impacts of sustainability changes on Shelton zone

Base DO (Ml/d)	DO with Sustainability Changes (Ml/d)	Reduction (Ml/d)
143	115	28

These licence changes have the effect of reducing the deployable output in the zone by 28Ml/d. The changes also move the deployable output constraint in the zone from Shrewsbury to Wolverhampton North, and effectively would mean that the Shelton zone would be split into two separate water resource zones.

North Staffs zone

The Phase 1 NEP included a total of 9.7Ml/d 'likely' sustainability reductions in the North Staffs zone, targeted at Swynnerton, Sheepwash, Peckforton, Tower Wood and Tattenhall groundwater sources. In the latest NEP the Aldford Brook (Peckforton, Tower Wood and Tattenhall) has been moved from Implementation into the Investigation and Options Appraisal list and so any licece reductions will not be confirmed until 2017 at the earliest.

Table A3.6: Impacts of sustainability changes on North Staffordshire zone

Base DO (Ml/d)	DO with Sustainability Changes (Ml/d)	Reduction (Ml/d)
148.0	147.0	1

The combined effect of these changes is a 1Ml/d reduction in deployable output for this zone. The modelled failure point for the zone remains in the Stone demand centre.

Nottinghamshire zone

The Phase 1 NEP included a total of 18Ml/d likely sustainability changes in the Nottinghamshire zone targeted at the Rainworth, Rushley and Norman's Hollow abstraction licences, all of which would be revoked. The latest NEP now also includes licence revocations for Salterford and Fishpool (Dover Beck) and also a reduction or revocation for Farnsfield (River Greet).

Table A3.7: Impacts of sustainability changes on Nottinghamshire zone

Base DO (Ml/d)	DO with Sustainability Changes (Ml/d)	Reduction (Ml/d)
270	270	0

However there is no loss to deployable output for this zone because these sites are currently disused.

Pragmatic estimate of further sustainability reductions

The EA's August 2012 Phase 1 NEP also provided a list of the remaining water bodies where the results of our current investigations are inconclusive. The licence changes at these sites have been classified as "unknown" in the phase 1 NEP and we have not included these potential sustainability changes in our final WRMP.

However, in October 2012 the EA subsequently provided a 'pragmatic' estimate of those currently unknown sites which they think could become 'likely' in the Phase 3 NEP for August 2013. The purpose of this pragmatic list was to allow us to sensitivity test our final WRMP planning scenarios. These additional assumed reductions are shown in Table A3.8 below and amount to about 43 Ml/d.

Table A3.8: Pragmatic assumptions around sites where our impacts are currently unknown

EA RSA Site Name	STWL Source Licence Name	Current Daily Average (Ml/d)	New Daily Average (Ml/d)	Type
GROUNDWATER SOURCES				
Cinderford Brook	Buckshaft	6.00	1.00	Licence reduction
Ell Brook	Newent	2.50	1.00	Licence reduction
River Churnet - Rudyard tributary	Pool End	12.40	11.40	Licence reduction
	Highgate			Licence reduction
Dover Beck & Oxton Dumble	Blidworth Group	61.80	57.80	Licence reduction
Rainworth Water	Clipstone Group	73.83	65.43	Licence reduction
Lower Worfe	Copley	4.97	13.57	Licence reduction
	Hilton	22.80		Licence reduction
Spadesbourne Brook	Bromsgrove Group	39.00	37.00	Licence reduction
Hadley Brook	Chaddesley Corbett	6.83	2.50	Licence reduction
	Dunhampton	3.41	0.50	Licence reduction

We have not included this pragmatic estimate of additional sustainability changes in our baseline deployable output or in our headroom assessment. We have instead used it to test the impacts of these potential additional changes on the proposals set out in our final WRMP. Further discussion of the impacts of these potential additional sustainability changes can be found in Appendix E.

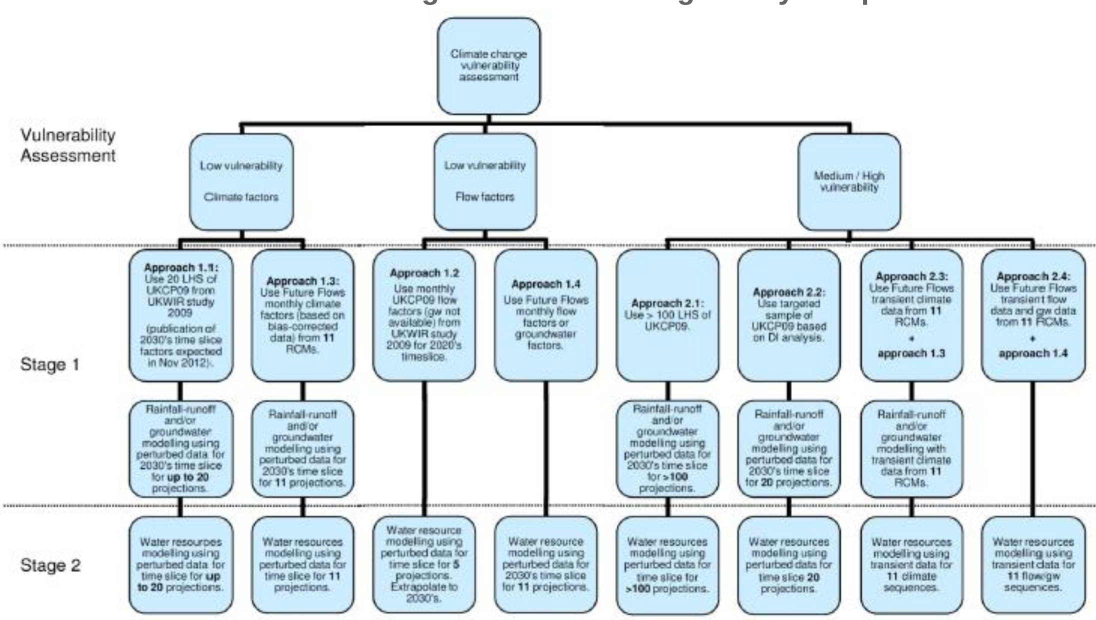
Following the completion of Impact Assessment reports it was shown that of the 'pragmatic' list the only licences that would be changed were those in the Dover Beck waterbody (Salterford and Fishpool).

A3.2 Impacts of Climate Change on Water Supply

Since the publication of our 2009 Water Resource Management Plan (WRMP09) we have continued to develop our assessment of the potential impacts of climate change on our water supply system. Our WRMP09 was informed by the then best available UK Climate Impact Programme 2002 (UKCIP02) climate change impact scenarios. In 2009, an update to the UK Climate Projections (UKCP09) was published.

The UKCP09 new set of data and tools enables water companies to carry out a probabilistic assessment of what the impacts of climate change are likely to be on their supply systems. The extent of UKCP09 tools and datasets means that there is a wide choice of methodologies that can be used to carry out impact assessments depending on the user's needs and circumstances. Figure A3.6 shows the range of methodologies recommended in the Environment Agency's Water Resources Planning Guidelines (WRPG) which was published in 2012.

Figure A3.6: Decision tree showing the climate change analysis options



The range of methodologies is described in detail in the joint UKWIR and Environment Agency report "*Climate change approaches in water resources planning – Overview of new methods*" (2013). Table A3.9 outlines some of the differences between the methodologies available to water companies now and when their 2009 Water Resource Management Plans were put together.

Table A3.9: Differences between methods available at WRMP09 and dWRMP13

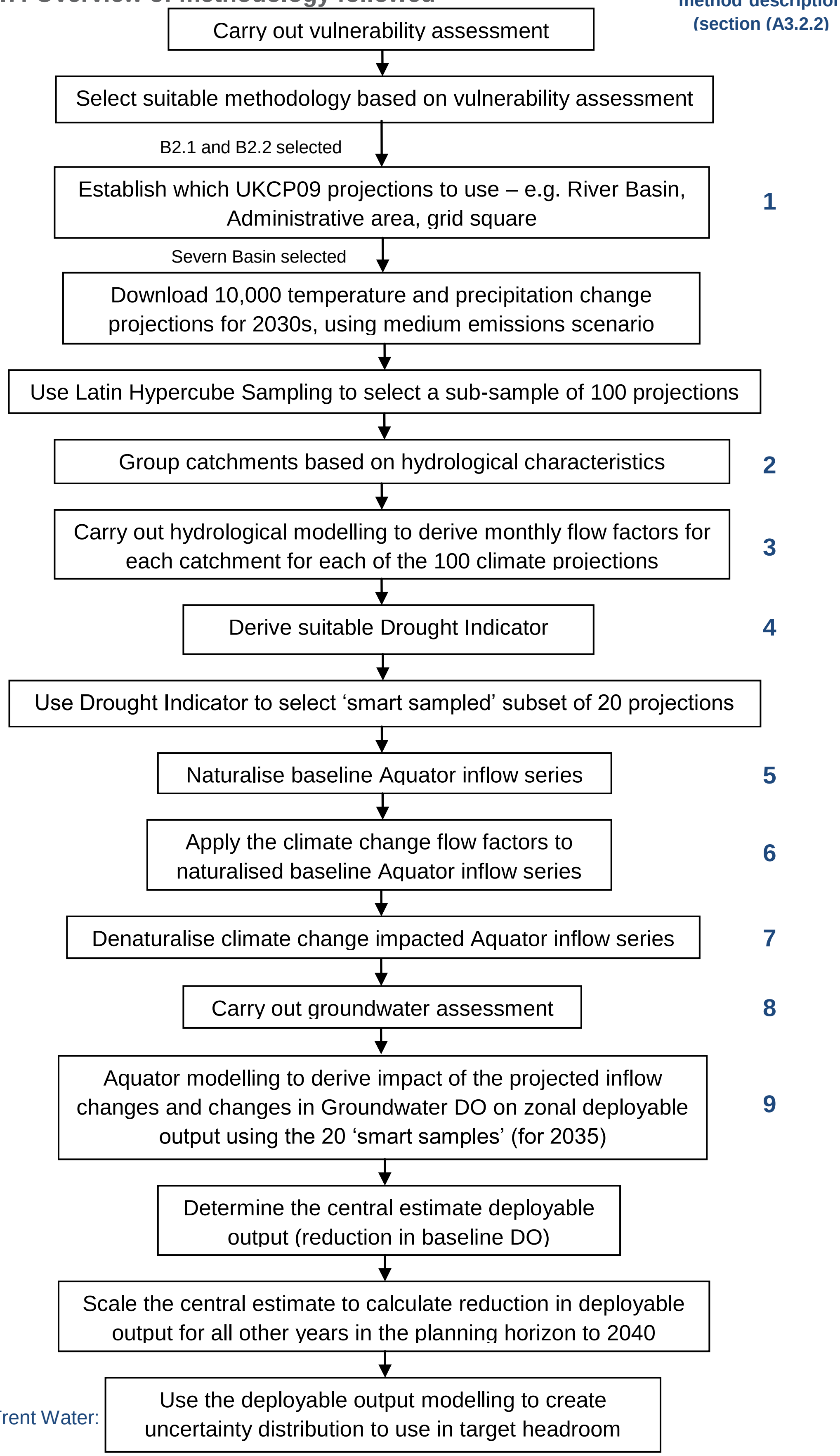
WRMP09 Method	Final WRMP13 Methods
Methodology based on UKWIR06 project which used the UKCIP02 projections	Multiple methods available, based on UKCP09 projections or 11 Regional Climate Models
Method selected depended on whether the company had rainfall-runoff models available to create climate perturbed flow series	Method selected depends on the initial assessment of vulnerability of the water resource zone (WRZ) to the impacts of climate change. Different approaches can be taken for different WRZs if the level of vulnerability is different
Method translated the projections into 3 scenarios – "Mid", "Wet" and "Dry" (i.e. 3 sets of DO runs in addition to the baseline)	Depending on method selected, outputs range from 11, 20 or 100 scenarios (i.e. 11, 20 or 100 sets of DO runs in addition to the baseline runs)
"Mid" scenario was adopted as the central estimate which was deducted from baseline DO in WRP tables	Companies must decide how to select a suitable central estimate to adopt as the likely reduction in terms of DO
"Wet" and "Dry" scenario outputs were used to provide a range of uncertainty due to climate change in target headroom	Outputs from all other scenarios feed into the range of uncertainty in target headroom
Method produced outputs indicative of the 2020s (2025)	UKCP09 gives a choice of time-slices. Method guidance produces outputs indicative of the 2030s (2035). Use of a different time-slice could produce different outputs

Overview of Approach

Figure A3.7 shows an overview of the methodology we have followed to assess the impact of climate change on our groundwater and surface water sources. A step by step description of our approach can be found in section A3.2.2, along with the decisions we have made to ensure consistency across all of our sources. In accordance with the EA's WRPG we first carried out a vulnerability assessment to determine how vulnerable each of our 15 water resource zones is to the impact of climate change. This then enabled us to determine an appropriate methodology to use.

An overview of the impacts of climate change on our surface water and groundwater sources can be found in sections A3.2.3 and A3.2.4 respectively, and details of the impact on our water resource zone deployable output in section A3.2.5.

Figure A3.7: Overview of methodology followed



Vulnerability Assessment: Surface water

In order to decide which method to adopt, we carried out a vulnerability assessment for each of our water resource zones. By doing this, we were able to identify which of our water resource zones are likely to be most sensitive to the effects of climate change and require a more detailed/complex modelling approach. To complete the vulnerability assessment we used a variety of sources of information, including:

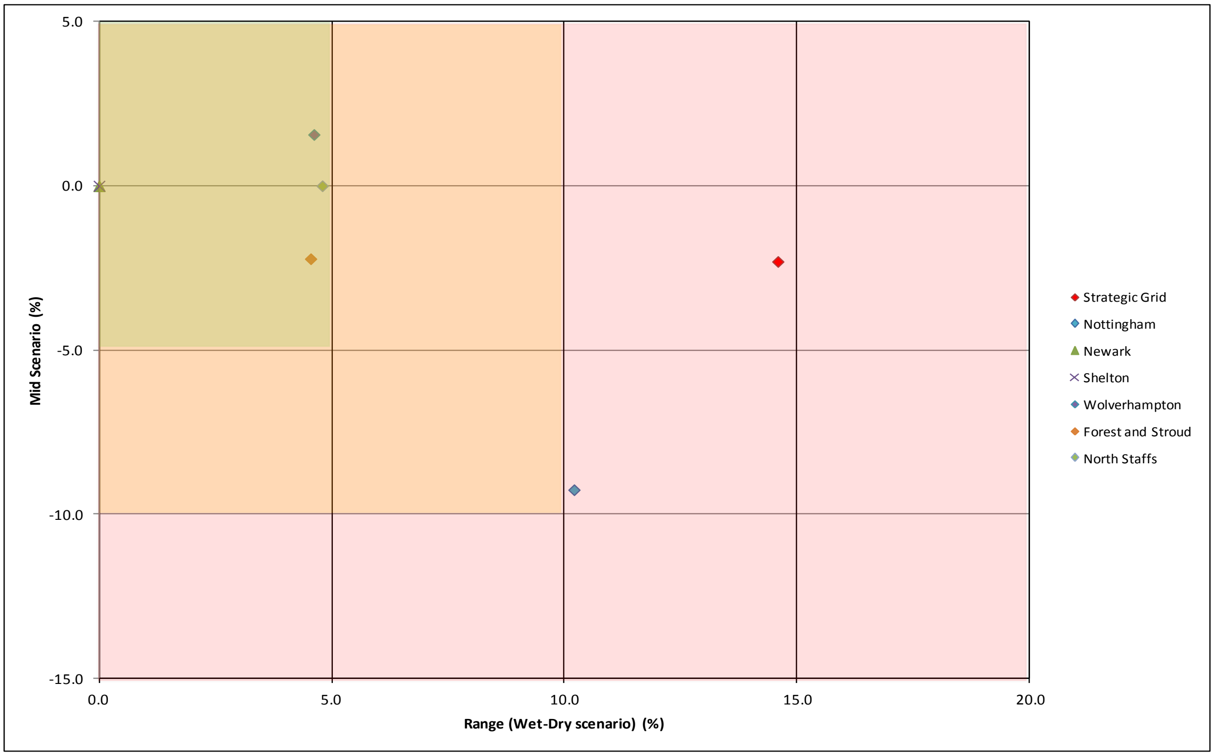
- Model outputs (deployable output modelling, modelled reservoir drawdown, Supply-Demand Balance)
- The Environment Agency's Catchment Abstraction Management Strategy
- Our abstraction licence documents and source information
- Our Drought Plan
- Our WRMP09
- Our Climate Change Adaptation Report, which was published in 2011.

We also carried out an initial stage of deployable output modelling to update our understanding of how our surface water supply system responds to the impact of climate change. Since we published our 2009 Water Resource Plan, we have increased our water resource zones from 6 to 15 WRZs which has required subsequent reconfiguration of our Water Resource Model, Aquator. We have also recalibrated the baseline flow series used in our deployable output modelling due to changes in the Met Office gridded rainfall methodology, which resulted in significant changes to the derived historical annual average and long term average rainfall for much of our region.

All of these changes meant we could not simply use our WRMP09 flow series datasets or model outputs to assess the likely impacts for our new WRMP. Instead of repeating the WRMP09 approach (which used the UKCIP02 climate projections) with the new baseline flow series we carried out initial modelling using approach A1.2 to assess the likely impact of the UKCP09 projections on our surface water sources. This initial modelling utilised the climate change analysis that was readily available following the 2009 UKWIR study "*Assessment of the significance to Water Resource Management Plans of the UK Climate Projections 2009*" (2009). The outputs and supporting information for the Future Flows and Groundwater Levels project were not published until April 2012 so could not be used in our vulnerability assessment.

The outputs of the A1.2 modelling were then cross-checked against the outputs of the WRMP09 climate change modelling to derive an overall vulnerability assessment for our surface water sources and conjunctive use water resource zones. The A1.2 assessment has been used to generate a magnitude versus sensitivity plot, shown in Figure A3.8.

Figure A3.8: Magnitude versus Sensitivity plot for our conjunctive use water resource zones showing the climate change mid scenarios percentage change in deployable output (from the baseline) and the uncertainty range



Using the results from the magnitude versus sensitivity plot, we identified the vulnerability classification for each water resource zone using the vulnerability scoring matrix shown in Table A3.10.

Table A3.10: Vulnerability scoring matrix

Uncertainty range (% change wet to dry)	Mid scenario (% change in deployable output)		
	<-5%	>-5%	>-10%
<5%	Low	Medium	High
6 to 10%	Medium	Medium	High
11 to 15%	High	High	High
>15%	High	High	High

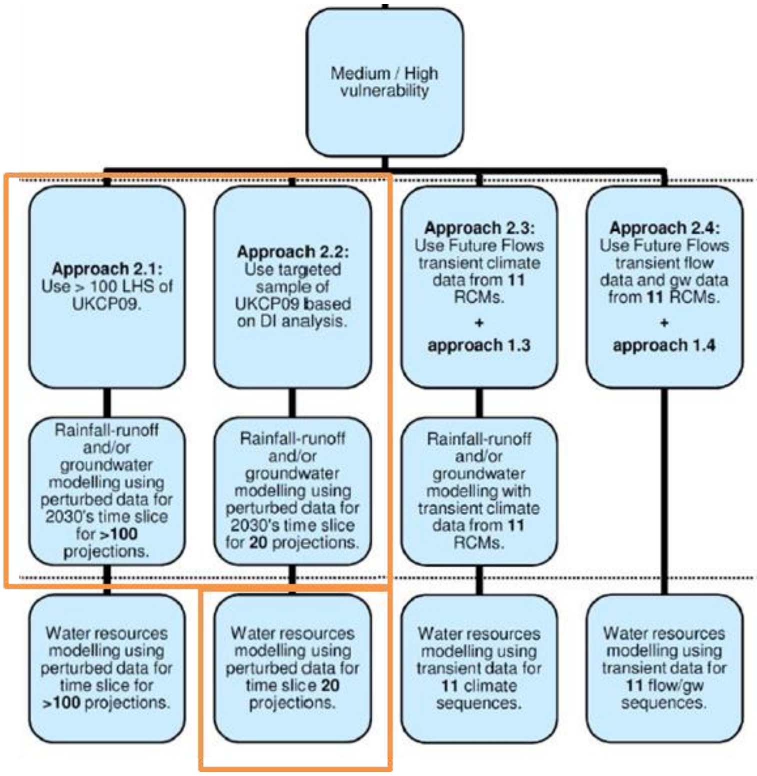
The magnitude versus sensitivity plot and scoring matrix indicate that our two largest zones, the Strategic Grid and Nottinghamshire, are both “high” vulnerability. All our other conjunctive use zones, which use a combination of impounding reservoirs, river abstractions and groundwater sources to supply our customers, are “low” vulnerability.

The Strategic Grid zone covers a large area of the Severn Trent region, and includes most of our strategic raw water reservoirs (with the exception of Tittesworth reservoir which is located in the North Staffordshire WRZ). This zone is classified as being "high" vulnerability as the modelling produces a wide range of uncertainty - under very wet conditions, the deployable output could be higher than our baseline and under very dry conditions, deployable output could be much lower than baseline depending on the scenario used. Although the Nottinghamshire zone is supplied by a number of groundwater sources, it also relies on an import from some of the surface water sources in the Strategic Grid. This surface water import may be impacted by climate change, which has led to the Nottinghamshire zone being classified as "high" vulnerability.

As discussed earlier in this Chapter, we have developed an integrated water resources modelling system using Aquator, which incorporates all of our water resource zones. Due to the complexity of our supply system, we need to ensure that any flow series derived from the climate change assessment are spatially coherent and can be used together at the same time in our Aquator model. Although few imports and exports exist between our water resource zones, several of our zones have "shared resources". For example, the Shelton, Wolverhampton and Strategic Grid zones are not physically connected but all abstract from the River Severn, taking water from different locations.

Our largest abstractions from these shared resources are used to supply the Strategic Grid zone. Adopting different climate change assessment approaches for our "low" and "high" vulnerability zones when they are modelled together could result in climate change flow series which are not spatially coherent, and could over- or underestimate the impact of the changing climate. We have therefore adopted a "high" vulnerability approach for all 15 zones to ensure consistency in our zonal deployable output modelling. That is the B2.1 method to derive 100 Latin Hypercube Samples from the full UKCP09 scenarios and then B2.2 to derive a sub-sample of 20 scenarios using a Drought Indicator derived specifically for the sources in our region. The selected methods are highlighted by the orange box in Figure A3.9.

Figure A3.9: Summary of climate change impacts assessment methods suitable for "Medium/High vulnerability" water resource zones



Vulnerability assessment: Groundwater

Our groundwater vulnerability analysis considered three methods of selecting which groundwater sources to include in the assessment of impacts on groundwater deployable output (DO) due to Climate Change:

- Option 1: Only consider the sources identified as flow or level constrained (i.e. where the DO defined for the source is limited by the flows or level at the abstraction point). These sources comprise approximately 15% of STWL GW sources. Under this assessment, only the sources that were initially screened as vulnerable to level or flow changes would be assessed for climate change;

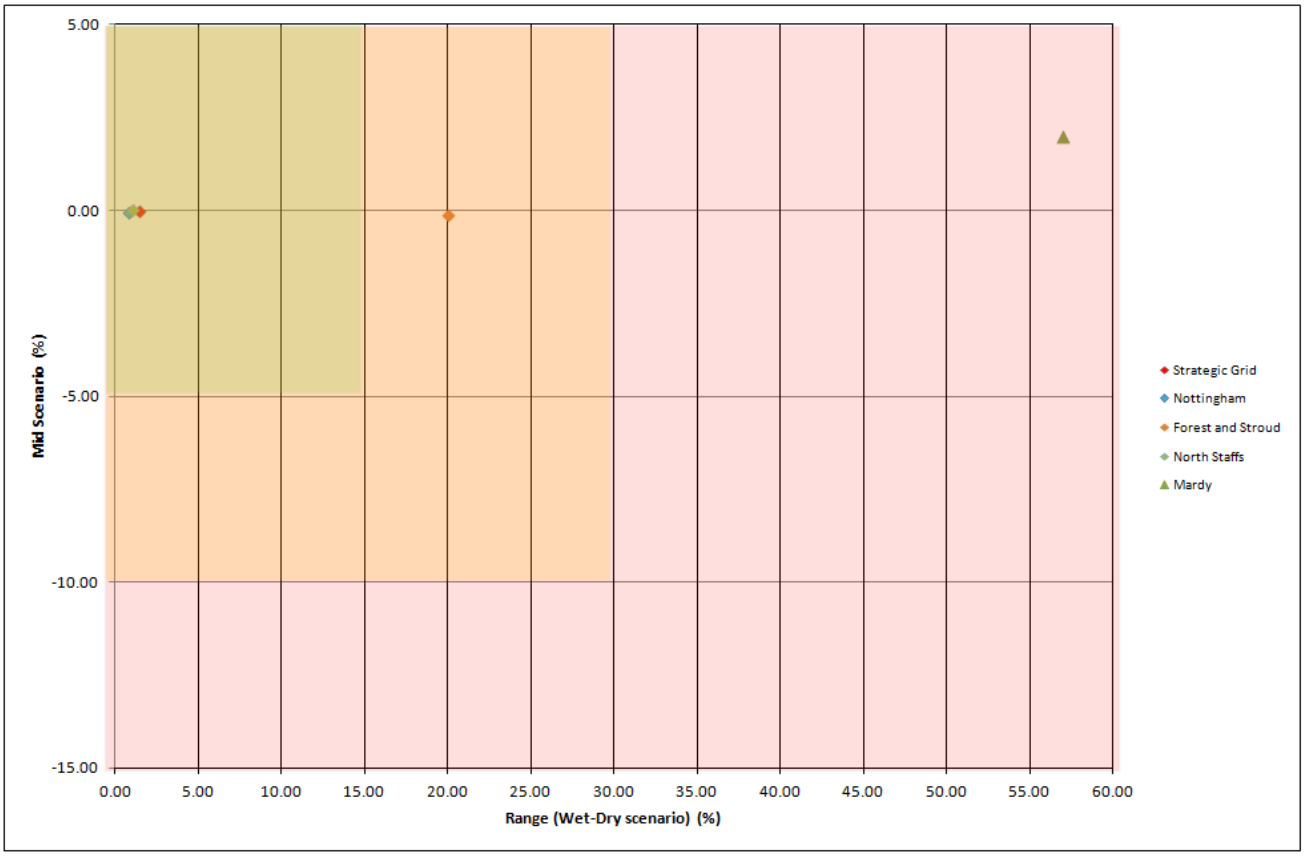
- Option 2: Consider the sources identified as flow or level constrained and those in the areas of the West Midlands, Bromsgrove and East Midlands and Yorkshire Sandstone groundwater model, that comprise a number of licence constrained sources. This approach is consistent with the approach adopted for WRMP09. Under this assessment the sources that were initially screened as vulnerable to level or flow changes would be assessed. Also, under this assessment the regional groundwater models would be utilised to predict recharge changes to the groundwater units under the various climate change scenarios. This assessment would proportionally reduce the deployable output of any licence constrained sources in the modelled units by the predicted recharge changes to the unit;

- Option 3: All groundwater sources, including infrastructure and licence constrained sources. Under this assessment the sources that were initially screened as vulnerable to level or flow changes would be assessed. The sources that were licence constrained and fell within the regional groundwater models would be assessed (as Option 2) and sources that were licence constrained and fell outside of the groundwater models would be assessed by applying a STWL wide change to recharge and proportionally reducing the deployable output by the predicted recharge (and licence) derived changes to the unit;

We were able to use outputs of the 2008 assessment and modelling work to undertake the initial groundwater vulnerability assessment. The 2008 work showed limited impact on level and constrained sources, whereas sources in the groundwater modelled area were predicted to have more variation; groundwater recharge in the modelled areas was approximately 32% and 61% higher in wet scenario (West Mids and Notts Doncaster groundwater models), mid recharge similar to baseline (1% and 17%) and 28 and 26% lower in the dry scenario. For our assessment, we selected groundwater sources based on Option 1. This approach was discussed and agreed with the Environment Agency.

The magnitude versus sensitivity was considered under Option 1, on a water resource Zone level, for groundwater sources, as shown in Figure A3.10.

Figure A3.10: Magnitude versus Sensitivity plot for our groundwater sources at water resource zone level showing the climate change mid scenarios percentage change in deployable output (from the baseline) and the uncertainty range



With the exception of groundwater sources in the Mardy and Forest and Stroud WRZs, the majority of groundwater sources were considered to be low vulnerability. However, in order to maintain spatial coherency with the surface water climate change assessment (especially for zones containing both surface water and groundwater sources), it was decided to assess the groundwater sources in the “high” vulnerability conjunctive use zones as also having high vulnerability. This approach was discussed and agreed with the Environment Agency through a series of workshops and meetings in 2012.

Vulnerability assessment: Water Resource Zone Vulnerability Classification

The vulnerability assessment for our conjunctive use and groundwater only zones followed the methodology described in the EA’s WRPG (2012). For each zone we have produced a table containing the information required, as per Table 3.0 of the WRPG, which we have shared with the EA. Table A.3.11 shows the vulnerability classification for each water resource zone.

Table A3.11: Water Resource Zone vulnerability classification

WRZ	Water Scarcity Indicator	Supply Demand Balance (based on dWRMP)	Vulnerability
Bishops Castle	All of the licences we hold for sources in this zone are in CAMS areas classified as being No Water Available	In surplus	Low
Forest & Stroud	74% of the licences we hold for sources feeding this zone are in CAMS areas classified as being Over Abstracted or Over Licensed	In deficit initially, but will have a small surplus through the later years of the planning period	Low/Medium
Kinsall	All of the licences we hold for sources feeding this zone are in CAMS areas classified as being Over Licensed	In surplus	Low
Llandinam & Llanwrin	All of the licences we hold for sources in this zone are in CAMS areas classified as being No Water Available	In surplus	Low
Mardy	All of the licences we hold for sources feeding this zone are in CAMS areas classified as being Over Licensed	In surplus	Low
Newark	All of the licences we hold for sources feeding this zone are in CAMS areas classified as being Water Available	In surplus	Low
North Staffordshire	50% of the licences we hold for sources feeding this zone are in CAMS areas classified as being Over Abstracted or Over Licensed.	In surplus (assuming sustainability reductions do not increase)	Low
Nottinghamshire	59% of the licences we hold for sources feeding this zone are in CAMS areas classified as being Over Abstracted or Over Licensed.	In surplus initially, then in deficit until the end of the planning period	High
Rutland		Bulk Supply agreement for a fixed volume.	Low
Ruyton	All of the licences we hold for sources feeding this zone are in CAMS areas classified as being Over Licensed	In surplus	Low
Shelton	66% of the licences we hold for sources feeding this zone are in CAMS areas classified as being Over Abstracted or Over Licensed.	Risk to supply demand balance is driven by sustainability changes	Low
Stafford	56% of the licences we hold for sources feeding this zone are in CAMS areas classified as being Over Abstracted or Over Licensed.	In surplus	Low
Strategic Grid	41% of the licences we hold for sources feeding this zone are in CAMS areas classified as being Over Abstracted or Over Licensed.	This zone will go into deficit. Key risks to this zone are sustainability changes and climate change	High
Whitchurch & Wem	All of the licences we hold for sources feeding this zone are in CAMS areas classified as being Over Licensed	In surplus	Low
Wolverhampton	All of the licences we hold for sources feeding this zone are in CAMS areas classified as being Over Abstracted	In surplus	Low

A3.2.1 Discussions with the Environment Agency

We have kept the EA involved and fully informed throughout each stage of our climate change assessment. We did this in a number of ways throughout 2012, including:

- Once we had completed our vulnerability assessment we held a “start up” meeting with the EA to agree which methodology we would be following before embarking on the full assessment.
- We arranged a technical session, focusing on the detail of the approach we followed and decisions made at each step. We used this session to agree appropriate next steps, including the groundwater approach as discussed in previous section).
- We produced briefing notes and presentations to keep the EA fully appraised of our progress
- We shared the deployable output modelling results as soon as the full assessment was complete.

Alongside this, we have also briefed Ofwat and Natural England on our approach and modelling results.

The response we have received following these communications has generally been positive.

A3.2.2 Choice of Climate Change scenarios

Whilst our groundwater sources are less vulnerable than surface water, the interconnectivity of our system (now and in the future) means that using different methods for the different zones was not appropriate. Using the same approach for zones supplied by groundwater only enables us to compare the climate change impacts between zones and to assess future options for improving the interconnectivity of our supply network. The “high” vulnerability, B2.2 method has therefore also been applied to all groundwater only zones for consistency.

As previously discussed, for consistency and to ensure spatial coherence we opted to carry out the more rigorous “high” vulnerability methodology for all of our water resource zones. This gave us a choice of four methodologies (as shown in Figure A3.6), two of which use the UKCP09 data directly and two which use the outputs of the Environment Agency’s Future Flows and Groundwater Levels project (known as ‘Future Flows’). We therefore had to give careful consideration as to which of these methods to use. Figure 3.7 shows an overview of the methodology we have followed to assess the impact of climate change on our groundwater and surface water sources.

The Future Flows project outputs were published in April 2012 and use the 11 member Regional Climate Models (RCM), one of the products of UKCP09. Each of the 11 RCMs represents a plausible, equally likely potential future. The projections from these RCMs have been used to produce transient flow series and transient climate series (rainfall and PET) which cover 1951 to 2098. These transient flow series have been generated using a hydrological model called CERF. The two alternative methods utilise the 10,000 UKCP09 projections by sub-sampling to a smaller sample size – 100 if Latin Hypercube Sampling is used, or 20 if a Drought Indicator is used.

Both types of method, Future Flows and UKCP09, offer a number of benefits as well as drawbacks. The Future Flows outputs enable companies to consider droughts of differing durations, recurrence and intensities not previously experienced within the historic record used in our baseline deployable output modelling. The UKCP09 methods perturb the historic record, making existing events more severe or less severe depending on the climate change scenario, but do not change their frequency or recurrence. Although Future Flows represents 11 plausible and equally likely potential futures, it does not capture the full range of uncertainty and potential futures captured in the 10,000 UKCP09 projections. Sub-sampling the 10,000 UKCP09 projections does capture the range of potential futures.

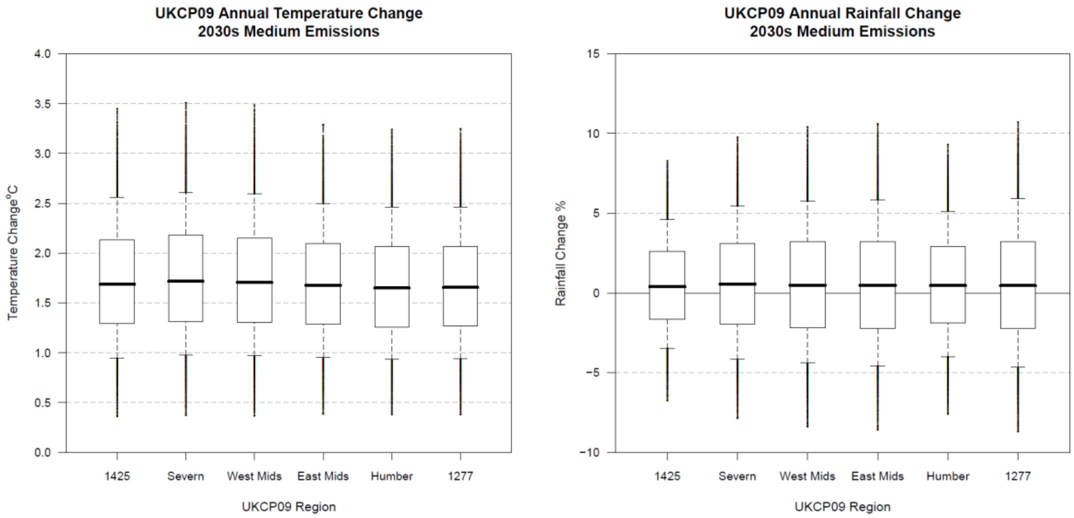
The Future Flows approach presents further difficulties specific to our water resources modelling methodology. Reconciling the transient flow series from Future Flows with our existing baseline flow series is problematic as Future Flows and our baseline flow series are derived using different hydrological models (CERF as opposed to HYSIM which is used in our baseline modelling). Future Flows is more suitable for companies who do not have their own hydrological models. The project directly covered 282 river catchments and 24 boreholes. Of these, 15 river catchments and 2 boreholes are located within our region. For catchments not included in the Future Flows project, the outputs must be transposed which can start to introduce some uncertainties in terms of compatibility of data.

Taking all this into consideration, we have used the UKCP09 projections method. The method adopted is summarised below:

Step1: Selecting the climate change projections

The UKCP09 projections are available at different resolutions – at River Basin level, Administration District level and individual 25km grid square level. As the Severn Trent region does not fall completely within the River Basin and Administration Districts used in UKCP09, the first stage of our analysis was to decide which projection set to use. An analysis of the different projection sets available for our region showed that the UKCP09 climate projections from different aggregate areas across our region all provide similar climate change impacts. The box plots in the charts in Figure A3.11 show the range of variation between aggregate areas for projected change in annual temperature and rainfall. The box plots summarise the median (thick black line), 25th/75th percentiles (box), 10th/90th percentiles (whisker tails) and the remaining values (outlying points).

Figure A3.11: Comparison of UKCP09 projections for annual temperature change (left plot) and annual rainfall change (right plot)



As previously discussed, the River Severn is an important source of supply for the Strategic Grid, Shelton and Wolverhampton water resource zones. The Severn River Basin area covers the headwaters and a large stretch of the River Severn and is also close in proximity to the headwaters of the River Trent. It was therefore deemed to be a valid approach to apply the Severn River Basin projection set across the whole of our region, ensuring consistency in the modelling approach. The UKCP09 Severn River Basin Medium Emissions projections for the 2030s were used for our assessment, with a sub-set of 100 projections being selected using Latin Hypercube Sampling (LHS) for use in the hydrological modelling.

Step2: Grouping of catchments

In our Aquator water resource model we use 91 years of daily inflow data for 65 catchment points across the Severn, Trent and Wye catchments. This inflow data series is derived using 79 hydrological models (HYSIM), with the outputs of these HYSIM models being grouped together and adjusted for artificial influences, such as spray irrigation and sewage effluent discharges, to allow them to be used in our Aquator model. Modelling all 79 HYSIM catchments 20 or 100 times using the climate change impacted UKCP09 rainfall and PET data would have been a major modelling task. Our Aquator model is a complex, representation of our resource and supply system. We considered simplifying this model to enable faster modelling of large numbers of climate change runs. However due to the inter-connected nature of both our supply system, and also the river network within our region, we concluded that any simplification of this kind would reduce the accuracy of our modelling to an unacceptable level.

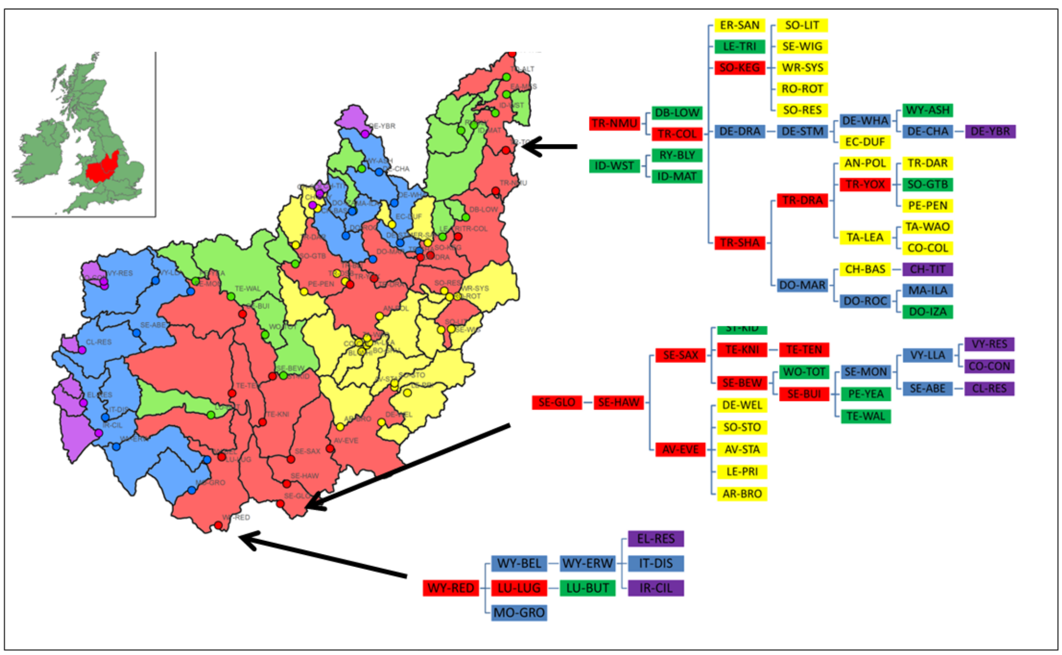
Therefore we have adopted a more streamlined approach to the climate change modelling. Many of the catchments in our region are physically very similar. An analysis of several different catchment attributes, including topography, Base Flow Index and SAAR (Standard Annual Average Rainfall) allowed us to classify all the HYSIM modelled catchments into five groups with similar hydrological characteristics and responses to climate. The catchment descriptions are shown in Table A3.12.

Table A3.12: Overview of the catchment groupings derived from hydrological analysis

Group	Minimum Area (Km²)	Maximum Area (Km²)	Minimum SAAR (mm)	Maximum SAAR (mm)	Minimum Base Flow Index	Maximum Base Flow Index	Number of models	Description
1	148	2027	936	1386	0.43	0.58	14	Larger intermediary catchments with generally higher rainfall
2	63	869	641	1165	0.59	0.79	13	Catchments with a high Base Flow Index reflecting a larger dominance of base flow
3	46	795	628	976	0.28	0.55	23	Smaller low lying catchments with lower rainfall
4	885	10443	654	1009	0.40	0.61	17	Large downstream, lowland catchments representing the main river reaches
5	10	246	926	1971	0.33	0.45	9	Small typically upland catchments with high rainfall and a flashy catchment response

Figure A3.12 shows the distribution of the HYSIM hydrological models in the Severn Trent Region. The catchment types are indicated by the colouring as shown in Table A3.12.

Figure A3.12: Distribution of HYSIM hydrological models in the Severn, Trent and Wye basins



From these catchment groups, five representative “exemplar” HYSIM catchments models were chosen (one for each catchment group) based on the following criteria:

- Calibration method for the baseline flow series – for the exemplar HYSIM catchment models it was preferable to use models which had been calibrated against naturalised flow data

- Number of nested upstream models – for the exemplar HYSIM catchment models this was zero as models nested downstream of another HYSIM model incorporate the hydrological response of both the upstream catchment(s) and the nested catchment, which could mask the hydrological response of the nested catchment

- Proportional size of artificial influences – for the exemplar HYSIM catchment the proportion of artificial influences should be as small as possible so that only the impacts on the natural catchment flow are seen in the climate change modelling. Where artificial influences were included in the baseline flow series, the artificial influences were removed from the models for the climate change analysis and were added on again before being used in the Aquator modelling

- Additional information collected during the derivation of the baseline flow series regarding the confidence in the model itself.

The five exemplar catchments are:

- Ithon at Disserth
- Wye at Ashford
- Wreak at Syston Mill
- Teme at Tenbury
- Elan Reservoirs

Step 3: Hydrological modelling

The five catchments were modelled in HYSIM using the 100 UKCP09 projections which had been selected from the 10,000 UKCP09 sample set in stage 1 of our approach. This HYSIM modelling generated 100 sets of climate change perturbed flow series for each of the five catchments. These flow series were then used to derive monthly flow factors for each catchment for each climate scenario. This enabled us to estimate the impacts of climate change on natural flows.

Step 4: Deriving a suitable Drought Indicator

In order to reduce the number of projections in the assessment from the 100 which were sampled using Latin Hypercube Sampling, a drought indicator is used to produce a targeted sample of 20 climate projections. The drought indicator analysis aims to identify the climatic drivers for historic droughts in our region and sub-samples the extracted 100 UKCP09 scenarios using this data.

An analysis of modelled historic reservoir data, including the drawdown and minima trends was carried out for four of our key impounding reservoirs – Tittesworth, Derwent Valley, Elan Valley and Clywedog. These reservoirs are all filled naturally by runoff and other inflows so are a good indicator of the impacts of climate variability. The drought indicator methodology aims to create a linear regression model between the reservoir annual minima and different combinations of the climatological variables. A regression model was created for each of these reservoirs, with the historic modelled data and historic rainfall and Potential Evapotranspiration (PET) data being fed in to create an Aridity Index for each reservoir.

For Clywedog reservoir the relationship between aridity and reservoir minima is less well defined. This is due to the nature of the way this reservoir is operated to help maintain flows in the River Severn as opposed to being used directly in the water supply system like the Tittesworth, Elan Valley and Derwent Valley reservoirs. As a result of the different operation of Clywedog reservoir, storage does not display a particularly strong relationship to climate in years when storage remains relatively high. The analysis showed that our reservoirs are sensitive to both annual aridity and shorter term April to August/September aridity. At Elan Valley, Derwent Valley and Tittesworth the shorter term April to August/September aridity provided the best relationship. At Clywedog the annual aridity provided the best relationship. This aridity assessment produced four drought indicators – one for each reservoir.

We also analysed the flow characteristics of the 5 exemplar HYSIM flow series identified in step 2, looking at mean annual flow change, mean April to September flow change and mean June to August flow change to develop potential flow indicators of drought.

As a result of the above, we were presented with seven potential drought indicators. These were:

- Aridity Index – Tittesworth reservoir
- Aridity Index – Elan Valley reservoirs
- Aridity Index – Derwent Valley reservoirs
- Aridity Index – Clywedog reservoir
- Mean annual flow change
- Mean April to September flow change
- Mean June to August flow change

To enable us to choose which drought or flow indicator was most applicable for our system, the 100 UKCP09 projections selected using the Latin Hypercube Sampling were applied to the data sets used to generate the drought and flow indicators (the historic rainfall and PET data for the drought indicators and flow series for the flow indicators). The 100 sets of climate perturbed data was then reanalysed and ranked from lowest to highest.

A comparison showed there was relatively good correlation between the Drought Indicators and Flow Indicators. However, in several instances, the Drought Indicator projections ranked higher than the Flow Indicator projections ranked. The Drought Indicator is based on statistical regression, which introduces greater variability. The Flow Indicator is based on hydrological modelling, which is more robust. We have therefore used the mean April to September flow change as our “Drought Indicator” as this is based on the more robust hydrological modelling and uses the information on the climate sensitive period gathered from the Aridity Index analysis.

The flow factors from step 3 were reviewed and the Drought Indicator was used to identify a split sample of 20 scenarios for use in our water resources impact modelling. The split sample provides 20 scenarios covering the full range of expected climate change impacts, but with 10 of these scenarios focussing on the drier end of the range.

Step 5: Flow naturalisation of baseline Aquator inflow series

As previously discussed, our Aquator inflow series is derived using the outputs of 79 HYSIM catchment models, which are grouped together to form the 65 catchments used in our Aquator model and adjusted for any in-catchment artificial influences, such as agricultural abstractions. In creating the climate change impacted inflow series, the artificial influences were removed from each catchment before the climate change factors generated in step 3 were applied to the HYSIM flows. This ensured that only the natural flows were being impacted by the impacts of climate change.

Step 6: Application of climate change flow factors to naturalised baseline inflow series

Using the Drought Indicator derived in step 4, the 100 UKCP09 projections were sub-sampled down to a targeted set of 20 projections. The climate change factors generated in step 3 for the sub-sample were applied to the naturalised flow series, using the catchment groupings to decide which factors were used for which catchment. This created 20 climate change impact naturalised flow series for us to use in our Aquator modelling.

Step 7: Denaturalisation of climate change impacted Aquator inflow series

Once the relevant flow factors had been applied to the naturalised inflow series, the artificial influences were put back in to the flow series and the HYSIM flows were combined into the Aquator catchments so that they could then be used in our Aquator model.

Step 8: Groundwater assessment

A groundwater assessment was completed using the 20 scenarios identified in step 4; this produced estimates of changes in GWL and DO for physical and flow constrained sources as explained in section A3.2.4. Licence constrained sources were assumed to be unchanged.

Step 9: Input of climate change data sets into Aquator

To enable us to model the combined impact of climate change on our inflow series and our groundwater sources in our conjunctive use water resource zones, we created a sequence set (to incorporate the climate change impacted inflow series) and a parameter set (to incorporate the climate change impacted groundwater sources) for each of our 20 climate change scenarios in our Aquator model, using the UKCP09 sample ID as the identifier.

We imported the climate change impacted flow series into our Aquator model, assigning them to the relevant catchment and the climate impacted constraint data for the affected groundwater components. For each climate change run we used the sequence set and parameter set with the same UKCP09 sample ID to ensure consistency between the datasets used. To ensure consistency with the baseline modelling, the climate change impacts were applied to the Aquator model which was used to derive our baseline DO. The same period of record was used in both our baseline and climate change assessments (1920 to 2010).

A3.2.3 Impact of Climate Change on our surface water sources

As discussed above, step 3 of our assessment involved producing flow factors for our five catchment groupings. For each of our five exemplar HYSIM catchments, the HYSIM model was run 100 times using the 100 Latin Hypercube Sampled UKCP09 climate projection data. The flow outputs for each HYSIM model were then used to create sets of flow factors, showing the percentage change from the baseline flow series for each month of the year. The 100 future projections were then "smart sampled" using the Drought Indicator to reduce the sample set to 20 representations of future climate.

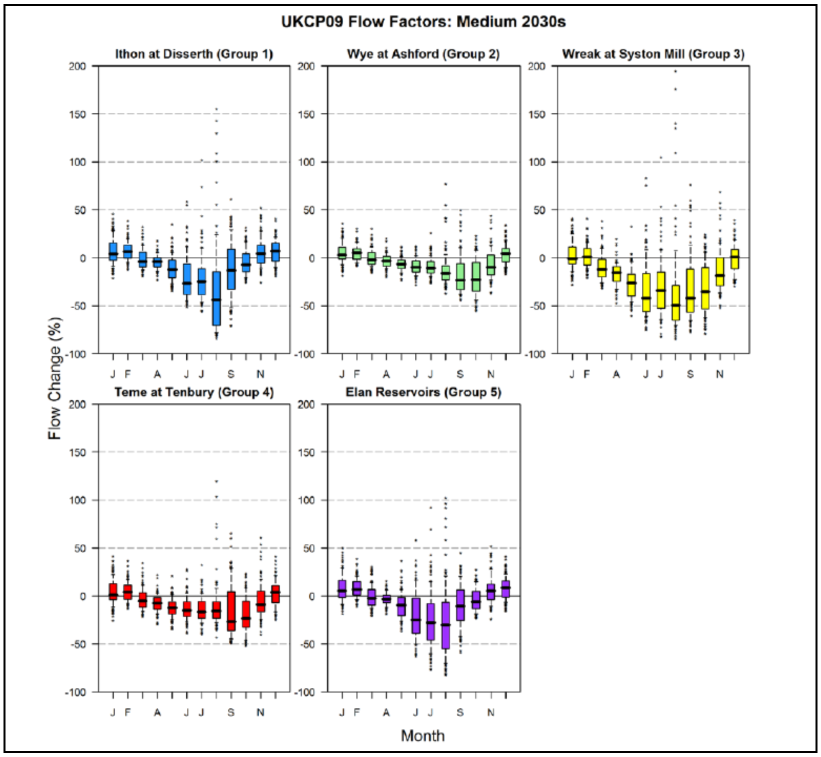
Under all 20 of our smart sampled climate change projections, significant changes in monthly rainfall and temperature are seen to occur, both positive and negative. These changes in climate will have a knock on effect to the flows in the water courses in our region. The annual average change in flows for our five catchment groupings is shown in Table A3.13 below. Monthly variations within these annual averages range from an increase in flows in some catchments of 58% (compared to the current baseline flows), to a decrease in flows of 85%.

Table A3.13: Annual average change in flows as a percentage change from current baseline flows

Rank	UKCP09 ID	Annual Change in flows (%)				
		Catchment Group 1	Catchment Group 2	Catchment Group 3	Catchment Group 4	Catchment Group 5
1	8632	-25	-24	-50	-28	-22
2	9855	-22	-19	-44	-21	-21
3	3111	-21	-20	-46	-22	-21
4	6108	-16	-13	-34	-16	-12
5	1090	-6	-18	-43	-22	-18
6	2203	-20	-17	-38	-19	-18
7	1345	-22	-23	-46	-30	-16
8	8282	-14	-10	-34	-12	-12
9	6461	-15	-10	-31	-11	-13
10	684	-19	-20	-41	-24	-15
15	2726	-14	-13	-34	-17	-11
20	9701	-15	-12	-32	-12	-14
30	3521	-8	-4	-25	-6	-7
40	281	-11	-12	-32	-13	-9
50	3903	-10	-12	-25	-17	-6
60	2745	-3	0	-16	0	-1
70	3306	-8	-12	-22	-18	-4
80	9623	0	1	-5	2	1
90	1467	14	19	18	25	11
95	8764	6	5	7	5	7

Figure A3.13 shows the range of flow changes for the five catchment groupings for the 100 HYSIM runs which were carried out using the 100 UKCP09 climate projections. The boxes show the quartile range and median with the whiskers extended to the 10th and 90th percentile.

Figure A3.13: Range of flow changes for the five catchment groupings



Across all of the catchment groupings there is a general seasonal cycle of summer decreases and small winter increases which reflects the overall pattern of rainfall changes from UKCP09. However, there are a number of different responses to the changing climate between the five catchment groupings which are important to note:

- Catchment groupings 1 and 5 represent higher rainfall regions, catchment 1 being large intermediary catchments with higher rainfall and catchment 5 being small, typically upland catchments with high rainfall and a flashy catchment response. Both of these groups show a similar response to climate change, with very large reductions in flows during the summer months (up to 83% in August under some scenarios) and larger increases in flows in the winter (approximately a 30% increase in December flows under some scenarios).

- Catchment grouping 3 represents small catchments in lower rainfall areas. The flow factors show more prolonged decreases across the summer months and fewer increases in flows during the winter months.

- Catchment grouping 2 which represents catchments with a higher Base Flow Index, have a much smaller range of flow changes compared with the other groupings. The largest flow reductions occur in September and October, which is later in the year compared to the other groupings.

- Group 4 represents the largest downstream catchments. The flow factors for this grouping have more prolonged summer decreases but are smaller in magnitude and than those seen in group 3. The maximum flow decreases occur later in the year, in September and October, reflecting the delayed response due to the larger catchment area.

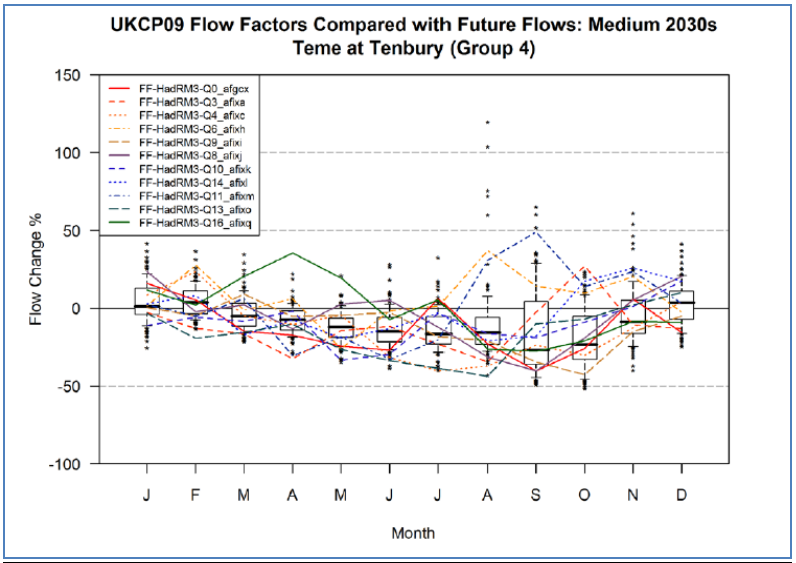
Comparison with Future Flows and the UKWIR Rapid Assessment

Within our region only one catchment, Teme at Tenbury, has been included in the different assessments carried out as part of the Future Flows project (Haxton et al, 2012) and the previous industry standard UKWIR Rapid Assessment (UKWIR, 2009). The flow factors produced using our methodology outlined above have therefore been compared as this is the only catchment where comparable data is available.

As part of the Future Flows project, a daily flow series was created for the Teme at Tenbury simulating the effects of climate change under the 11 scenarios discussed in section A3.4, using a medium emissions scenario. We converted the flow series into monthly flow factors for the 2030s time horizon to allow a comparison with the flow factors generated through our own UKCP09 assessment of the 100 samples.

The Future Flows flow factors cover a similar range to the 100 LHS UKCP09 flow factors displaying a similar seasonal cycle, with decreases in maximum flow in late summer into autumn. The overall range of changes is similar, and although some variation exists there is good corroboration between the two sets of data. It is important to note that the sets of flow factors are created using different climate projections and hydrological models. Figure A3.14 shows the comparison between the 100 LHS UKCP09 flow factors, which are marked by the box plots, and the 11 Future Flows derived flow factors, shown by the lines, for the Teme at Tenbury in the 2030s.

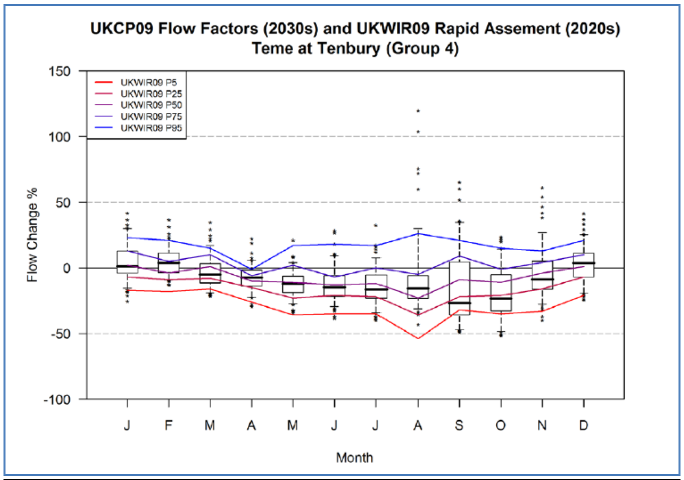
Figure A3.14: Comparison of the 100 LHS UKCP09 flow factors (box plots) and 11 Future Flows derived flow factors (line plot) for the Teme at Tenbury in the 2030s



The UKWIR Rapid Assessment (UKWIR, 2009) aimed to provide a first look at the impacts of the new UKCP09 climate projections for water supply planning. The project modelled 20 UKCP09 projections for 70 catchments, providing a set of percentiles covering the range of each monthly flow change. As discussed above, we carried out some initial modelling using method A1.2, which utilises the outputs of the UKWIR Rapid Assessment to help inform our vulnerability assessment. The rapid assessment provided flow changes for the 2020s, whereas our assessment is based around the 2030s as per the EA's WRPG (2012).

The main difference in flow changes derived by the two different methods is that the flow factors generated by the UKWIR rapid assessment display smaller decreases in flow between August and October compared with the flow factors generated using the LHS UKCP09 data. Between August and October the median LHS UKCP09 flow change is equivalent to the lower quartile of the UKWIR rapid assessment flow changes. This difference is likely to be a result of the larger impact of climate change in the 2030s compared with the 2020s. Figure A3.15 shows the comparison between the 100 LHS UKCP09 flow factors, which are marked by the box plots, and the percentiles generated by the UKWIR Rapid Assessment, for the Teme at Tenbury.

Figure A3.15: Comparison of the 100 LHS UKCP09 flow factors for the 2030s and the percentiles from the UKWIR Rapid Assessment in the 2020s for the Teme at Tenbury



A3.2.4 Impact of Climate Change on our groundwater sources

Approximately 34% of our deployable output is abstracted from groundwater sources. Of our operational groundwater sources, the majority (~88%) abstract from Sherwood Sandstone or sandstone aquifers in the Midlands region, with a small percentage of sources taking water from limestone and river gravels.

The sandstone aquifers have substantive storage; meaning they are generally not sensitive to short term changes in climate. Unlike most chalk or limestone aquifers, the Midlands sandstones generally show only small annual responses in water level due to extreme wet or dry conditions and are generally considered to be resilient to drought conditions. In severe drought it takes several years for water levels to fall in the sandstone aquifers. During the 2008 – early 2012 period, recharge to the Midlands aquifers was significantly depleted by low average rainfall over this period, and some of the lowest ever groundwater levels were recorded across the region. Despite this, at our sources, groundwater level decline during this period was only of the order of <5m. In summary, this means that the impact of climate change is likely to be limited on our sandstone resources in comparison to other aquifer units across the UK.

Possible impacts on our limestone and river gravel sources are likely to be more significant as these aquifers generally have less storage and are potentially more susceptible to changes in climate.

The process for calculating the change in Deployable Output (DO) for groundwater sources due to climate change has been calculated by taking the updated UKCP09 projections and assessing the impacts according the GR2 methodology as originally described in the UKWIR2006 guidance. This involved:

1. assessing the sensitivity of pumped sources to water level changes resulting from any changes in recharge;

2. for all zones, use of representative synthesized hydrographs (calibrated to observed data) at sources to determine the change in recharge to the aquifer under the various UCKP09 projections, and using the GR2 methodology to determine the modelled range of water level change for each site;

3. converting the modelled water level change into a range of DO changes using the Source Performance Diagrams;

4. the assessment of likely changes in summer flows at our spring sources as a result of changes in recharge in these catchments.

In addition to the above work, we had planned to use the EA's groundwater models to assess groundwater response to climate change driven changes to recharge in our region, under Options 2 and 3 of the vulnerability assessment. This analysis could determine the likely scale of any future licence reductions needed to mitigate effects on the environment and to prevent mining of groundwater where sources were currently licence constrained.

We explored this potential approach with the EA and it was confirmed on 10th October 2012 that it would not be appropriate for us to make assumptions about climate change driven abstraction licence changes in the WRMP. As such, the risks around climate change driven potential licence changes is not included in our WRMP. The impacts of climate change on our groundwater sources are therefore limited to those sources vulnerable to short term changes in water levels or flow.

Initial Screening

For our groundwater sources, an initial review of individual groundwater source sensitivity to groundwater level change was conducted as a preliminary screening exercise to the overall vulnerability assessment. This screening assessment utilised the source specific Source Performance Diagrams, as illustrated in Figure A3.16, to determine what the current constraint to abstraction was at the source. This can be broken down into five main constituents:

1. Licence constrained – the source can abstract up to licence

2. Infrastructure constrained – the source is constrained by infrastructure (usually pump capacity, which is set slightly below the licence in order to prevent breach of licence)

3. Level constrained – the source is constrained by a specific level in the borehole below which groundwater levels should not be taken in order to preserve pumping equipment (pump depth), water quality (adits or Deepest Advisable

Pumped Water Level (DAPWL)), aquifer resource (DAPWL), borehole integrity (borehole casing, DAPWL, adits) etc. These are site specific and may vary source to source

4. Flow constrained – the source is constrained by gravity fed flows into the site. This is applicable to spring sources

5. Water Quality constrained – the source may not be able to abstract above a certain rate in order to preserve water quality

This review highlighted the following number of sources falling into each constraint category as shown in table A3.14.

Table A3.14: Number of groundwater sources in each constraint category by WRZ

Water Resource Zone	Licence	Infrastructure	Level	Flow	WQ
Bishops Castle	1	1	0	0	0
Forest & Stroud	3	0	0	3	0
Kinsall	2[1]	0	0	0	0
Llandinam & Llanwrin	1	1	0	0	0
Mardy	0	1	0	0	0
North Staffordshire	18[2]	8	2	0	3
Stafford	0	5	0	0	0
Newark	2[3]	0	0	0	0
Nottinghamshire	13[4]	3	0	0	6
Ruyton	1	0	0	0	0
Shelton	11[5]	6	1	0	3
Strategic Grid	13[6]	18	1	3	11
Whitchurch & Wem	2	0	0	0	0
Wolverhampton	1	2	0	0	1

[1] Two constrained by overarching Group Licence (within Group Licence constrained, at source specific level: one licence and one infrastructure constraint)

[2] Ten constrained by overarching Group Licence (within Group Licence constrained, at source specific level: four licence, four infrastructure and two WQ constraints)

[3] Two constrained by overarching Group Licence (within Group Licence constrained, at source specific level: one licence and one infrastructure constraint)

[4] Nine constrained by overarching Group Licence (within Group Licence constrained, at source specific level: two licence, five infrastructure, one level and one WQ constraints)

[5] Three constrained by overarching Group Licence (within Group Licence constrained, at source specific level: one licence, one infrastructure, one WQ constraint)

[6] Six constrained by overarching Group Licence (within Group Licence constrained, at source specific level: two licence and four infrastructure constraints)

The initial screening assessment utilised the SPDs to determine the operational profile of the source in drought conditions and consider how far this drought curve sat above a source specific groundwater level constraint (i.e. borehole pump depth, DAPWL etc.).

In the example presented in Figure A3.16, the source is constrained by pump capacity at ~15.7Ml/d in both average years (red curve) and drought years (black curve), and when operating at this constraint in drought conditions, there is approximately 12m of groundwater level "headroom" before water levels would start to be constrained by a level constraint (in this instance DAPWL), rather than the pump capacity.

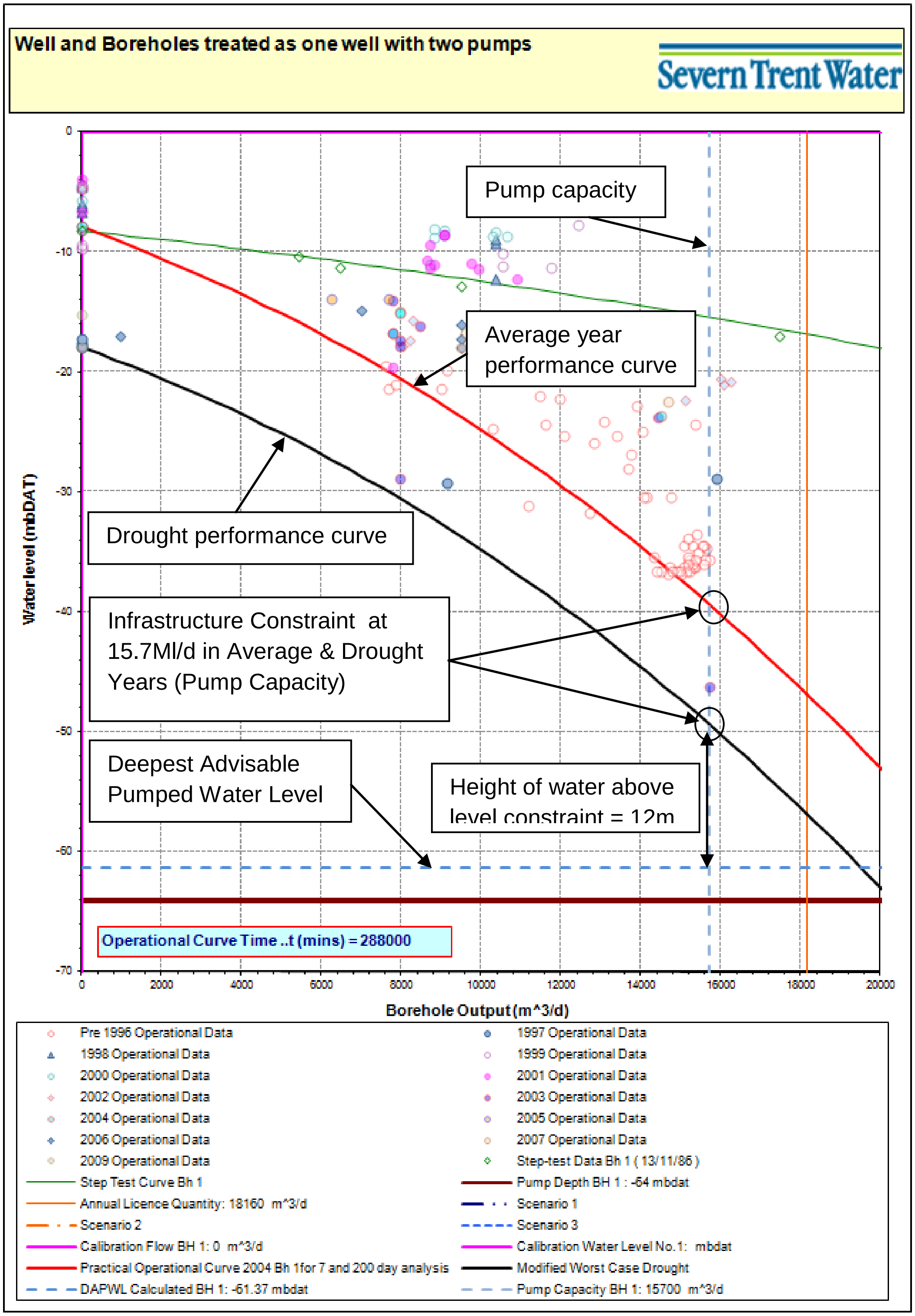
From the initial screening assessment, it was considered that sources that are currently level constrained in drought conditions and sources that are constrained by gravity fed flows (spring sources) should be taken forward for climate change assessment. Twelve sources were initially highlighted and these sources were considered to be vulnerable to climate change (some of these sources were later found to be constrained by Water Quality (WQ) constraints, so are not shown under the Flow column in Table A3.14).

Furthermore, it was considered that sources that had less than 5m of groundwater level "headroom" between the intersect of the drought performance curve and an infrastructure constraint, and a level constraint, should be taken forward for Climate Change assessment as these were considered to be potentially vulnerable to climate change. Twelve sources were initially highlighted.

Sources that had greater than 5m of groundwater level "headroom", or were currently licence or water quality constrained were considered to be at low vulnerability to climate change and were not assessed.

In addition to the initial screening, a series of interviews were conducted with STWL Operational staff which indicated an additional 11 sources which may be potentially sensitive to dry weather conditions. These sources were considered as potentially vulnerable to climate change and were taken forward for climate change assessment; even though assessment of the SPDs suggested that they were likely to have low vulnerability to climate change. The inclusion of these additional assessments is considered to be conservative.

Figure A3.16: Source Performance Diagram and example initial source vulnerability screening. Note there is 12m of water level "headroom" in drought conditions, before the constraint on the source would change from an infrastructure constraint (pump capacity) to a level constraint (DAPWL). In this instance the initial screening is low vulnerability to climate change.



Head Dependent Changes in DO (Pumped Sources)

The majority of our groundwater abstractions are from deep boreholes in the Sherwood Sandstone. As there is significant storage in this aquifer, water level changes due to recharge variation are usually buffered and can take several years or decades to have any significant effect. In addition, due to the depth of many of our boreholes, there would usually be space to lower the pumps in the borehole and maintain the same output if regional water levels dropped significantly.

However, for certain sources, a change in recharge could produce a significant borehole water level change within the planning horizon (i.e. the next 25 years), where:

1. the aquifer has low storage (e.g. fissured limestone) and responds rapidly to recharge;

2. the pumping water level is already close to the base of the borehole;

3. there is some inflow feature particular to that source that would cause a rapid loss of yield if water levels dropped beyond a certain level (e.g. an adit or a fissure zone); or

4. the source is an aquifer of very limited vertical or horizontal extent with limited capacity to buffer recharge variation

The screening exercise identified approximately 27 sources that might fall into one or more of the above categories. These were then considered in detail using the UKWIR06 methodology to predict the likely change in water level and thus DO for each of the UKCP09 scenarios. Of the 27 sources, only eight were determined to have climate change impacts after detailed assessment. These are shown in Table A3.15 below.

Table A3.15: Head dependant groundwater source impact

WRZ	Source	Range of Changes in DO (Ml/d) using 20 smart sampled UKCP09 scenarios	
		Min	Max
North Staffordshire	Draycott Cross	-0.9	1.0
	Mossgate	-0.1	0.2
Nottinghamshire	Clipstone Forest	-1.0	1.0
Shelton	Much Wenlock	-0.7	1.0
Strategic Grid	Lillington	-0.5	0.8
	Meriden Shafts	-0.61	0.67
	Campion Well[1]	1.6	3.0
	Ladyflatte[1]	2.0	3.7

[1] For the Campion well and Ladyflatte sources, the estimates were made on the basis of changes in annual recharge. This is because of the nature of the sources it is not appropriate to apply a conventional GR2 assessment.

The results indicate that none of our groundwater only zones are predicted to have head (level) dependant deployable output impacts resulting from the modelled climate change scenarios. The predicted impacts on groundwater sources in conjunctive use zones, as presented above, were then input into our Aquator model.

Head-Dependent Changes in DO (Gravity-Fed Sources)

We have ten abstraction sources fed by springs or drainage tunnels. As these are gravity-fed and in fracture-flow aquifers, they are likely be more sensitive to groundwater level changes than our other sources. The effects on the Homesford source have been considered as part of the surface water climate change assessment.

Changes to flows in these sources were predicted using the UKWIR06 methodology. This applies the selected climate change projections to actual or synthesized flows from the sources, and the outputs are reported for the average yearly minima and the drought year minima (based on lowest observed year recharge data). Any special conditions at those sites that constrain reported DO (eg. minimum observed flow, licence condition or infrastructure constraint), are noted. Of the ten gravity fed spring sources, six were determined to have climate change impacts after detailed assessment. These are shown in Table A3.16, below.

Table A3.16: Head dependant gravity-fed spring source impact

WRZ	Source	Range of Changes in DO (Ml/d) using 20 smart sampled UKCP09 scenarios	
		Min	Max
Forest & Stroud	Bigwell	- 0.1	0.22
	Chalford	-1.3	1.2
	Lydbrook	-0.18	0.36
Strategic Grid	Coombe	-0.1	0.08
	Millend	-0.18	0.12
	Homesford[1]	Perturbed flow series provided for assessment within Aquator	

[1] Assessed as part of the surface water climate change assessment

Gravity fed springs sources at Pinnock and Postlip were assessed as not impacted by climate change (WQ constraints), and Charlton Abbots spring was assessed as not impacted by climate change (disused).

The results indicate that none of our groundwater only zones are predicted to have head (gravity fed) dependant deployable output impacts resulting from the modelled climate change scenarios. The predicted impacts on spring sources in conjunctive use zones, as presented above, were then input into our Aquator model.

A3.2.5 Modelling the impact of Climate Change on Deployable Output

As previously discussed, we have modelled the impact of climate change on our surface water and groundwater sources in our Aquator model. By adopting method B2.2 we were able to reduce the 100 UKCP09 projections selected using Latin Hypercube Sampling for method B2.1, based on a flow indicator to a targeted sample of 20. This targeted sample included 10 projections towards the “dry” end of the projection range and 10 projections which were equally spaced across the remaining range.

Each of the targeted samples was given a “weighting” to estimate the probability of this projection occurring. The weight describes the relative probability of each projection in the sub-sample of 20 with respect to the original 100. Including 10 samples towards the “dry” end of the projection range means we could be including some “outliers” in our assessment, i.e. extreme changes in climate which have a low probability of occurring. By applying the weighting we were able to assign a low probability to these outcomes, but are still able to consider the full range of potential impacts in our overall assessment.

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. Nor is there any best practice guidance on how to appropriately deal with the wide range of uncertainties presented by the multiple scenarios. We have therefore tested the impacts of adopting different "central estimates" of future climate change impacted supplies, along with different approaches to capturing the range of uncertainty around this estimate.

One option is to derive a "weighted average" impact on deployable output from the full range of scenarios. This uses a statistical calculation taking into account the weightings assigned to each scenario and the change the scenario causes to deployable output. Alternatively we could choose to use the outputs of a particular high-weighted scenario, such as the rank 50 which is also the median of the 100 Latin Hypercube Sample.

There are mathematical reasons for adopting a weighted average approach, because it includes the full range of scenarios, including all drier scenarios and any potential "outliers". However, by applying a weighted average approach we would be unable to relate the implications back to any one UKCP09 climate change scenario or modelled hydrological dataset. Instead, by averaging the implications of a number of very different UKCP09 scenarios across the hydrological data, it will produce a scenario that is not actually generated by UKCP09, meaning we would not be able attach a weighting or probability to this artificial scenario. Therefore to maintain transparency in our impact assessments, we prefer to base our modelling on the outputs from the specific UKCP09 climate change scenarios, each of which have probability weightings attached to them.

Our preference is to use the values from the median model output (rank 50) scenario from the Latin Hypercube Sample as our central estimate of climate change impacts. We believe this better represents a physically plausible hydrological scenario and is more representative of what could happen to our region. We have then assessed the range of uncertainty around this central estimate, for use in our headroom model.

The full range of the impact of the climate change scenarios on our deployable output are shown in Figure A3.17 to Figure A3.21. As our vulnerability assessment indicated, the greatest impacts of climate change are seen in the Strategic Grid and Nottinghamshire water resource zones.

Both the Strategic Grid and Nottinghamshire zones are most affected by the impacts the changing climate will have on our surface water sources – the Strategic Grid is affected directly by reduced river flows and reservoir refill, which in turn reduces the availability of water in the Strategic Grid zone to export to the Nottinghamshire zone. Our source assessment has shown that few of our groundwater sources are vulnerable to potential future changes in climate and where groundwater sources are vulnerable the resultant change in source yield is likely to be relatively small. The groundwater sources in the Nottinghamshire zone are largely resilient to climate change.

Following the publication of our draft WRMP we made some improvements to our groundwater source assessments, which we then incorporated into our baseline deployable output scenario. This resulted in a minor change to the baseline deployable output for the Strategic Grid and the North Staffordshire zones. To test whether these changes altered our other scenarios, we re-ran the 10th, 50th and 90th ranked climate change scenarios. The changes resulted in a minor improvement in the 50th and 90th rank scenario for the Strategic Grid zone (less than a 1% change in each case), but no change to the dry scenario. In the North Staffordshire zone the deployable output is constrained by the same point under the baseline and the three climate change scenarios.

For the Forest and Stroud zone we have made some changes to our assumptions around the operation of the Mitcheldean to South Gloucester link which we feel better reflects the actual network. Our climate change assessment now shows a 1Ml/d reduction in DO in the Forest and Stroud zone under our 50th rank scenario compared to the slight increase in DO which was seen in our draft plan modelling. Under the 90th rank scenario the zone sees a 2Ml/d increase from the baseline in our most recent modelling. We believe that this is a more realistic representation of how the zone would respond to climate change.

These changes are all reflected in our target headroom assessment.

A detailed description of how we have tested and used the range of uncertainty around climate change can be found in Appendix C2.

Figure A3.17: Strategic Grid zonal impacts of climate change using the 20 smart sampled UKCP09 scenarios

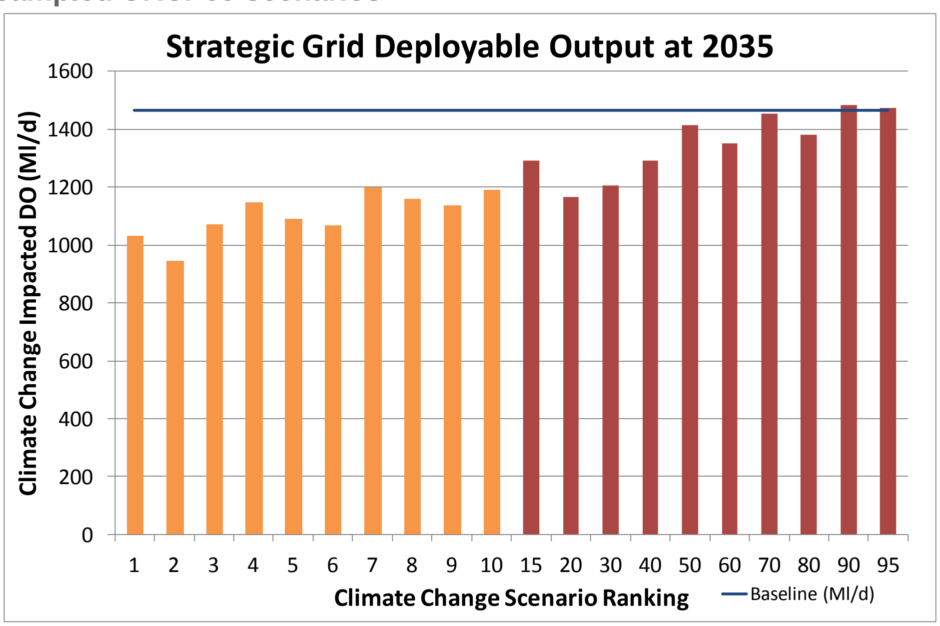


Figure A3.18: Nottinghamshire zonal impacts of climate change using the 20 smart sampled UKCP09 scenarios

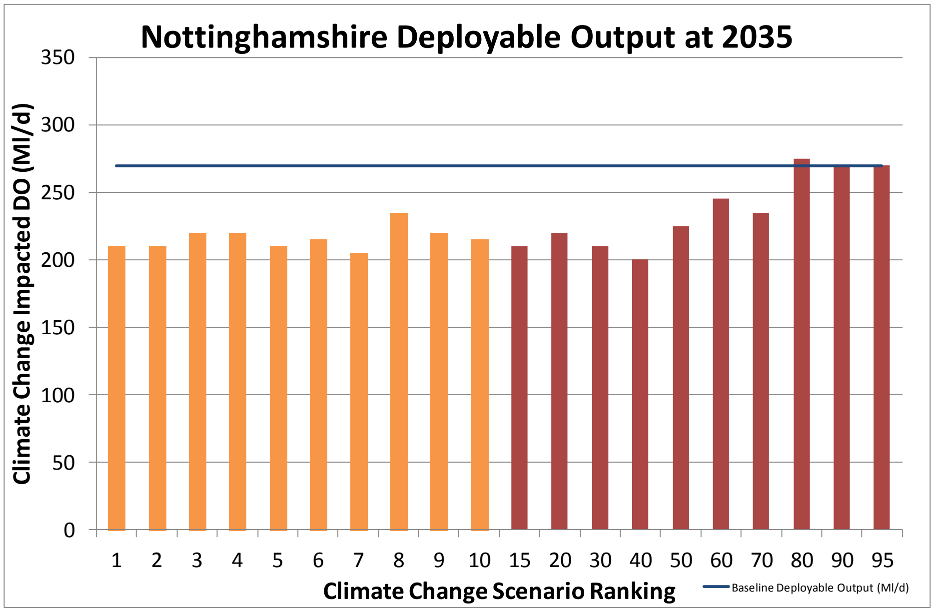


Figure A3.19: North Staffordshire zonal impacts of climate change using the 20 smart sampled UKCP09 scenarios

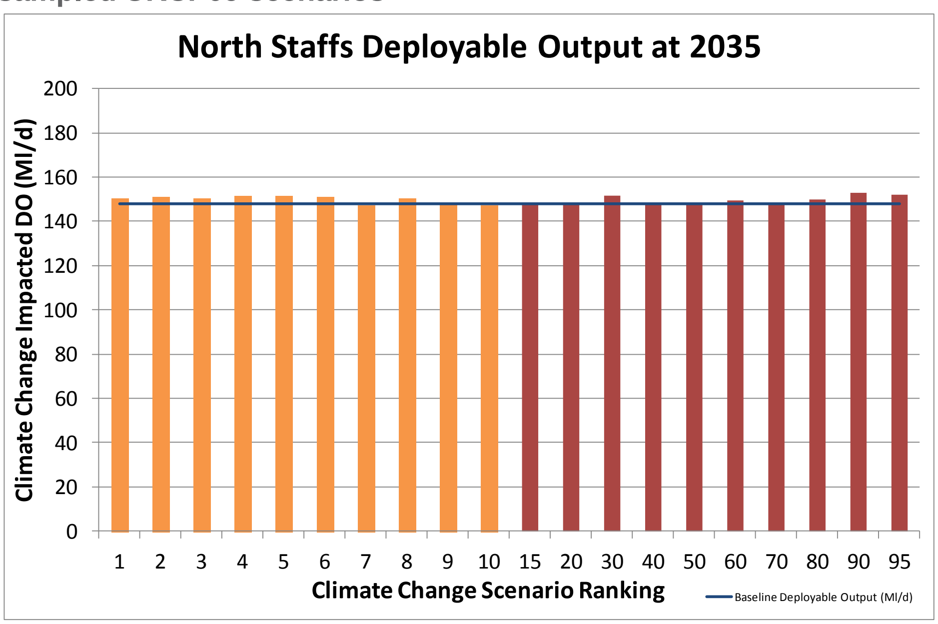


Figure A3.20: Forest and Stroud zonal impacts of climate change using the 20 smart sampled UKCP09 scenarios

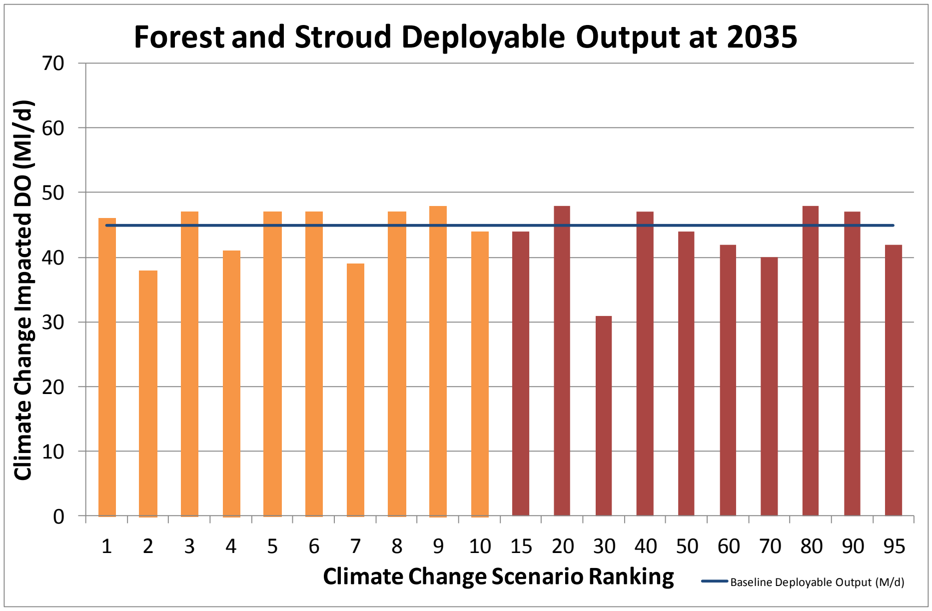
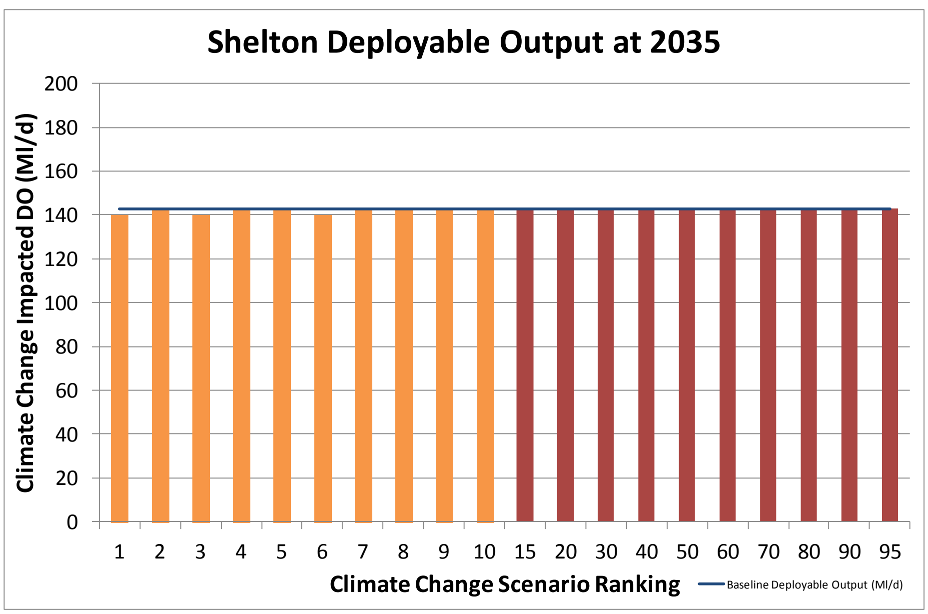


Figure A3.21: Shelton zonal impacts of climate change using the 20 smart sampled UKCP09 scenarios



3.3 Combined impacts of climate change and Sustainability Reductions

Our initial modelling looked separately at the impacts of climate change and the "confirmed" and "likely" changes to our licences as part of the Sustainability Reductions. Following on from our initial modelling work, we have carried out significant sensitivity testing. This work included modelling the combined impacts of the climate change impacted system with the licence changes flagged up by the Environment Agency as "confirmed" and "likely" changes to our abstraction licences which will come into force in 2020.

To ensure consistency with the baseline modelling, the climate change (rank 50 scenario) and sustainability changes were applied together to the baseline Aquator model. The same period of record was used in both our baseline and combined impact assessments (1920 to 2010).

In our draft plan modelling for the Strategic Grid zone, when the sustainability reductions were modelled with the climate change perturbed inflow series and groundwater yield constraints in the combined run the affects of the sustainability changes were amplified. This was because the raw water resource availability is reduced under the climate change scenario. The impact of the River Wye Habitats Directive changes to the operation of Elan Valley was further compounded by the reduced flows in the River Wye under the climate change scenario, which trigger increased releases from the Elan Valley reservoirs.

In our modelling for the final plan, following our work with Natural Resources Wales to minimise the impact of the Wye ROC, the effect of combining the sustainability reductions with the climate change modelling is a slightly reduced overall impact.

As mentioned in section A3.1 the Nottinghamshire zone is not directly affected by any sustainability changes. All of our licences in the Nottinghamshire area which the EA are intending to revoke are for sources which are currently disused and not included in our baseline deployable output modelling. The impact of climate change in the Nottinghamshire zone is mainly due to the reduced surface water import available from the Strategic Grid zone.

As noted above the combined impact is greatest in the west of the Strategic Grid zone, where the changing operation of the Elan Valley system due to the Wye ROC is affected by the reduced raw water availability under the climate change scenario. There is however spare resource available in the north east of the grid which can be transferred to the Nottinghamshire zone via the linkages between the two zones. This reduces the overall impact of climate change on the Nottinghamshire zonal DO under the combined model run.

The Environment Agency's Wye ROC licence changes are based on historic and current baseline flow data. The Environment Agency's Wye ROC modelling did not investigate the potential impacts of climate change on the River Wye catchment and how the changing climate would affect the way the reservoir would need to be operated in the future to improve river levels.

The impact of the Wye ROC licence change at Mitcheldean when modelled on its own and combined with climate change, shows little impact on the DO of the Forest and Stroud zone. However when the climate change perturbed inflow series is modelled on its own there is a slight impact.

For all of our zones which are affected by both climate change and sustainability changes apart from the Forest and Stroud zone, we have chosen to use the combined impact model outputs in our baseline supply demand balance assessment. For the Forest and Stroud zone we have used the individual modelled outputs, so as to take account of the slight reduction due to climate change.

The breakdown of these reductions is shown in Table WRP1BL Supply of water resource planning tables.

Figure A3.22 and Table A3.17 show the variation in the DO projection for the Strategic Grid zone dependent on how we model the DO reductions.

Figure A3.22: Modelled impacts of climate change and RSA reductions on deployable outputs in the Strategic Grid zone

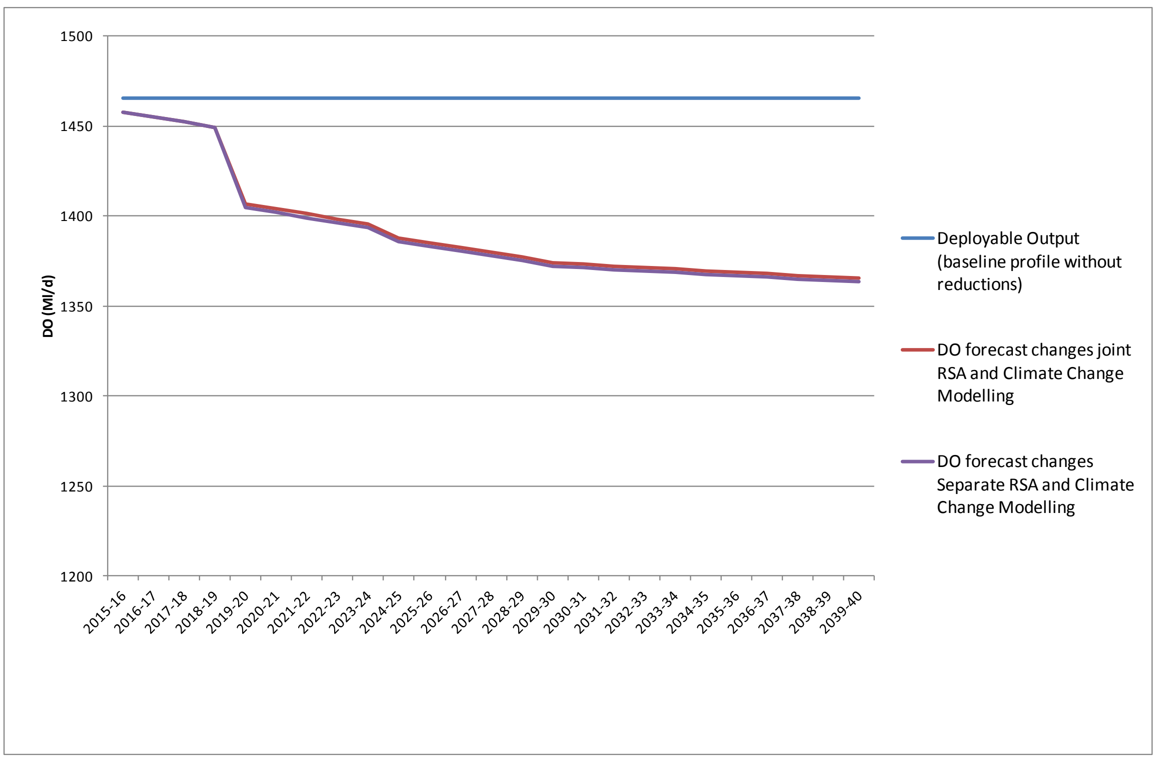


Table A3.17: Breakdown of impacts of Climate Change and RSA reductions from baseline deployable output - Strategic Grid zone

	Climate Change Impact (Ml/d)	RSA/Wye HD Impact (Ml/d)	Combined Impact (Ml/d)
Forecast changes in DO: combined RSA / rank 50 climate change modelling	-52*	-45*	-97
Forecast changes in DO: separate RSA and rank 50 climate change modelling	-52	-47	-99

*assumed split

Figure A3.23 and Table A3.18 show the variation in the DO projection for the Nottinghamshire zone dependent on how we model the DO reductions.

Figure A3.23: Modelled impacts of climate change and RSA reductions on deployable output in the Nottinghamshire zone

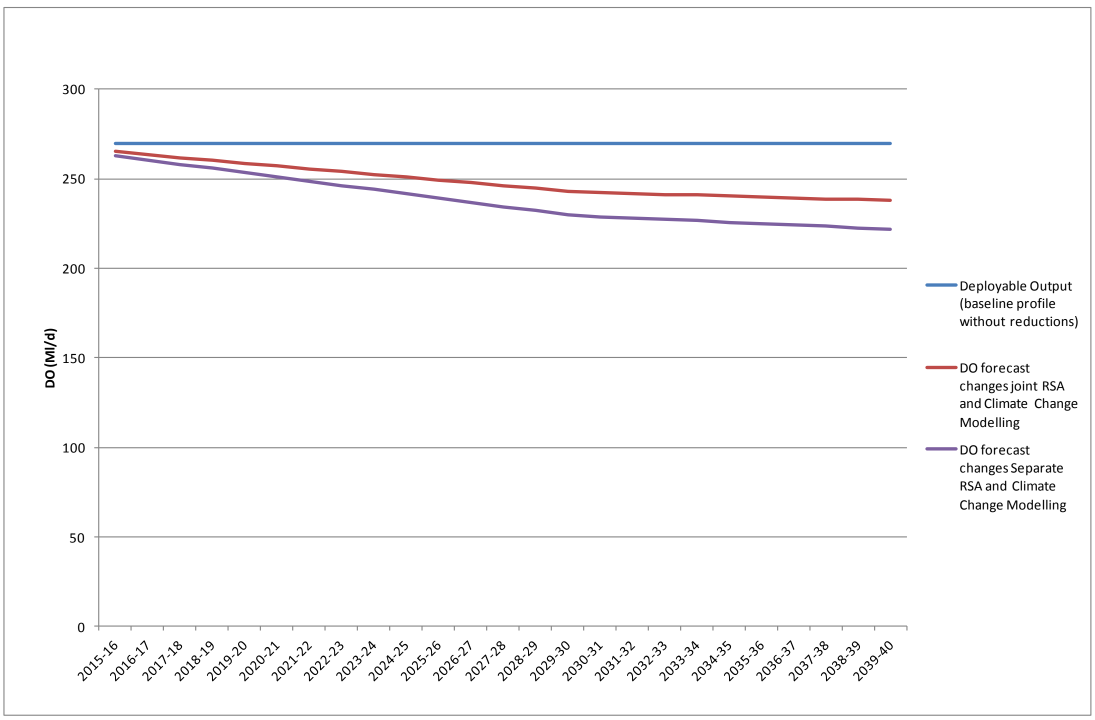


Table A3.18: Breakdown of impacts of Climate Change and RSA reductions from baseline deployable output - Nottinghamshire zone

	Climate Change Impact (Ml/d)	RSA Impact (Ml/d)	Combined Impact (Ml/d)
Forecast changes in DO: combined RSA / rank 50 climate change modelling	-30 *	0 *	-30
Forecast changes in DO: separate RSA and rank 50 climate change modelling	-45	0	-45

*assumed split

Figure A3.24 and Table A3.19 show the variation in the DO projection for the Forest and Stroud zone dependent on how we model the DO reductions.

Figure A3.24: Modelled impacts of climate change and RSA reductions on deployable output in the Forest and Stroud zone

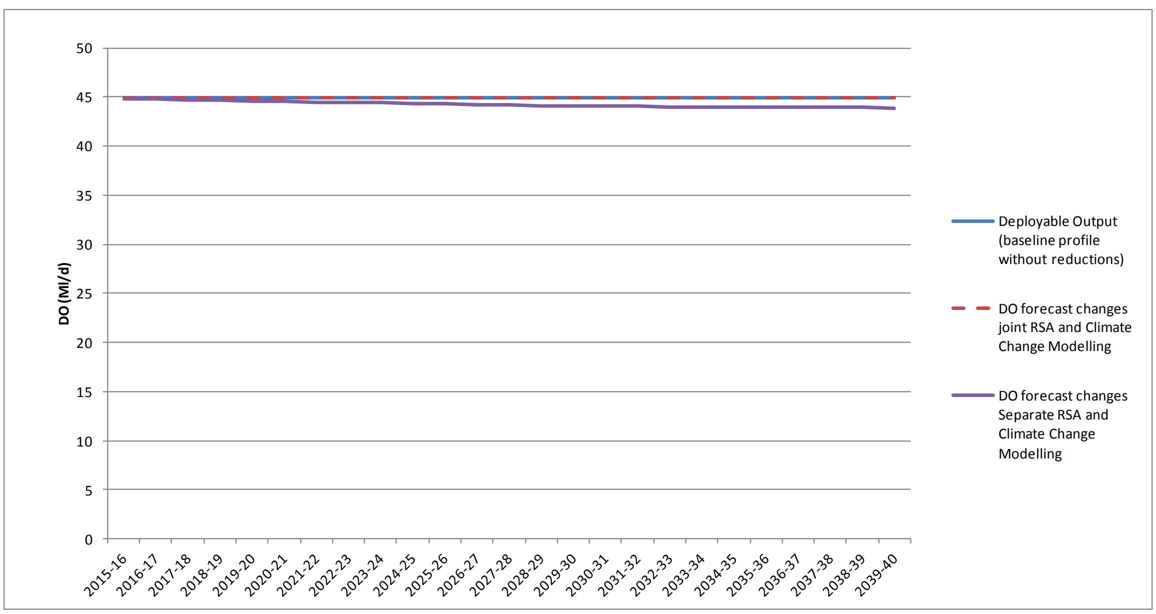


Table A3.19: Breakdown of impacts of Climate Change and RSA reductions from baseline deployable output – Forest and Stroud zone

	Climate Change Impact (Ml/d)	RSA Impact (Ml/d)	Combined Impact (Ml/d)
Forecast changes in DO: combined RSA / rank 50 climate change modelling	0*	0*	0
Forecast changes in DO: separate RSA and rank 50 climate change modelling	-1	0	-1

*assumed split

A3.4 Scaling the impacts of climate change from the base year to 2040

As already discussed, the climate change modelling provides us with estimates of changes in deployable output at 2035. In order to estimate the impact of climate change for each year of the planning period from 2013 up to 2040, we scale the DO change using two sets of equations. These equations enable us to interpolate and extrapolate the 2035 DO estimates to produce a smooth times series which we can then include in our supply demand balance calculations.

For the zones which are affected by both climate change and sustainability reductions we have scaled the climate change impacts, using the climate change portion of the combined model run.

The scaling equations are described in the EA's Water Resources Planning Guidelines (2012). We have applied these equations to our central estimate for each water resource zone.

Equation 1 is used to extrapolate from 2030/31 onwards. In the equation "Year" is the year of interest.

$$\text{Scale factor} = \frac{\text{Year} - 1975}{2035 - 1975} \quad \text{(Equation 1)}$$

Equation 2 is used to avoid a step change in 2012/13 between baseline deployable output and the underlying trend. It interpolates linearly between 2013/14 and 2029/30 (inclusive).

$$\text{Scale factor} = \frac{\text{Year} - 2012}{2031 - 2012} \quad \text{(Equation 2)}$$

References

UKWIR, 1995. A Methodology for the Determination of Outputs of Groundwater Sources. UKWIR Technical Report 95/WR/01/2.

UKWIR, 2000. A Unified Methodology for the Determination of Deployable Output from Water Sources. UKWIR Technical Report 00/WR/18/2.

UKWIR, 2012. Water Resource Planning Tools 2012. UKWIR WR27 Technical Report 12/WR/27/6.

A4 Outage

Our water supply planning projections include an assessment of the likelihood of source outages occurring in our system. An outage is defined as a temporary loss of deployable output that lasts typically for less than 3 months and "includes observed events and perceived risks, resulting in either partially reduced output of a source or complete closure" (Environment Agency Water Resource Planning Guidelines, 2012). Outages include events which affect the "water available for use", by restricting our ability to supply our customers and also events which do not affect the "water available for use" 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.

In 2007 we implemented a new company reporting system for recording planned and unplanned outages occurring at our major surface water treatment works. Once this recording process was fully established as business as usual at our surface water treatment works, we increased coverage to capture outage events at our groundwater sources. We have used this database to inform our latest assessment of future outage risk. The database records the following information:

- which source(s) is affected;
- what is 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.

As our recording of outages has improved significantly since WRMP09, we have used the recorded data in our assessment where available. We now have approximately 5 years of historic outage data for our surface water sources and approximately 3 years of data for our groundwater sources. Due to the shorter length of our groundwater outage records, not all of our groundwater sources have experienced issues during this time so we have had to make some assumptions around potential outage issues in these cases (this will be discussed in more detail in section A4.3).

As with our WRMP09 assessment of outage, we have not included any "extreme" events in the outage assessment. These are rare, unpredictable events which cannot reasonably be foreseen but when they occur would result in a major disruption to supplies, such as the failure of one of our aqueducts. The nature of these kinds of extreme events means that they are outside of our normal day to day water resources management. These "extreme" events are dealt with separately as part of our emergency planning and supply resilience investment programme.

In line with our outage assessment for WRMP09, we have considered both planned and unplanned events in our analysis.

In accordance with the EA's Water Resource Planning Guidelines (2012) we have considered our outage allowance outside of our target headroom assessment. This is discussed in more detail in Appendix C2.1.

A4.1 Our 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.

As with our other Water Resource Planning models we have reconfigured our outage allowance modelling tools to represent our 15 new water resource zones. As part of this reconfiguration work, we have improved our outage model to allow 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 an improvement over our previous modelling for WRMP09, which adopted a “top down” approach, using more generic assumptions of outage risk based on the type of source. We believe the reconfigured model and the use of site specific outage records results in a more appropriate assessment of future outage risk. Our new outage allowance models use the data from our specially developed “Event Tracker” tool, which takes the data directly from our surface water treatment works and groundwater source outage databases. The outage allowance model uses triangular distributions for assessing the magnitude and duration of outage risks and a Poisson distribution for event frequency. The Event Tracker interrogates our outage databases to extract the outage events and consolidate the information into suitable distributions which are required to perform the Monte Carlo simulations in the outage allowance model.

Our new 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.

Due to the interconnectivity of our supply network, outages at the majority of our sources do not impact on our ability to supply our customers. In most cases other sources in our network are able to increase output to make up any potential shortfall caused by the partial restriction or full shutdown of other sources on our “grid”. For operational purposes the daily records of outages at our surface water sources record how much of the maximum sustainable treatment capacity is available (and unavailable) due to planned and unplanned restrictions and shutdowns. The outage allowance model has an additional function built in, which allows us to assess the impact of the outage in two ways:

1) The outage is included in the model as a proportion of the full source deployable output.

2) 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 DO is equal to maximum capacity, in which case it will be equal).

In our modelling for this dWRMP we have used the second option. 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 enable 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 Event Tracker then it has been included in the outage assessment;
- Due to the shorter length of the event records for groundwater, some generic issues have been included such as local and widespread power loss, pump failures, and planned maintenance.

A4.2 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 run 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. As previously discussed, since 2007 we have maintained a database to record all planned and unplanned outages at our sources. We also have a record of actual planned outages going back to 2005. Our database records the cause, the duration and the impact of the planned outage events. The records for recent years have been examined and the loss of output in each month has been identified.

Analysis of the records from our surface water treatment works indicates that output restrictions are often due to the prolonged partial or complete closure of a works for a major refurbishment. 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 in so that works may be brought back into production at short notice if required.

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

A4.3 Unplanned outages

The Environment Agency's WRPG (2012) defines an unplanned outage as being "an unforeseen or unavoidable outage event affecting any part of the sourceworks and which occurs regularly enough that the probability of occurrence and severity of effect may be predicted from previous events or perceived risks". Their definitive list of unplanned events is:

- pollution of source
- turbidity
- algae
- power failure
- system failure

Surface Water Sources

The risk of unplanned outages has been assessed by examining the operational records in our outage database of the unplanned events that actually caused loss of output from our water treatment works. A summary of the key types of issues included in the assessment of unplanned outage events is given 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)
- 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, algae issues)

Groundwater sources

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 2009, several of our sources have not been affected by outage events during this time. Therefore for groundwater sources we have included allowances for some key generic risks. These risks are:

- Pump failures: a 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.
- Local power loss: a frequency of 1.2 events per source per year; and a duration average of eight hours, between a minimum and maximum of 0.1 and 24 hours respectively.
- Widespread power loss: a frequency of three events per year; and a duration average of eight hours, between a minimum and maximum of 0.1 and 24 hours respectively.

A4.4 Annual average outage allowances to 2040

The output from the probabilistic analysis of outage risks we have undertaken is summarised in Table 1. The table shows the likelihood of different outage quantities occurring in the year. For example, in the Forest and Stroud zone our assessment shows that there is a 60% chance that in any given year, up to 1.12 Ml/d will be lost due to outage, and a 90% chance that up to 5.55 Ml/d will be lost due to outage.

Table A4.1: Range of Outage Allowances at different levels of risk

		Outage (Ml/d)				
Water Resource Zone	**DO (Ml/d)**	**60% (40% risk)**	**70% (30% risk)**	**80% (20% risk)**	**90% (10% risk)**	**100% (0% risk)**
Bishops Castle	4.67	0.01	0.03	0.09	3.31	4.66
Forest & Stroud	44.97	1.12	1.64	2.94	5.55	24.30
Kinsall	5.00	0.04	0.08	0.19	5.00	5.00
Llandinam & Llanwrin	19.85	0.17	0.30	0.68	15.51	19.85
Mardy	3.65	0.02	0.05	0.11	2.88	2.88
Newark	15.50	0.00	0.00	0.47	11.31	15.50
North Staffordshire	147.99	1.52	1.89	2.49	3.91	64.48
Nottinghamshire	269.97	3.44	4.45	6.10	9.98	270.00
Rutland	0.00	0.00	0.00	0.00	0.00	0.00
Ruyton	5.32	0.04	0.09	0.22	5.30	5.30
Shelton	142.99	1.49	1.89	2.48	3.39	13.32
Stafford	25.50	0.51	0.73	0.97	1.35	4.81
Strategic Grid	1465.75	79.99	112.59	157.98	241.72	1102.54
Whitchurch & Wem	10.90	0.03	0.07	0.11	0.23	2.15
Wolverhampton	65.00	0.14	0.29	0.55	0.85	4.35

As shown in Table A4.1 there is a large difference between the 80th percentile outage value and the 95th and 100th percentile outage values, but that difference between the 80th percentile and the 60th and 70th percentile values is relatively small. In some of the smaller zones, such as Kinsall and Ruyton, adopting a lower level of risk would increase the Outage Allowance significantly, with the whole zonal DO being lost to outage. Consistent with WRMP09 we have therefore used the 80th percentile values of the cumulative frequency distribution of outage probabilities in our water resources planning. Table A4.2 shows the Outage Allowances we have adopted with the percentage of the zonal deployable output that is affected.

Table A4.2: Summary of Outage Allowances adopted for WRMP14

Water Resource Zone	Outage allowance (Ml/d)	Percentage of Deployable Output (%)
Bishops Castle	0.09	1.9
Forest & Stroud	2.94	6.5
Kinsall	0.19	3.8
Llandinam & Llanwrin	0.68	3.4
Mardy	0.11	3.0
Newark	0.47	3.0
North Staffordshire	2.49	1.7
Nottinghamshire	6.10*	2.3*
Rutland	0.00	0
Ruyton	0.22	4.2
Shelton	2.48	1.7
Stafford	0.97	3.5
Strategic Grid	157.98	10.8
Whitchurch & Wem	0.11	1.0
Wolverhampton	0.55	0.9

*from 2020 the Nottinghamshire Outage Allowance reduces to 5.45Ml/d / 2% of zone DO

Overall, the Outage Allowance is low as a percentage of total DO at both a company level and at individual zone level, being a maximum of 10.8% of DO in the Strategic Grid zone and being less than 3% in nine of the 15 Zones. At a company level, Outage Allowance is 8% of our total DO.

The allowances vary widely between our Water Resource Zones, according to the nature of the sources and the degree of supply integration of the zones. The allowances are greatest in the Strategic Grid zone, which makes up 90% of the company's whole vulnerability total under the 80th percentile. As with WRMP09, we are adopting the 80th percentile Outage Allowance across the whole of our planning period.

A4.5 Components of Outage Allowance

The relative contribution of the various components of the overall outage risk have been estimated by running the outage model with different events excluded from the calculation. It should be noted that because a probabilistic model is used, the results from the analysis should be regarded as indicative rather than definitive. The results, as shown in Table A4.3, are useful in understanding the sources of outage and can guide management decisions on addressing that risk, and on improving the information base on which it is assessed.

Table A4.3: Components of Outage Allowances

Water Resource Zone	Relative contribution of cause of outage (%)					
	Quality	Process Maintenance	Burst/ Leak	Capital Improvement	Electrical	Pumps/ Valves
Bishops Castle	0.0	0.0	0.0	0.0	100.0	0.0
Forest & Stroud	1.9	0.0	0.0	0.0	60.7	37.4
Kinsall	0.0	26.2	0.0	0.0	73.8	0.0
Llandinam & Llanwrin	0.0	100.0	0.0	0.0	0.0	0.0
Mardy	0.0	0.0	0.0	0.0	100.0	0.0
Newark	0.0	0.0	0.0	0.0	100.0	0.0
North Staffs	0.0	23.3	0.0	0.0	63.9	12.9
Nottingham	6.7	23.0	0.0	0.0	54.8	15.6
Ruyton	0.0	0.0	0.0	0.0	100.0	0.0
Shelton	0.0	0.0	0.0	0.0	74.1	25.9
Stafford	0.0	38.9	0.0	0.0	49.2	11.9
Strategic Grid	78.1	18.3	1.2	0.9	0.4	1.1
Whitchurch & Wem	0.0	100.0	0.0	0.0	0.0	0.0
Wolverhampton	0.0	33.0	0.0	0.0	55.8	11.1

A4.6 Reducing future outage risks

Our wider PR14 investment plans include a major programme of capital maintenance, resilience and water quality improvement work which will improve the condition of our assets, making treatment processes more reliable and lowering the risk of their failure. At the time of publishing our draft WRMP in May 2013, our capital improvement and maintenance plan for AMP6 and beyond was still being formulated. To help inform our draft WRMP we used an early version of the capital improvement and maintenance plan to carry out a sensitivity analysis to see what impact the required work would have on our outage allowance. As our draft WRMP showed, that early work plan had relatively little impact on outage allowance, except in the Nottinghamshire zone where borehole maintenance will help reduce outage allowance from the end of AMP6.

Appendix A: How much water do we have available?

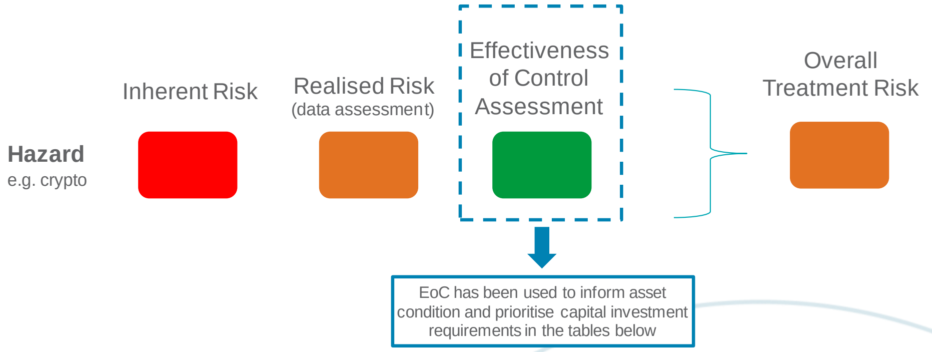
The PR14 capital improvement and maintenance plan for water treatment works has now been fully formulated and has been designed to target those sites which have the highest risks of being affected by specific water quality and equipment issues. We are now able to link this to our outage allowance analysis to help assess how the planned risk reduction work will reduce our outage allowance in the longer term.

The capital improvement and maintenance plan has adopted a risk based approach following the principles of our Drinking Water Safety Plans (DWSPs). During AMP5 we developed DWSPs for each of our sources of public water supply, and are where we assess and record our water quality risks along with the details of controls and corrective actions. We use the DWSPs for regulatory reporting (Reg 28 reports) and to support the need for water quality capital investment schemes. They are recognised by DWI and OFWAT.

The DWSP approach has given us a much greater understanding of asset and water quality, and this has revealed the need for a step up in investment at water treatment works in AMP6 compared to previous AMP periods. Our DWSP risk assessment model is broken down as follows:

- inherent risk describes the catchment risk, e.g. the presence or absence of cryptosporidium defined by risk assessment and/or data.
- realised risk confirms the existence of the inherent risk through water quality sample data
- the Effectiveness of Control (EoC) is a detailed assessment of the effectiveness of a process at controlling the Water Quality hazard it was designed to control e.g. the effectiveness of a Rapid Gravity Filtration process to remove cryptosporidium. Assessed biannually through detailed on-site process reviews against engineering standards.

Figure A4.1: Drinking Water Safety Plan Risk Calculation

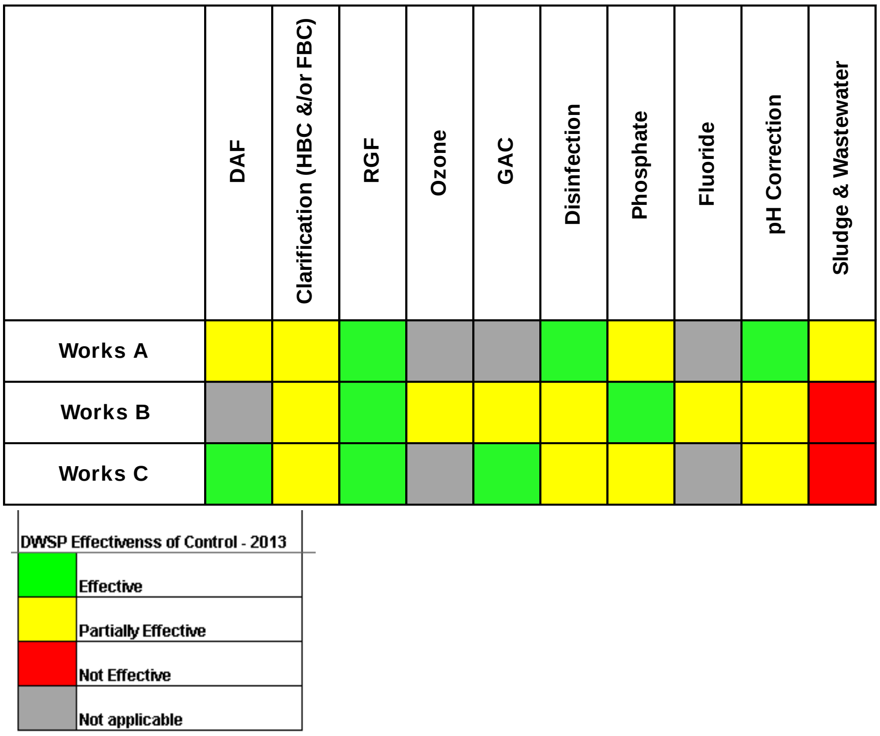


Title	Definition
Inherent Risk	Risk posed by the catchment, source or upstream asset
Realised Risk	Assessment of water quality sample data
Effectiveness of Control	Assessment of how effective our treatment assets are at controlling the relevant/identified hazards

The Effectiveness of Control (EoC) denotes how effective a treatment process is at controlling the water quality hazards it is intended to address. Each of our surface water treatment works has been reviewed on a process by process basis, from AMP6 onwards, using the Drinking Water

Safety Plans as the starting point. From this a Red Amber Green (RAG) status has been assigned to show the future risks and deterioration of the treatment processes at each works if no capital maintenance investment is made.

Figure A4.2: Example Drinking Water Safety Plan Effectiveness of Control Matrix



Those processes which currently have or are forecast to have a red EoC are likely to contribute to a water quality exceedence at a site and result in reduced output or site shut down while the problem is resolved. The investment plan has been designed to address the highest risk sites and to remove known current risks, and to prevent future risks arising from deterioration of the assets and treatment processes. Our PR14 capital improvement and maintenance investment plan will address the high risk issues at our surface water treatment works.

For this final WRMP, we have incorporated the benefits of our wider PR14 capital maintenance and water quality investment plans. We have reviewed the record of historic outage events against our PR14 capital improvement and maintenance plans. We have identified which of the past “unplanned” outage events are likely to be resolved or prevented in future as a result of our PR14 investment plans. From this we have carried out sensitivity analysis by removing those resolved “unplanned” issues removed from our outage risk modelling. Our sensitivity testing shows that the outage risk to deployable output in the Strategic Grid zone will reduce by around 9Ml/d by the end of AMP6, and by around 24Ml/d by 2040.

Table A4.1 shows the future changes in outage allowance in the Strategic Grid zone resulting from our wider PR14 investment plans.

Table A4.1: Reductions in Outage Allowance in the Strategic Grid zone following investment

AMP	6	7	8	9	10
Years	2015-19	2020-24	2025-29	2030-34	2035-39
Outage Allowance (Ml/d)	157.98	149.32	147.17	134.11	134.11
% of Deployable Output	10.8	10.2	10.0	9.1	9.1

We have used this outage reduction profile in the final planning supply / demand scenario published in the accompanying final WRMP data tables.

A5 Imports and exports of water

We operate a number of raw and potable transfers and bulk supplies between the water resource zones within our region, as well as externally to and from third parties.

As we have described in Appendix A1, we have significantly changed our Water Resource Zones (WRZs) since our 2009 Water Resources Management Plan (WRMP09). We now work to 15 separate WRZs and these more closely align with the WRZ definition set out in the 2012 Water Resources Planning Guideline. As a result, our 15 WRZs are broadly self contained with little, or limited, connectivity across borders. The few internal transfers that remain are described in the following section:

A5.1 Internal transfers

In our water resources deployable output (DO) modelling our Aquator model optimises the use of internal transfers based on least cost and resource state. In our WRMP tables all of our internal transfers are included within the DOs. When we calculate DO for our WRZs we ensure that the import to a receiving WRZ is consistent with the export from the donor WRZ. We do not include internal transfers as separate rows in the WRMP tables as this would double count them. The following table shows the utilisation and capacity of these transfers in Mega litres per day (Ml/d) rounded to one decimal place:

Table A5.1: Inter zonal transfers modelled within baseline deployable output

Name of transfer	Exporting WRZ	Importing WRZ	Average 91 year utilisation (Ml/d)	Max capacity (Ml/d)
Derwent Valley Aqueduct (DVA) to Nottinghamshire (Notts)	Grid	Notts	22.6	28.0
DVA to Strelley (Notts)	Grid	Notts	17.2	42.8
Church Wilne to Notts	Grid	Notts	56.5	84.0
Higham to North Notts	Grid	Notts	14.9	22.9
Mythe to Mitcheldean	Grid	Forest & Stroud	0.0*	0.0*
Notts to Chesterfield	Notts	Grid	5.6	9.9
Mitcheldean to S. Gloucestershire	Forest & Stroud	Grid	0.0	10.0
Notts to Newark	Notts	Newark	14.8	15.9

** We did not include this transfer in our base DO modelling nor have we included it in the base year (2011-12) of our WRP tables. However we have assumed a transfer of 2 Ml/d in our WRP tables from 2013-14 onwards. This is because we do not expect this AMP5 scheme to deliver this benefit until 2013-14.*

A5.2 External strategic transfers

We have assumed in our base DO modelling that the external bulk supplies operate in line with the relevant licence or commercial agreement. Table A5.2 shows average and maximum utilisation of these transfers in our baseline DO model run, rounded to the nearest Ml/d:

Table A5.2: External strategic transfers, modelled utilisation, maximum capacity and limiting factors

Neighbouring Company	Location	Average Aquator 91 year simulation (Ml/d)	Maximum Aquator flow (Ml/d)	Min. Aquator flow (Ml/d)	Maximum transfer capacity	Limiting factors
Export to Yorkshire Water Services	Derwent Valley reservoirs (Grid WRZ)	49	50	16	Up to 60 Ml/d of untreated water	Terms of the agreement. Also quantity reduces as storage in the Derwent Valley reservoirs reduces
Wing import from Anglian Water	Split between our Grid WRZ and our Rutland WRZ	18*	18*	18*	Up to 18 Ml/d of treated water	Terms of the agreement
Export to Dŵr Cymru Welsh Water (DCWW)	From our Forest and Stroud WRZ	9	9	8	We provide DCWW with up to 9 Ml/d of treated water.	Terms of agreement - Volume is supported by regulation releases from the Elan Valley. This is not usually variable in a drought.

Appendix A: How much water do we have available?

Neighbouring Company	Location	Average Aquator 91 year simulation (Ml/d)	Maximum Aquator flow (Ml/d)	Min. Aquator flow (Ml/d)	Maximum transfer capacity	Limiting factors
Import from Dŵr Cymru Welsh Water	To our Grid WRZ from the Elan Valley reservoirs .	338	345	114	DCWW provide up to 356 Ml/d of untreated water via the Elan Valley Aqueduct (EVA). This reduces to 327 Ml/d when the Elan Valley Licence Rule Curve is crossed.	Terms of agreement and also by sustain-able capacity of aqueduct.
Hampton Loade import from South Staffordshire Water (SSW)	River Severn to the Wolver-hampton WRZ	33	48	28	Average of 34 Ml/d (peak day of 48 Ml/d) of treated water.	Terms of agreement
Import from South Staffordshire Water (SSW)	Brindley Bank	1.4**	n/a	n/a	Estimated at 5 Ml/d	Terms of agreement

** Although we have this supply in our Aquator model it is not connected to the rest of our network and the flow does not vary. In our planning we assume that the maximum transfer of 18 Ml/d is available throughout the planning period. We assume that up to10 Ml/d of this import can supply the Rutland WRZ and the remaining 8 Ml/d enters our strategic grid WRZ.*
*** We do not model this within Aquator*

We have contacted the relevant companies to ensure that the assumptions we make are consistent with those made by the other party and that there are no significant inconsistencies. The following text explains how we manage our external transfers in normal years and under a dry year/ drought year scenario:

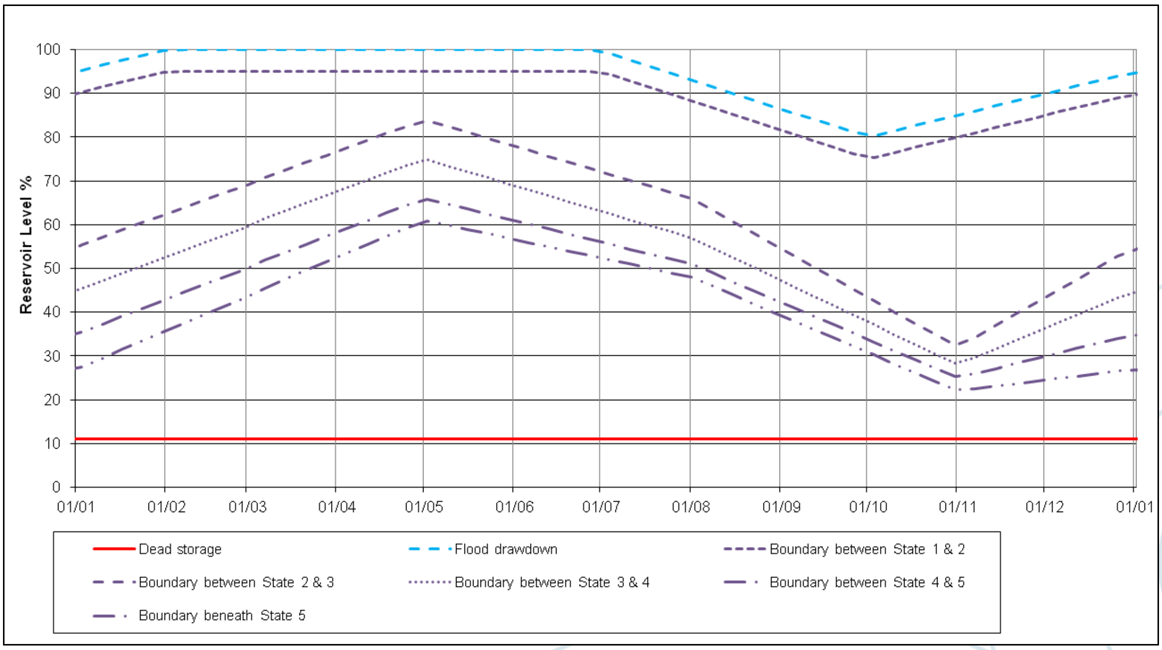
Bulk supply arrangements with Yorkshire Water

The normal operation of this bulk supply is governed by an agreement signed by both companies in 1989. The minimum supply rate between Severn Trent Water and Yorkshire Water Services (YWS) is 35Ml/d unless storage falls below state 5. Operationally we operate to the terms of this agreement and so does YWS.

However, there is provision in the agreement to modify these rules and this occurred during 1995-96, in 2003 and 2013. In events like droughts or during major outages in our region we may approach Yorkshire Water and ask if it can ease pressure on our water resources by taking a reduced supply.

We understand that the response we receive to these approaches will depend on the water resources position in Yorkshire. For example, during the drought of early 2012 we explored with Yorkshire Water the possibility of them reducing their take. However, the prevailing hydrological conditions changed dramatically before any change to the bulk supply was necessary. Nevertheless we would make a similar approach in the future if required. The graph below shows the control lines that help to guide how we work with Yorkshire Water to operate this system:

Figure A5.1: Control lines for Derwent Valley bulk transfer to Yorkshire Water



We are also aware that, as Yorkshire Water has stated in its 2013 drought plan, the decision on whether to impose restrictions in their supply area is triggered by their resources and not our water resources situation. The opposite is also true: if Yorkshire Water has imposed restrictions but we have not, we will make our decision based upon our wider water resources situation. However, in scenarios of this sort we will work closely with Yorkshire Water, and all other stakeholders, to minimise the impact of a drought on customers and the environment.

Ultimately the decision on whether to impose customer restrictions lies with each company and depends on their own water resources position. This applies not only to us and Yorkshire Water but also to our interaction with all neighbouring companies.

Bulk supply arrangements with Anglian Water

We have a bulk supply agreement with Anglian Water which provides up to 18 Ml/d from their Wing WTW into the rural areas of the former county of Rutland. Under normal circumstances around 8 Ml/d of this import supplies our Rutland zone while around 6 Ml/d feeds into the strategic grid zone. When we take the full supply, the split is 10 Ml/d to Rutland and 8 Ml/d to the grid. We have used these values in our supply demand balances and WRMP tables. In our Aquator modelling this bulk supply will vary on a daily basis depending on the demands in each of these WRZs.

This bulk supply does not automatically vary with any drought management measures, and the agreement does not stipulate that we will reflect any drought management measures that Anglian Water have to impose on its customers that are fed from their Wing WTW system. Nevertheless, in such circumstances, we will liaise closely with Anglian Water to minimise the impact on our customers whilst supporting Anglian Water's efforts to maintain supplies from the Wing WTW system.

Bulk supply arrangements with Dŵr Cymru Welsh Water (DCWW)

We provide a bulk supply of up to 9 Ml/d to DCWW from our treatment works at Mitcheldean along with some minor supplies from our Llandinam zone.

We receive a bulk supply from the DCWW reservoirs in the Elan Valley. The quantities of this supply and how it may vary throughout the year are dictated by the abstraction licences of the associated water sources. For example, the transfer from the Elan Valley reservoirs is controlled by licence rule curves. If reservoir storage is below the lower licence rule curve it reduces the licensed maximum transfer along the Elan Valley Aqueduct (EVA) as well as affecting the required compensation flow.

Bulk supply arrangements with South Staffordshire Water (SSW)

We receive a bulk supply of treated water from SSW to supply the Wolverhampton area. In a severe drought we would review the way we apportion our respective shares of the joint abstraction licence on the River Severn with SSW and the Environment Agency (EA). This licence allows for the transfer of the overall quantity between SSW and us. The intention would be to review our respective positions with regard to the other resources SSW have at their disposal, and our resource availability in this part of our region, and allocate the balance between SSW's and our abstraction points accordingly. This agreed arrangement has existed for over 15 years and has worked satisfactorily throughout this time.

The annual River Severn Regulation meetings with SSW, the EA and the Canal and Rivers Trust provide a forum for collaborative management of water resources on the River Severn. In addition to this we talk to SSW about the numerous emergency connections between ourselves but, we place no reliance on such emergency supplies being available for a protracted period during a drought. We have also been working with SSW so that our and their Aquator modelling assumptions are aligned. Another area where we are working together is in relation to the potential for us to apply for a drought permit at Trimpley.

We also receive a smaller supply of potable water from SSW to support our Stafordshire WRZ. This bulk import provides us with an average of 1.4 Ml/d and we usually refer to it as the Brindley Bank import. Our working estimate for the peak capacity of this supply is 5 Ml/d.

A5.3 Maximum transfer capacity and factors which limit this capacity

Internal transfers

We earlier described the maximum transfer capacity and the limiting factors for our internal transfers in table A5.1. The limiting factors for these transfers are the maximum capacities of the pipelines. The maximum capacities shown in table A5.1 are those we use in our Aquator modelling as model parameters. These maximum values are either hydraulic capacities or where the flow is limited by operational factors such as water quality and discolouration risks.

External strategic transfers

The maximum transfer capacity and the limiting factors for our external transfers are described in table A5.2. We note that in most cases the relevant infrastructure will be sized so that it does not allow significantly more than the agreed quantity of the bulk transfer:

How we manage our transfers in a dry year scenario

For our internal transfers our DAT (drought action team) makes decisions about intra and inter-zonal transfers. This decision making process is described in more detail in our drought plan. We have described above how we manage our external strategic transfers in a dry year scenario.

Reliability of transfers involving neighbouring companies

We have described above the assumptions we make in relation to the reliability of these inter-company transfers in a drought. We have also provided a high level description of the nature of these transfers and any limiting factors. We have not provided further details in the WRMP as these are commercially confidential agreements between the two companies. There have been no occasions since the WRMP09 when the requested import or export quantities were not provided.

A6 Levels of service

Levels of service are "a contract between a water company and its customers, setting out the standard of service that customers can expect to receive from a water company." Our WRMP sets out our recommended strategy for maintaining the minimum standard of service that our customers can expect for restrictions on water use.

Our stated levels of service that we provide for our customers are that:

- On average, as a result of drought we will need to use temporary use bans to restrict customers' use of water no more than three times every 100 years
- We will need drought orders to restrict non essential use no more than three times in every 100 years
- Rota cuts/ standpipes for our customers are unacceptable as a response to drought.

If we ever had to restrict our customers' use of water we would either impose a temporary use ban (TUB) or, in a more severe drought we could apply to Government for a drought order to restrict wider use through a non essential use ban. A TUB is roughly equivalent to what we referred to as a hosepipe ban in our WRMP09.

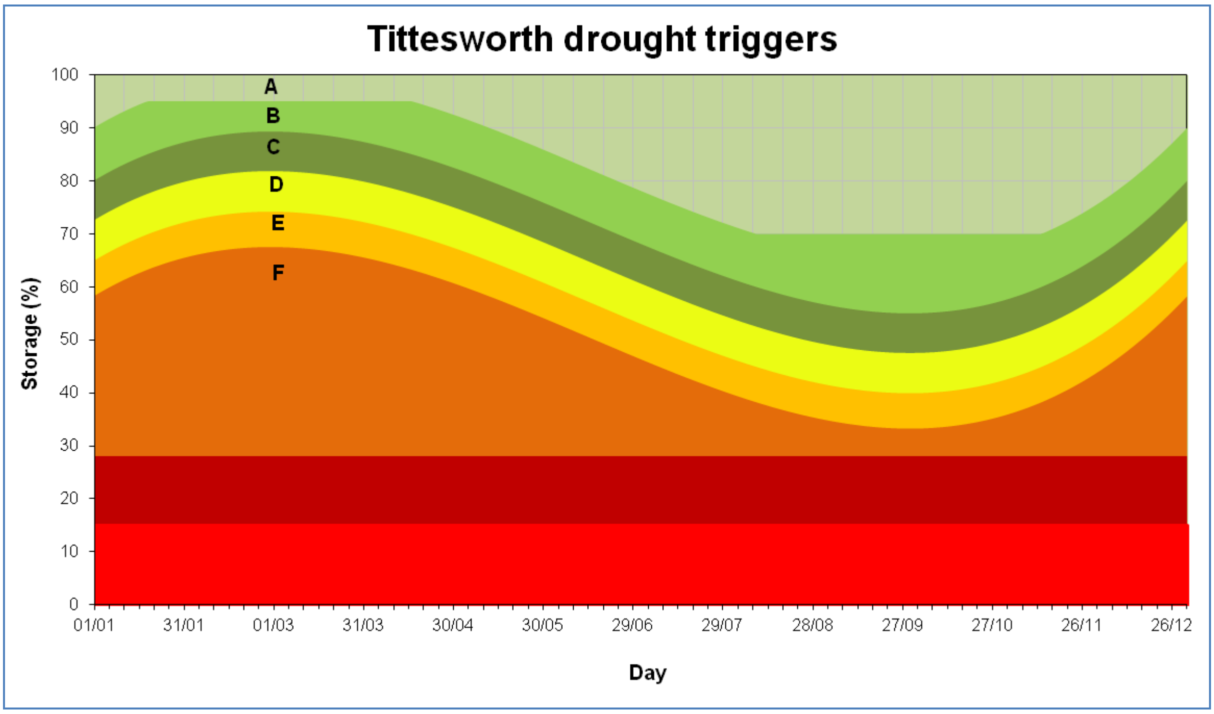
As we would not restrict non essential use unless we already had a TUB in place we would not expect non essential drought orders more than three times in a century. The actual frequency of non essential use drought orders could conceivably be less than three in 100 years. In fact our modelled frequency of non essential use bans is approximately 1 in 100. As table A6.1 shows this is consistent with the levels of service we state to customers as it is not more than 3 in 100. When we talk to our customers we do not distinguish between temporary use bans and non essential use bans. We think that this helps to avoid confusion.

A6.1 Links to our drought plan

Our target levels of service are consistent with those we have quoted in other Severn Trent publications, such as WRMP09 and our 2014 drought plan. In our drought plan we explain how we have improved the way we respond to changes in drought indicators, such as strategic reservoir storage, by using new drought trigger zones and an associated action plan. We use these action plans to help our decision making during a drought.

The example below shows the revised triggers for our reservoir at Tittesworth, in North Staffordshire. We have given more details of our revised drought trigger zones and the associated measures in our 2014 drought plan.

Figure A6.1: Drought trigger zones for Tittesworth reservoir



The following table is based on table six in the 'water resources planning tools 2012: report ref. No.12/WR/27/6 Deployable Output (DO) report'. We have not included the planned frequency of media campaigns as these are not specifically part of our stated levels of service.

Table A6.1: Levels of service (LoS) frequency calculations

LoS control rule threshold "level"	Number of events in the record from water resources modelling simulation	Length of record (years)	Frequency per 91 year length of record (%)	Company stated LoS frequency	Example description of LoS frequency and water use restriction measures
Threshold No 1	3	91	3.3	Not > 3 in 100	Temporary use ban (TUB)
Threshold No 2	1	91	1.1*	Not > 3 in 100	Non essential use ban (NEUB)
Threshold No 3	0	91	0	Not acceptable	Rota cuts/ standpipes

* This is the frequency of this occurring in our baseline DO model run – it will differ in other modelled scenarios and does not change the stated company levels of service

Our baseline deployable output (DO) modelling of the 91 year period from 1920 to 2010 shows that the three most critical droughts in our region are: 1944, 1976 and 1984. Our water resource modelling shows that these are the three droughts when we would have needed to impose a TUB. These three droughts are the same critical drought events mentioned in our 2014 drought plan. We have used our stated three in 100 level of service for TUBs and non essential use bans in both plans. Our stated and our modelled frequency of restrictions is consistent between our WRMP and our drought plan.

Our water resource model, our drought trigger zones and our assumptions in relation to demand reductions are consistent between this final WRMP and our drought plan. As a result there are no discrepancies between the level of service in our drought plan and the level of service in our final WRMP.

Although we provide a higher level of service than most companies, we do this at the lowest possible cost to our customers. If we planned on the basis that we will never impose restrictions even during times of drought, it would not be economically or environmentally feasible to meet unrestrained consumer demand in all possible circumstances. If we planned never to restrict the use of water, customers' bills would have to be higher. Conversely there are potential savings if we planned to restrict customers more frequently.

In order to produce this WRMP we carried out extensive water resources modelling using an Aquator model of our water resources system. This modelling enabled us to review and improve our estimates of deployable output (DO). Our 'baseline' DO is consistent with our existing three in 100 stated level of service. We describe the way that we modelled TUBs and non essential use bans in Appendix A2, which contains more detail on the modelled frequency of these restrictions and the associated reduction in demand that we assume in our modelling.

Figure A6.2: Elan Valley modelled baseline DO storage entering drought trigger zones E and F in the 1976 'summer'

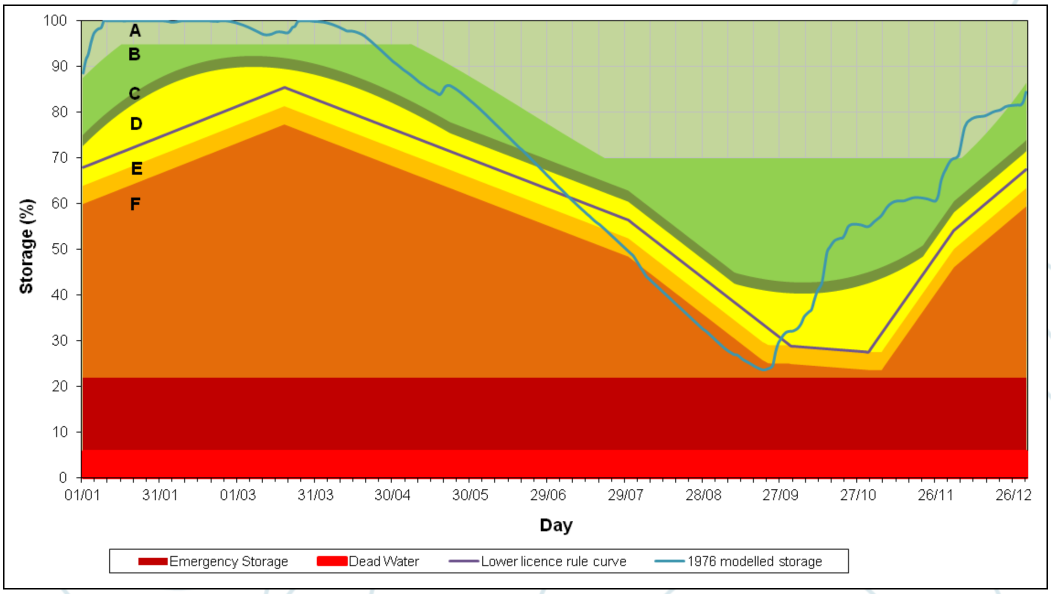
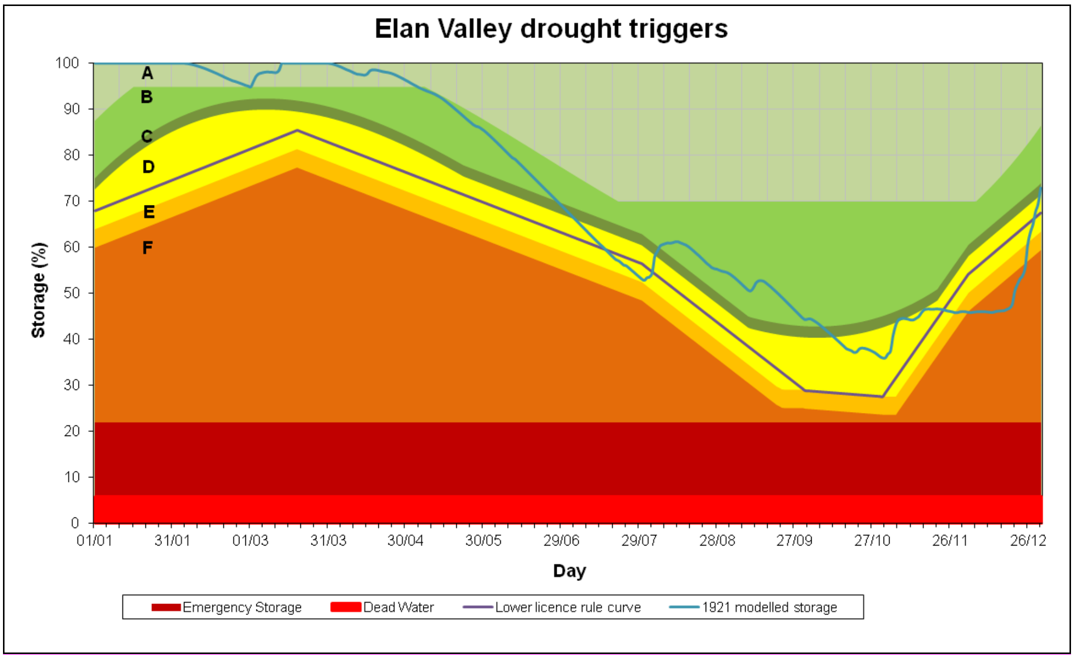


Figure A6.3: Elan Valley modelled baseline DO storage entering drought trigger zones E and F in the 1921 'winter'



We describe how we derived these updated drought triggers and the associated drought management actions in our 2014 drought plan.

A6.2 A flexible approach to levels of service

Section 2.9 of the EA's *2012 Water Resources Planning Guidelines* suggests that water companies consider whether they "*can deliver a given level of service more efficiently by taking a flexible approach, bringing forward investment or increasing operating expenditure (for example, to reduce leakage) when the risk of exceptionally dry weather becomes a reality."* We have recent experience of this. For example, during the drought which ended in 2012 we implemented several drought management schemes in the south of our strategic grid WRZ. We did this as a direct response to low storage in Draycote reservoir. One of these schemes was to transfer water from elsewhere in our grid to Draycote (see figure below).

Figure A6.4: Transfer from Leamington to Draycote reservoir

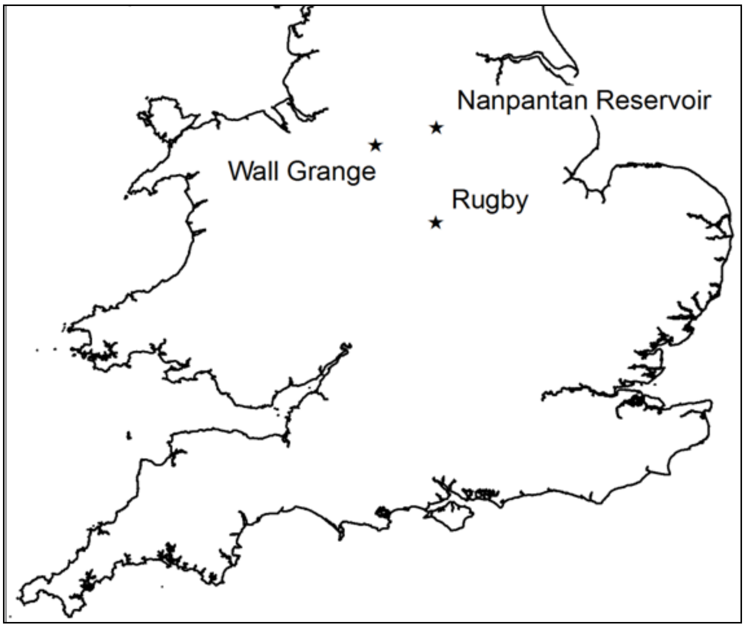
Although these schemes increased our operating costs in the short term they reduced the likelihood that we would need to take more drastic drought management actions such as TUBs or drought permits. We have provided more operational detail of this and other drought management actions in our 2014 drought plan.

A6.3 Extending the period of our hydrological analysis

The modelling we undertook to support our *WRMP09* used an 88 year flow time series for the period 1920 to 2007 for catchments across our region. The water resources modelling we have used to support this plan uses a 91 year flow record. This flow record extends from 1920 to 2010 and we do not have hydrological flows for the period before 1920. However, as a frequency of three TUBs in 91 years is equivalent to 3.3% of the modelled years having TUBs, we consider this to be consistent with our three in 100 level of service.

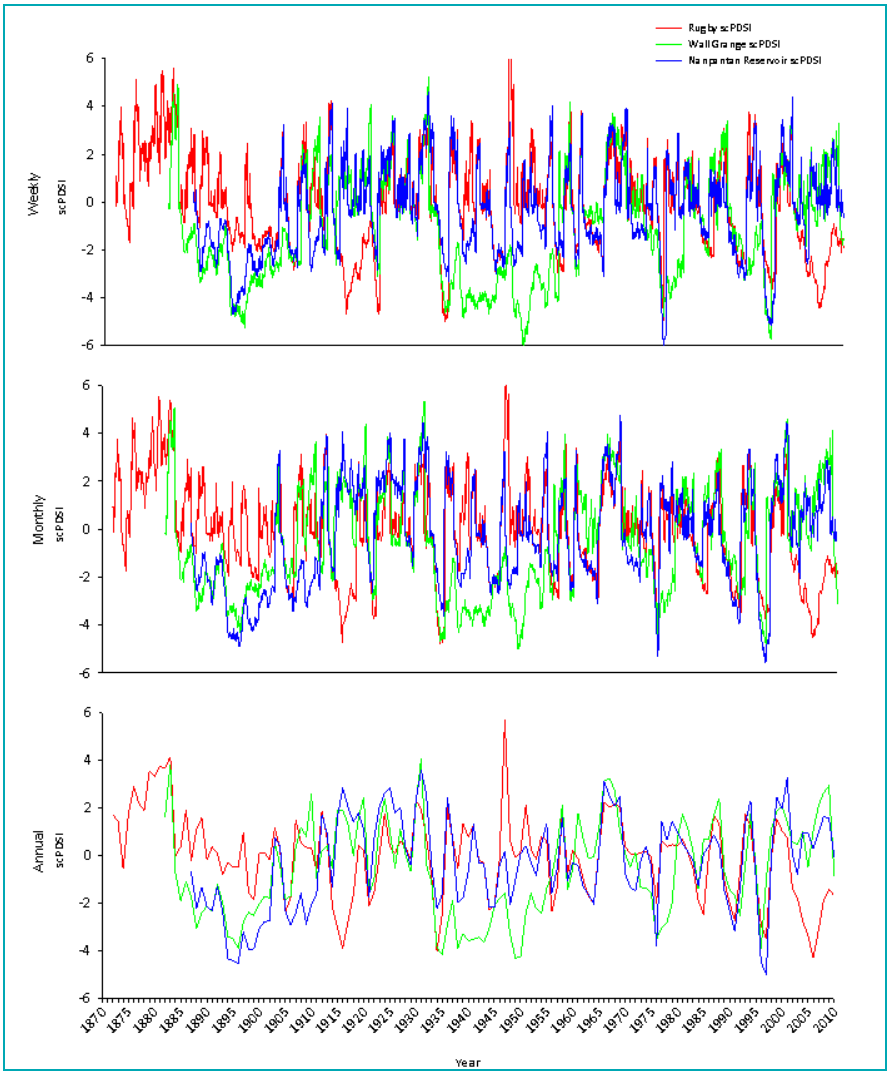
In order to provide us with further confidence in our ability to meet our stated level of service, we have worked with Liverpool University to study rainfall records within our region that date back to the 1880s. This research looked at long term rainfall records in three locations: Wallgrange, Rugby and Nanpantan. The following figure shows the location of these three sites:

Figure A6.5: Location of Liverpool University research study sites



One of the lessons we learned from this research was that, although there were some longer duration drought events in the forty year period prior to 1920, none of these drought events was more severe than the worst three droughts between 1920 and 2010. The following graphs show how the Self Calibrating Palmer Drought Severity Index (scPDSI) varies across the three locations from the 1870s to 2010.

Figure A6.6: Drought severity index at Wallgrange, Rugby and Nanpantan



We have presented graphs here of a drought index rather than a measure like annual rainfall as we consider a drought index will correlate more closely with the likelihood that we will need to impose restrictions on our customers' use of water. The Liverpool University research demonstrated that this specific drought severity index is the most appropriate one for this study. This research is available on request.

As described above we extended our flow record between our *WRMP09* and this final plan. We plan to extend it further before we start to prepare our 2019 WRMP. When we do this it will then include the flows to cover the period of the drought that ended in 2012.

A6.4 Relationship between levels of service and deployable output (DO)

Appendix A2 demonstrates the sensitivity of the relationship between our level of service and deployable output. For example, figure A2.10 shows how the DO in our strategic grid water resource zone (WRZ) is the same with the reference level of service, one TUB every ten years, as it is for 3 in 100. This graph also shows that, in the strategic grid, if we planned to improve our level of service to customers so that they received no TUBs then this would reduce the DO available.

We have reviewed the output of the modelled scenarios looking at the sensitivity of our system to different levels of service. In the modelling we have done to support this final WRMP, a change in levels of service as an option to balance supply and demand does not make a material difference to the scale of investment that we would need. This is one reason why we have not selected this option in our final WRMP. We have also reviewed the available evidence from customer views, set out below.

A6.5 Customer views on our levels of service

In preparation for our final WRMP we have reviewed the evidence we have about customer support for different levels of service. In summary, this evidence shows that:

- Our 2007 survey supported the current level of service;
- Information we collected in 2012 conflicted with this and with at least some customer research by other water companies;
- The evidence from the 2012 survey suggests that customers may not have been clear about the options that we proposed
- Our most recent research shows that our customers support a frequency of restrictions of once every 38 years.

This is so close to our existing level of service that we do not propose making any changes to it.

When talking to our customers on the question of restrictions we do not distinguish between the different types of restrictions. We will not make any decisions about the level of service that we offer our customers without clear evidence. We think that customer support is particularly important if we were ever to change the levels of service that we provide to our customers. This is true of any change, but is particularly important if we were to reduce our levels of service, even if this helped keep bills lower than would otherwise be the case.

A6.6 Consistency between actual and planned levels of service

In the Severn Trent region our customers have not experienced a restriction on their use of water since the 1995-96 drought. This period includes the twelve month period to February 2012 which was the driest in the Midlands region since records began in 1910 (source: *Environment Agency water situation report, February 2012*). Despite this extremely dry period we were able to manage our water resources without recourse to customer restrictions.

As our baseline DO modelling showed, the three most critical droughts in our record for the Severn Trent region are: 1944, 1976 and 1984. There is an apparent inconsistency in the fact that these three years do not include 1995-96 which was a drought that actually caused us to restrict our customers demand. However, this is because there are numerous differences between the current demands and infrastructure that are reflected in our Aquator model and those that existed in reality during 1995 and 1996. For example, we have reduced leakage significantly since 1996. What this modelling has shown is that our current water resources network, the demands for water and the associated infrastructure, as currently modelled, are significantly different to what existed in 1995-96.

Throughout the planning period (2015 to 2040) we plan to maintain the level of service we currently provide to our customers. As we described earlier, when we carry out our baseline DO modelling we set the maximum number of TUBs as three within the 91 year run. These DO values, based on the three in 100 year level of service, then feed into our baseline WRMP tables. If there is a supply-demand deficit in any WRZ the timing and the magnitude will be shown in Ml/d. In our final planning tables we then show how we plan to reduce demand or increase supplies to make up any predicted deficits. This approach is consistent with our previous WRMP. However, this approach to deriving our baseline scenario does not allow for the level of service to vary across the planning period. As mentioned previously we considered this as an option to balance supply and demand but have not selected it as part of our least cost mix of options.

As this approach to levels of service and DO means that there is no difference between baseline and planned level of service there is no need to reconcile any differences.

A7 Baseline supply projections

Appendices A1 to A5 describe how we have modelled current and projected water available for use. Appendix A7 summarises the baseline deployable output projections, showing the impacts of the Restoring Sustainable Abstraction programme and climate change. We also show the projected water available for use in each zone, taking account of outage risks and available bulk imports and exports.

Bishops Castle zone

Figure A7.1: Bishops Castle baseline deployable output

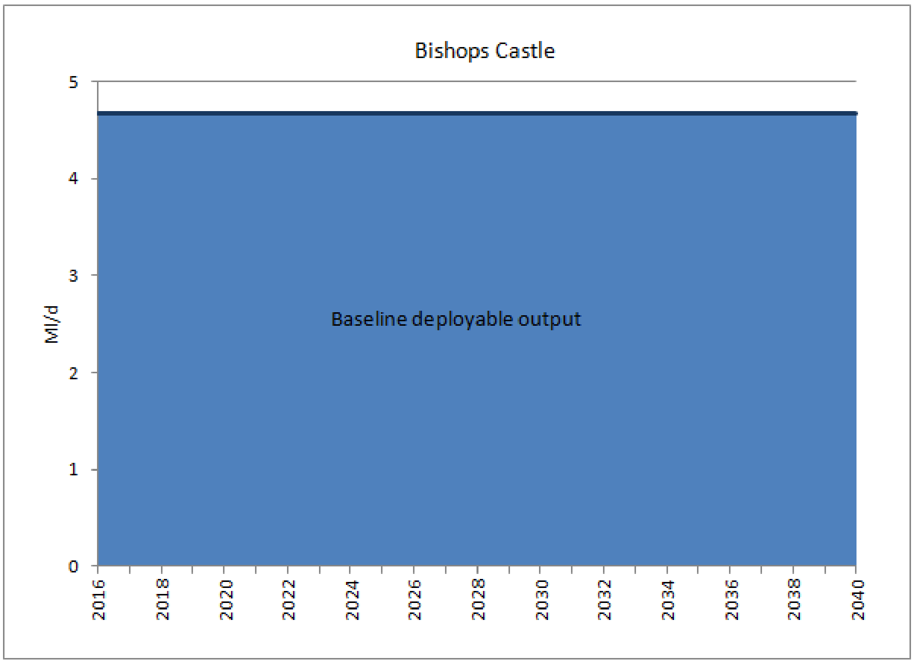
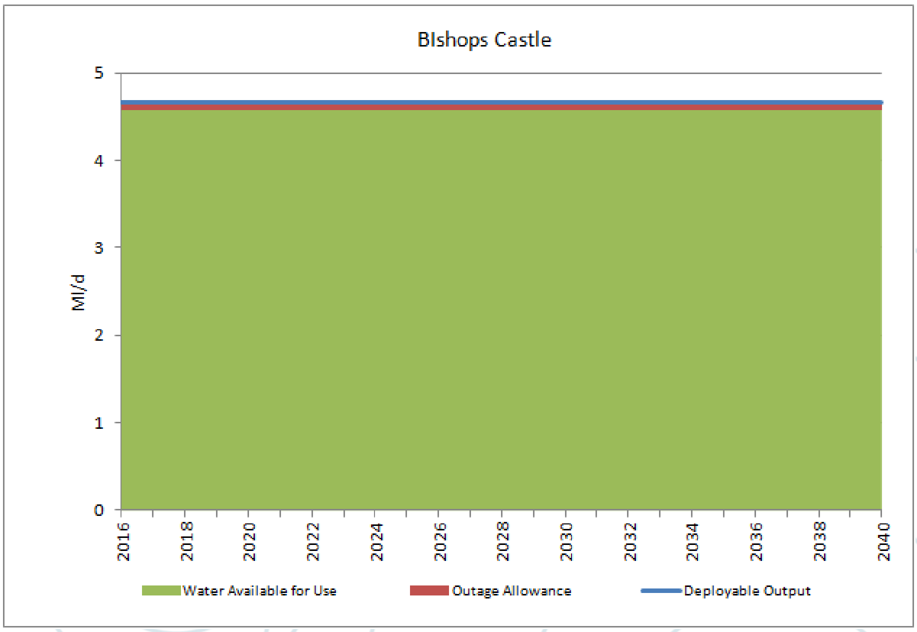


Figure A7.2: Bishops Castle baseline water available for use



Forest and Stroud zone

Figure A7.3: Forest and Stroud baseline deployable output

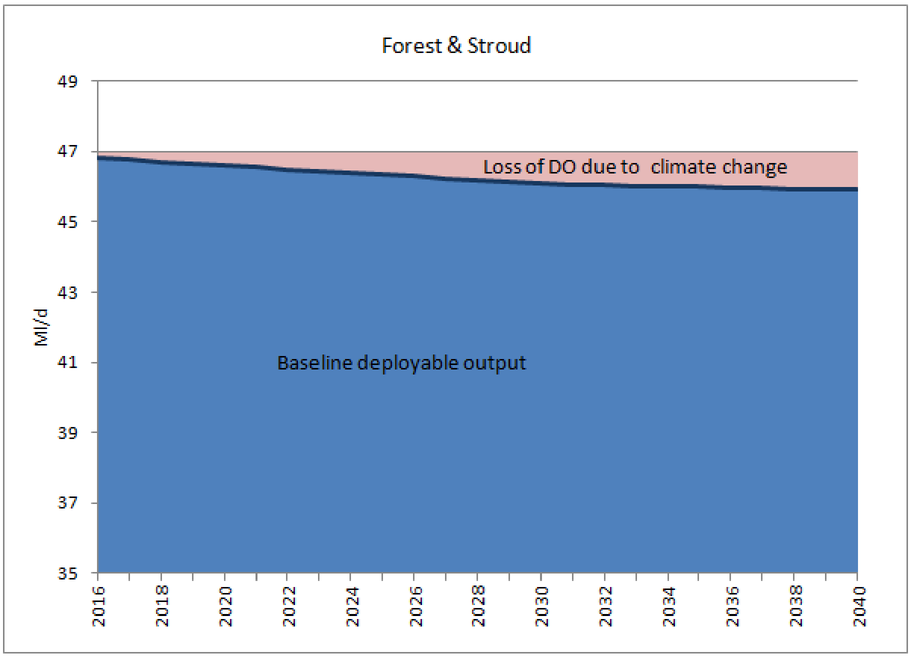
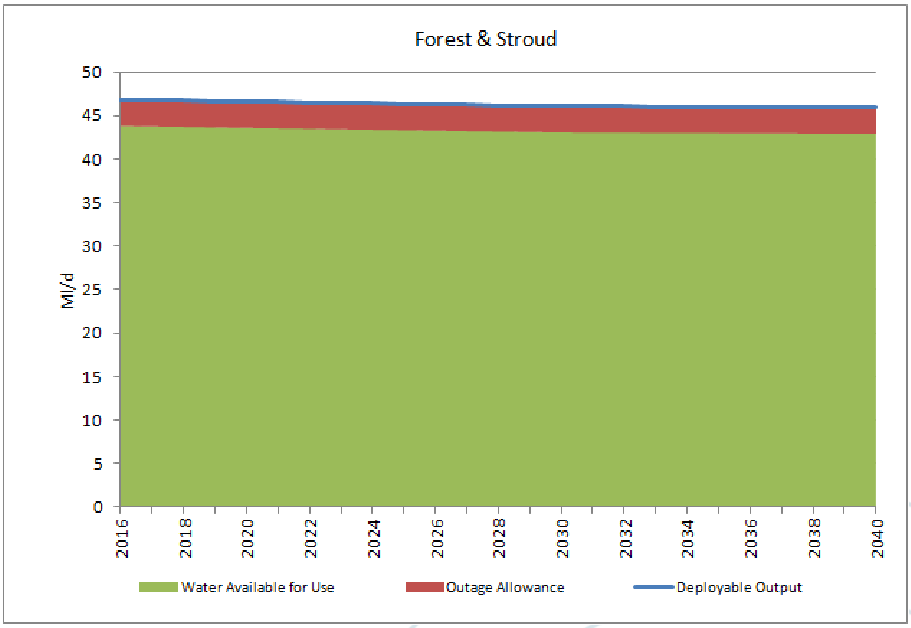


Figure A7.4: Forest and Stroud baseline water available for use



Kinsall zone

Figure A7.5: Kinsall baseline deployable output

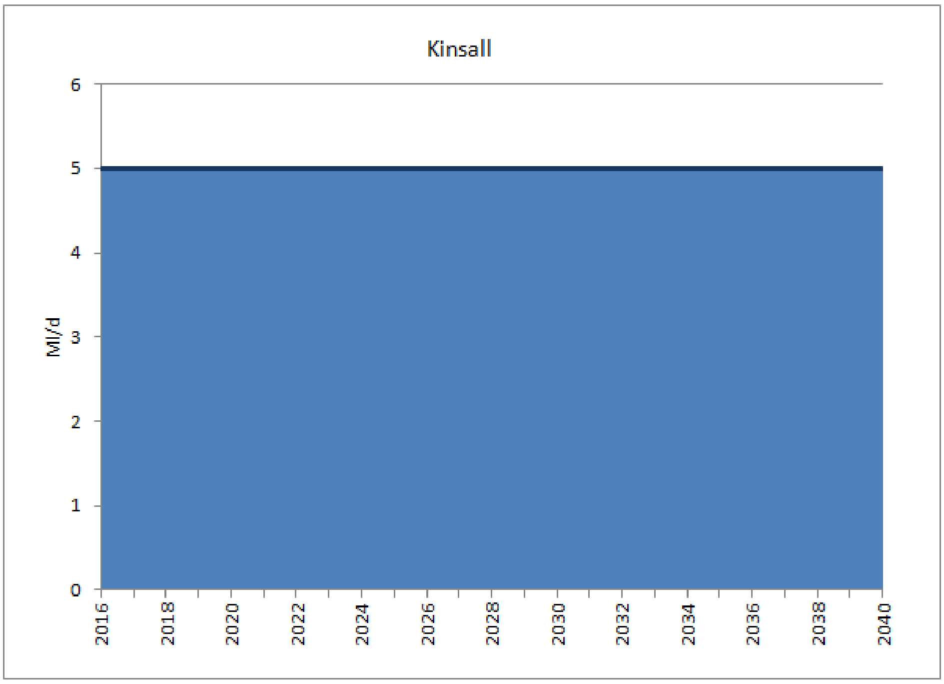
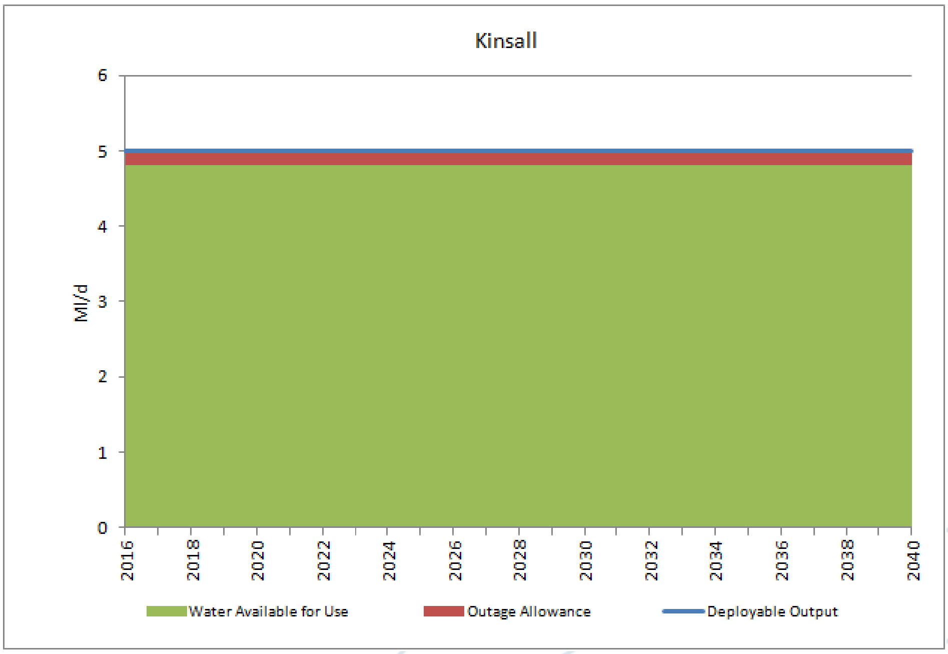


Figure A7.6: Kinsall baseline water available for use



Llandinam and Llanwrin zone

Figure A7.7: Llandinam and Llanwrin baseline deployable output

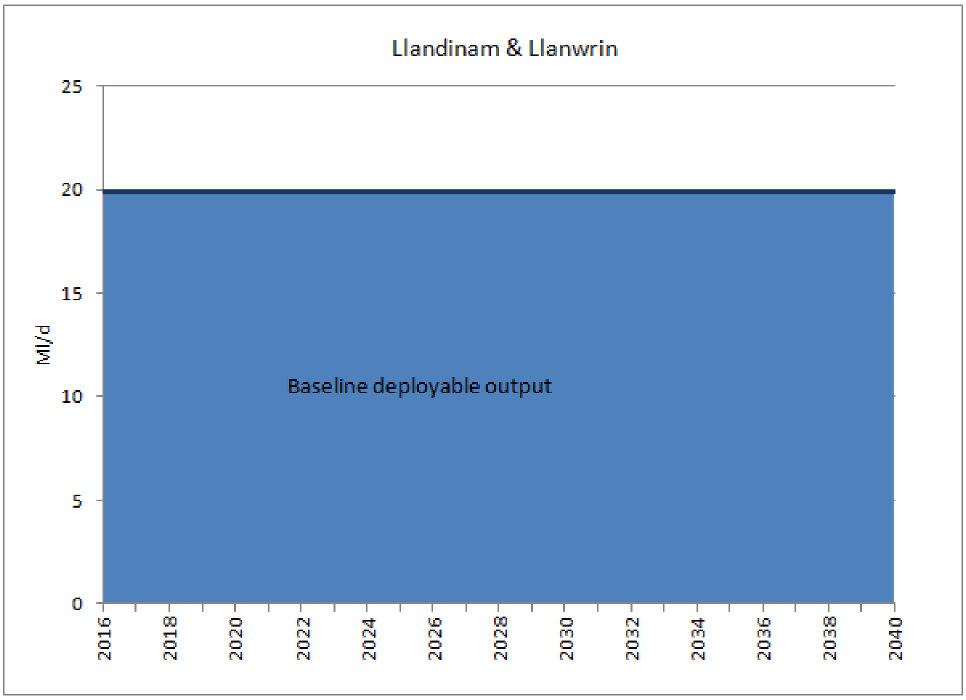
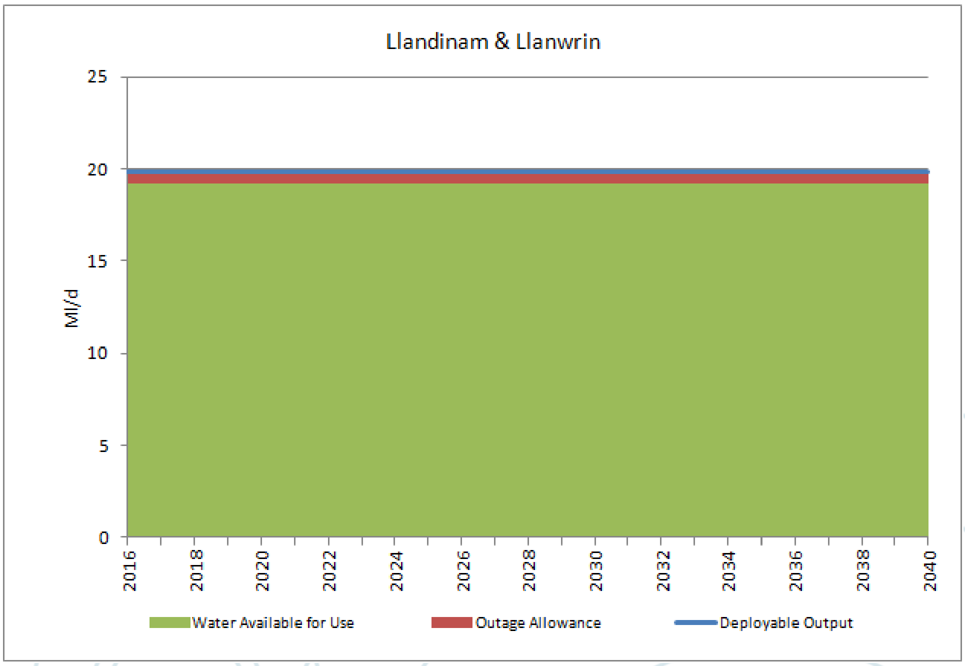


Figure A7.8: Llandinam and Llanwrin baseline water available for use



Mardy zone

Figure A7.9: Mardy baseline deployable output

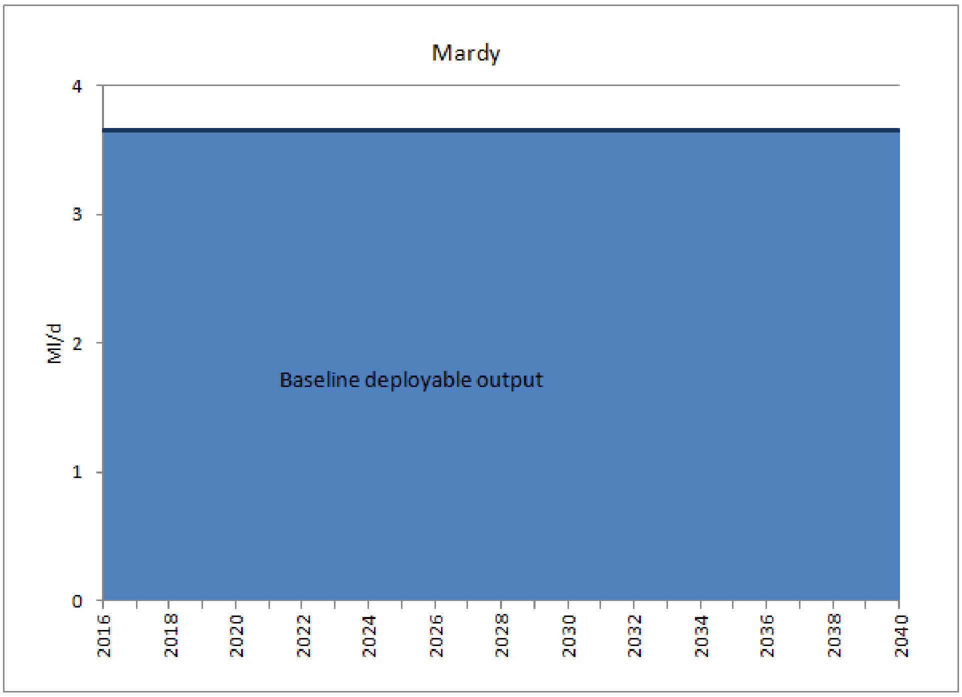
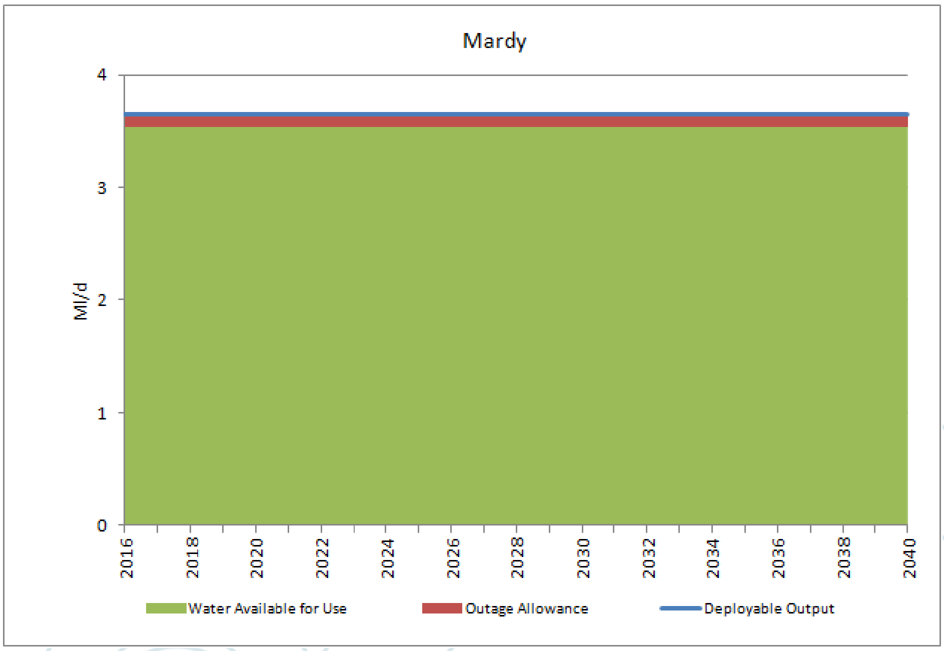


Figure A7.10: Mardy baseline water available for use



Newark zone

Figure A7.11: Newark baseline deployable output

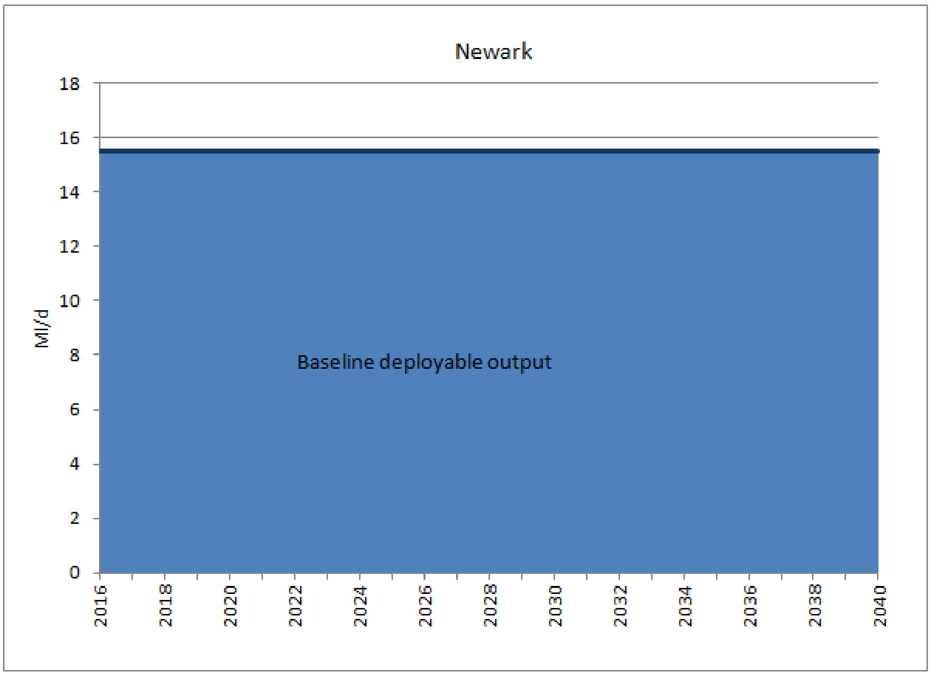
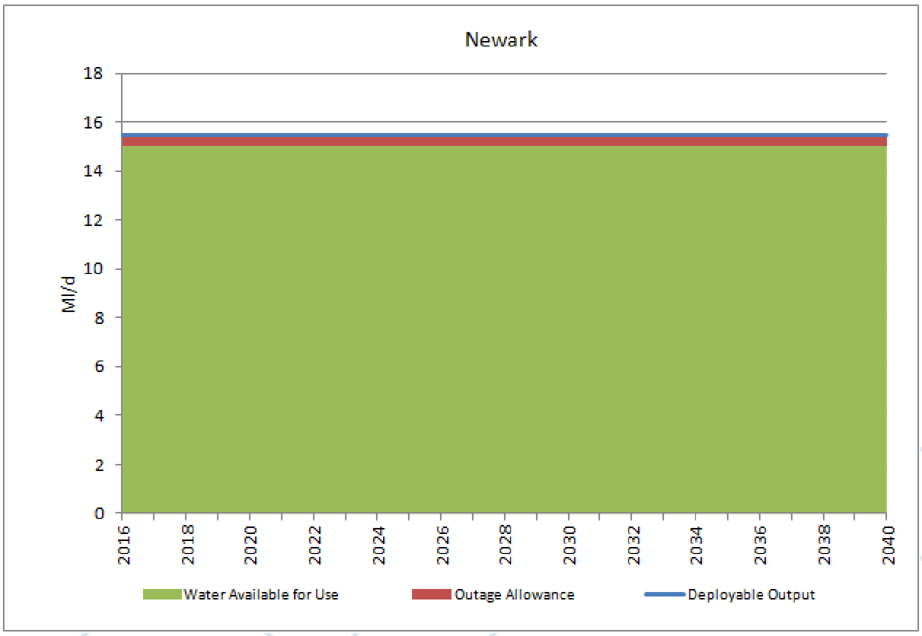


Figure A7.12: Newark baseline water available for use



North Staffs zone

Figure A7.13: North Staffs baseline deployable output

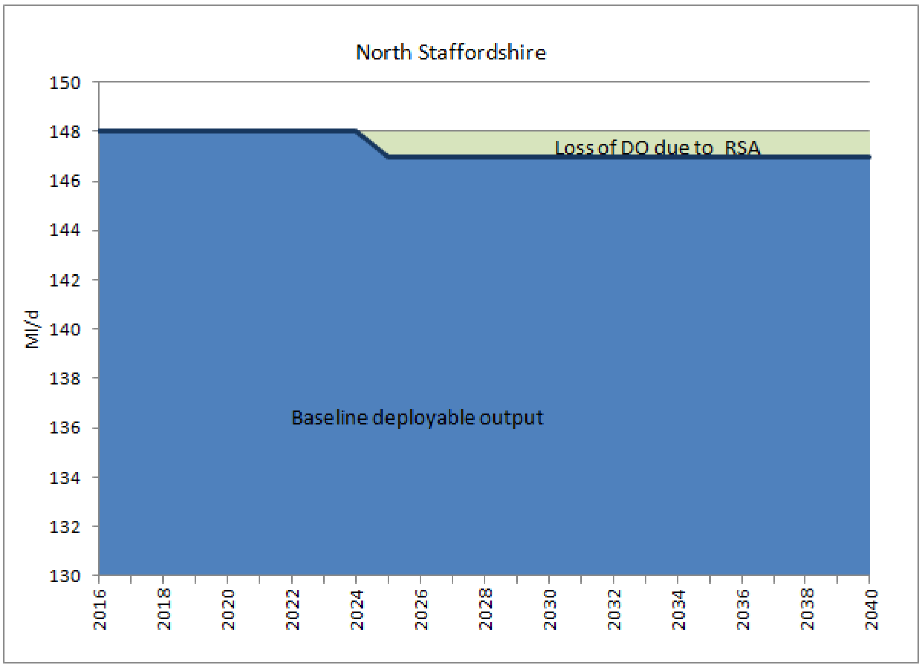
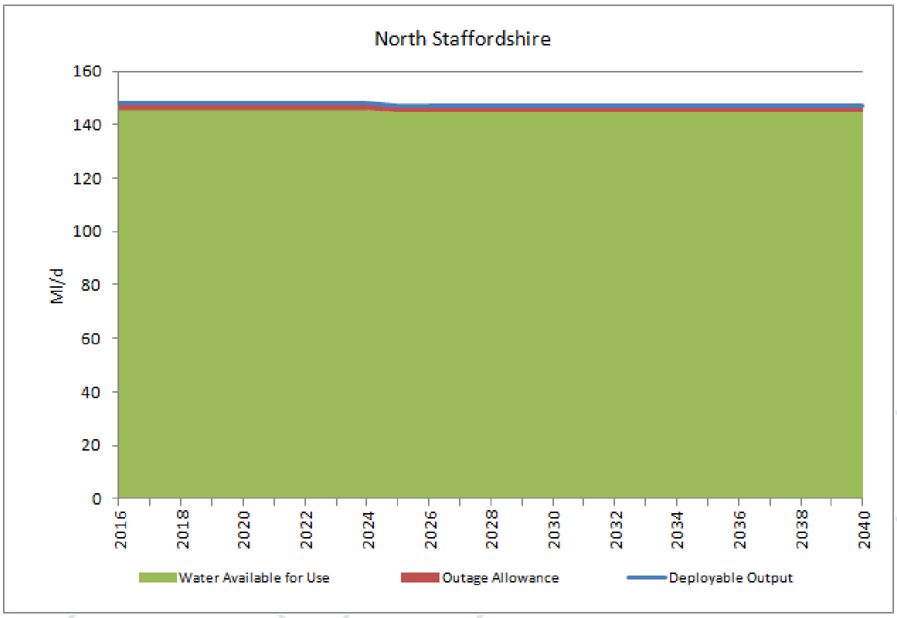


Figure A7.14: North Staffs baseline water available for use



Nottinghamshire zone

Figure A7.15: Nottinghamshire baseline deployable output

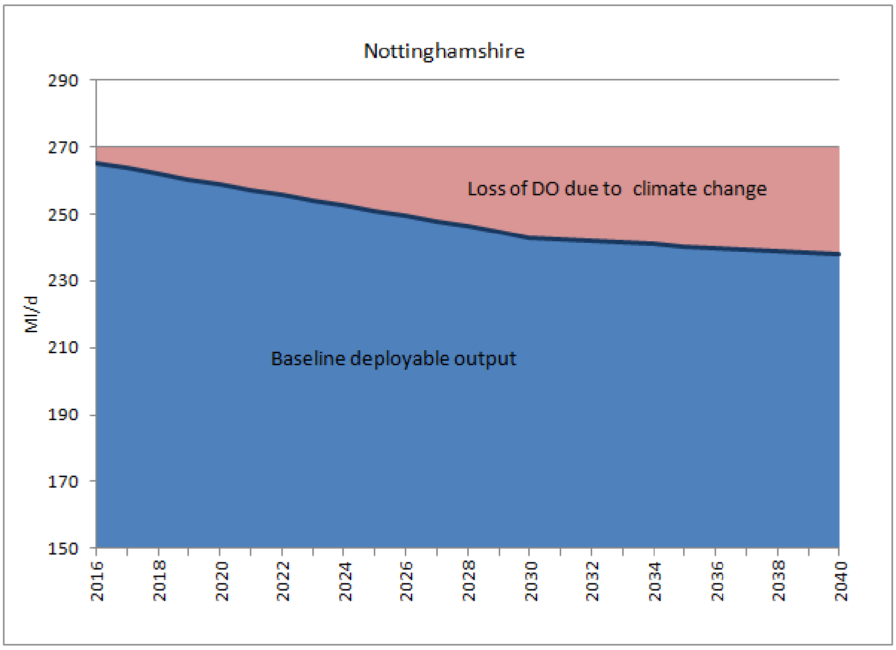
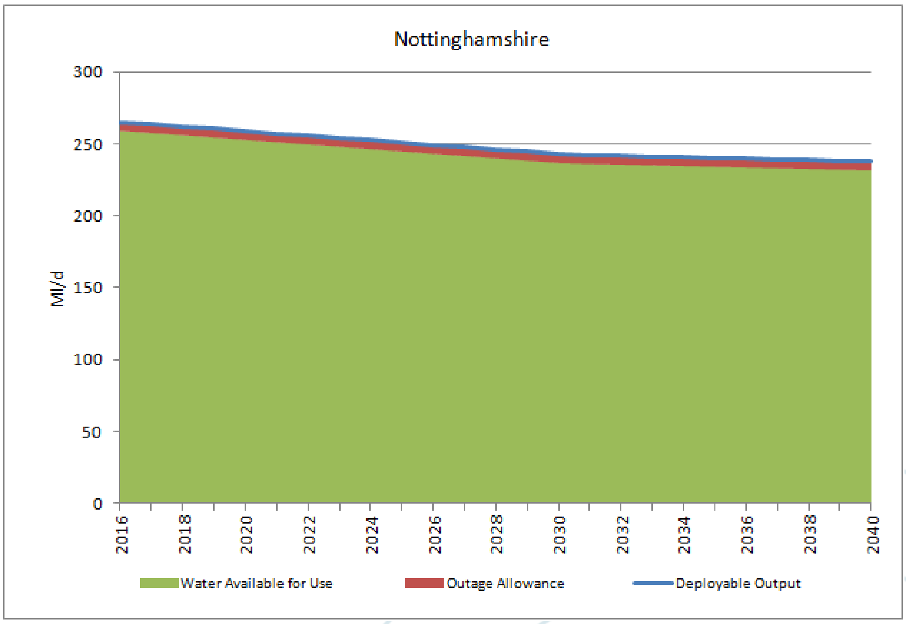


Figure A7.16: Nottinghamshire baseline water available for use



Rutland zone

Figure A7.17: Rutland baseline deployable output

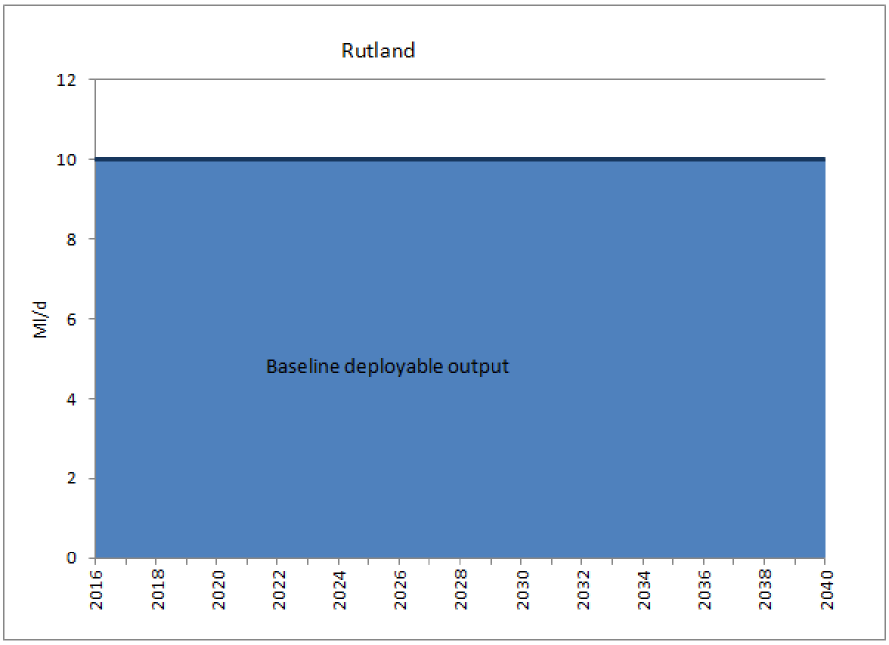
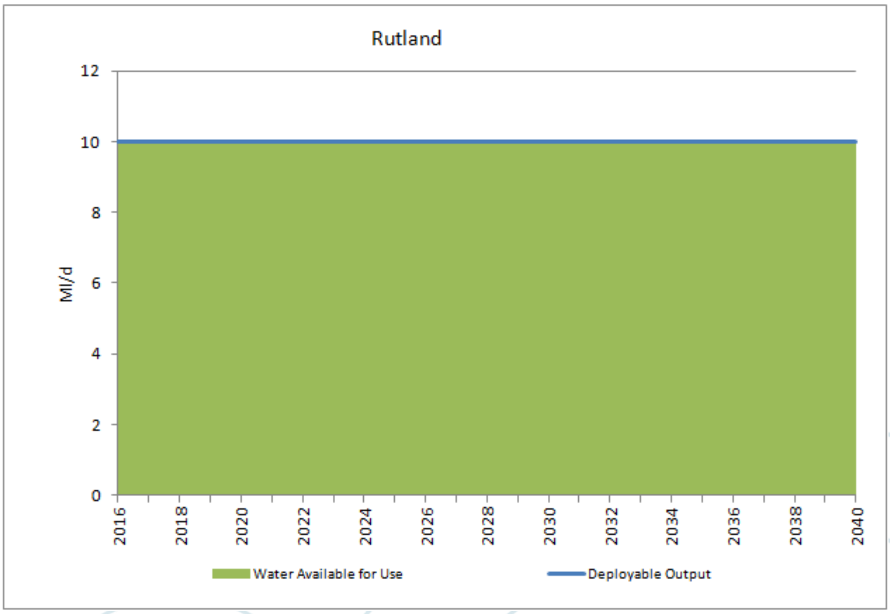


Figure A7.18: Rutland baseline water available for use



Ruyton zone

Figure A7.19: Ruyton baseline deployable output

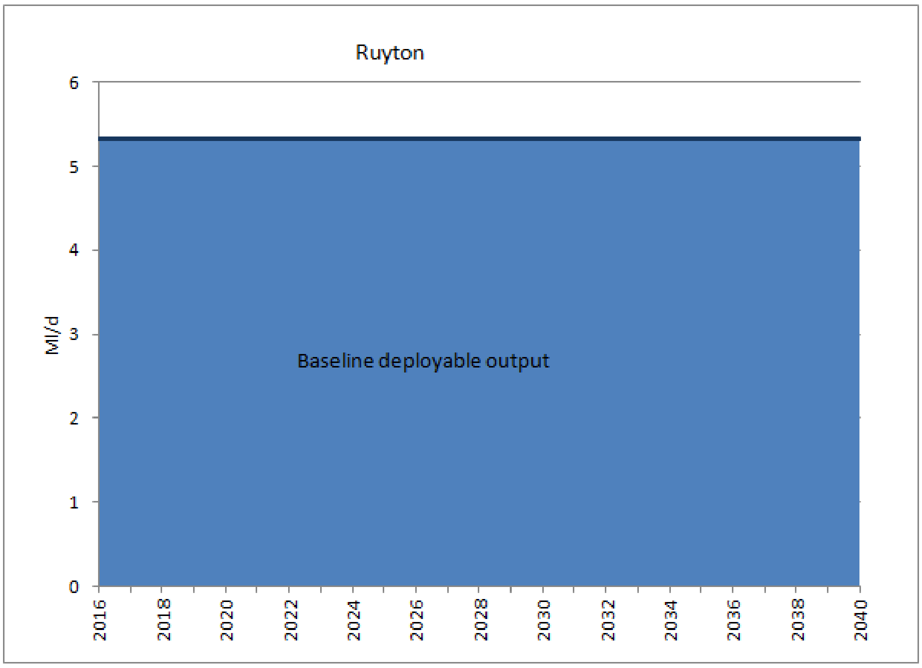
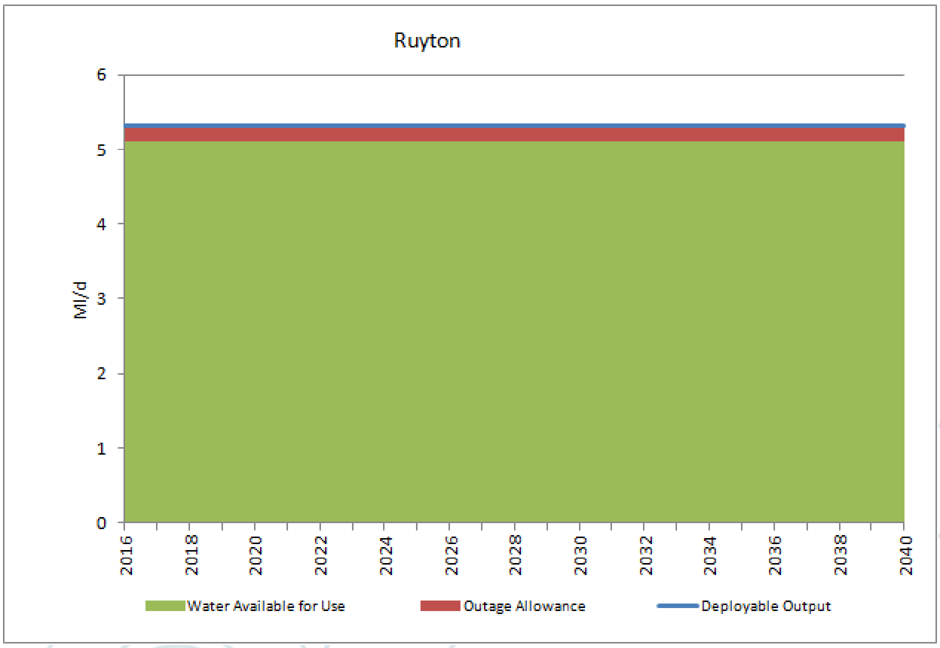


Figure A7.20: Ruyton baseline water available for use



Shelton zone

Figure A7.21: Shelton baseline deployable output

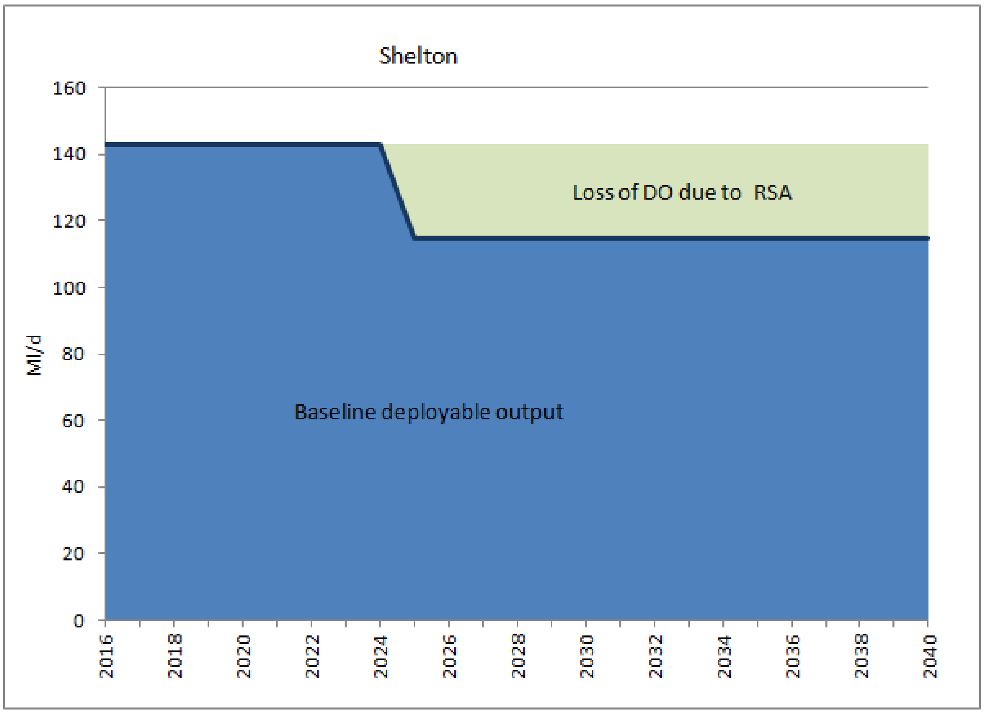
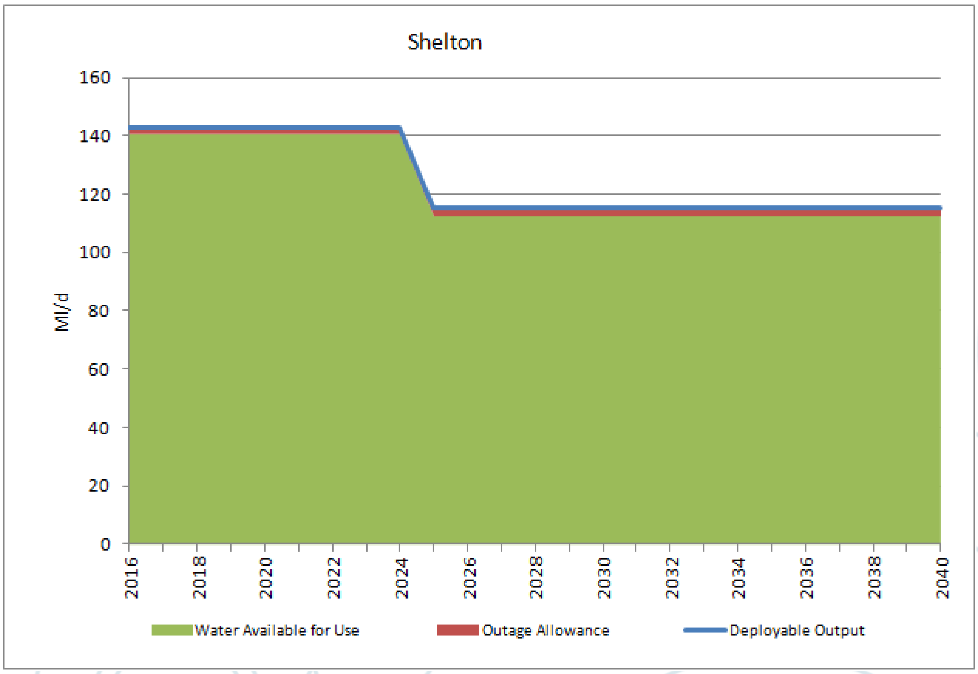


Figure A7.22: Shelton baseline water available for use



Stafford zone

Figure A7.23: Stafford baseline deployable output

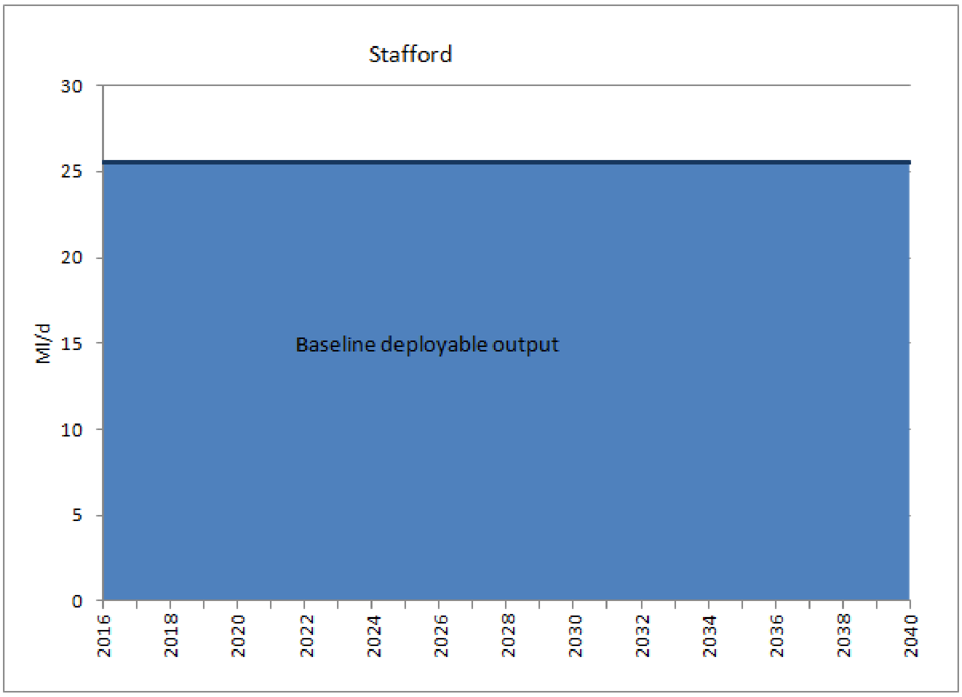
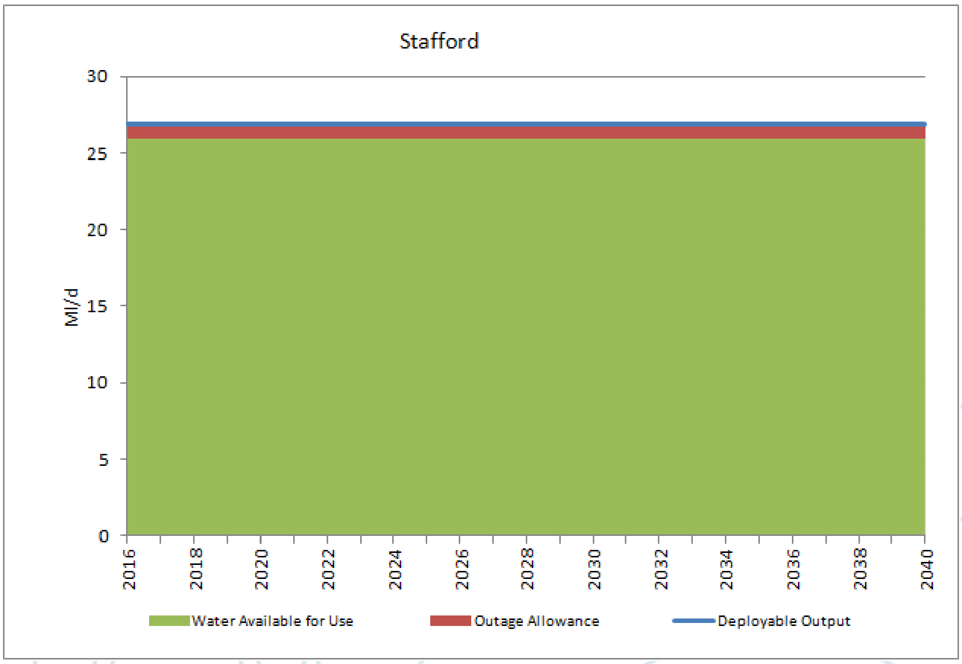


Figure A7.24: Stafford baseline water available for use



Strategic Grid zone

Figure A7.25: Strategic Grid baseline deployable output

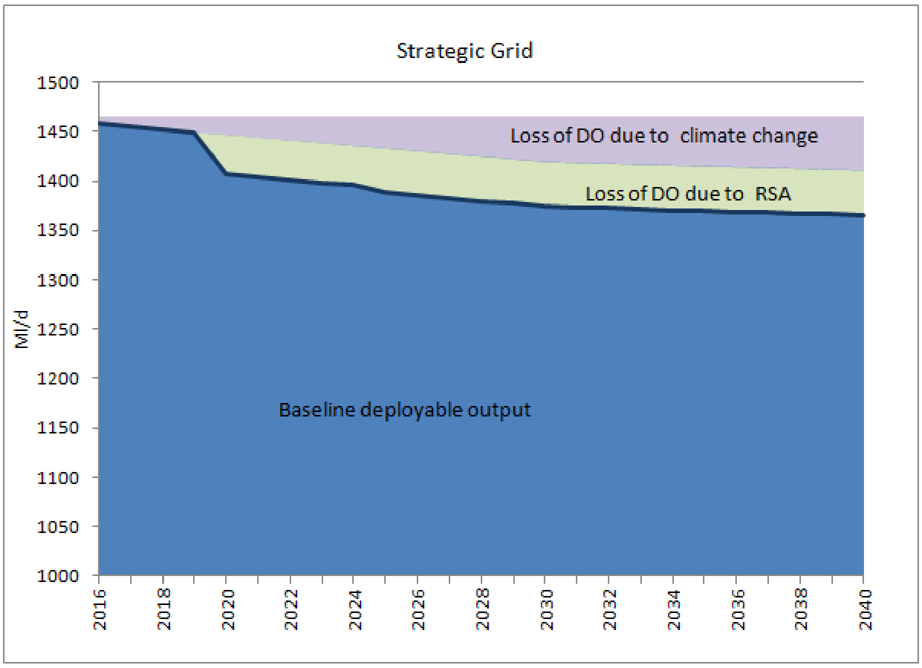
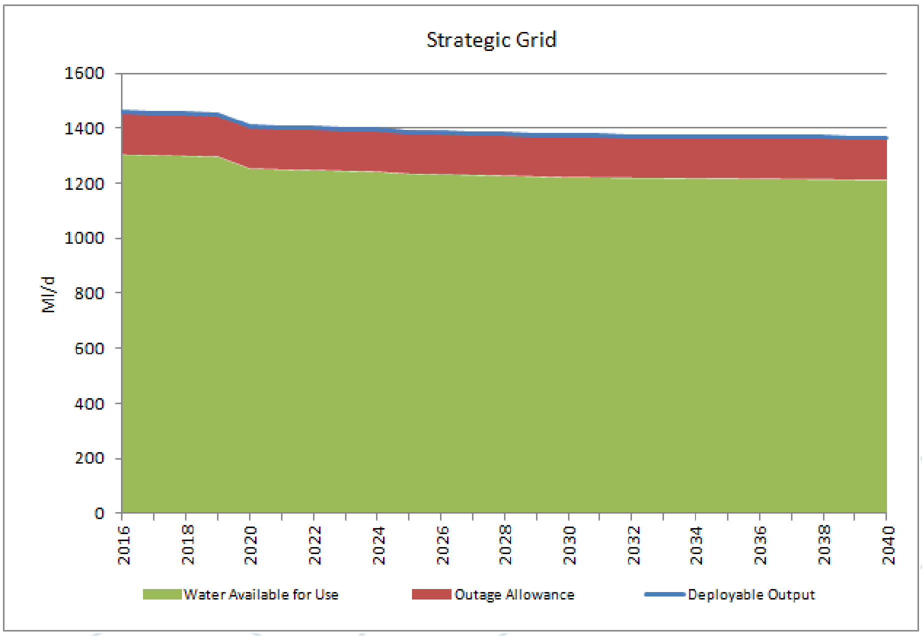


Figure A7.26: Strategic Grid baseline water available for use



Whitchurch and Wem zone

Figure A7.27: Whitchurch and Wem baseline deployable output

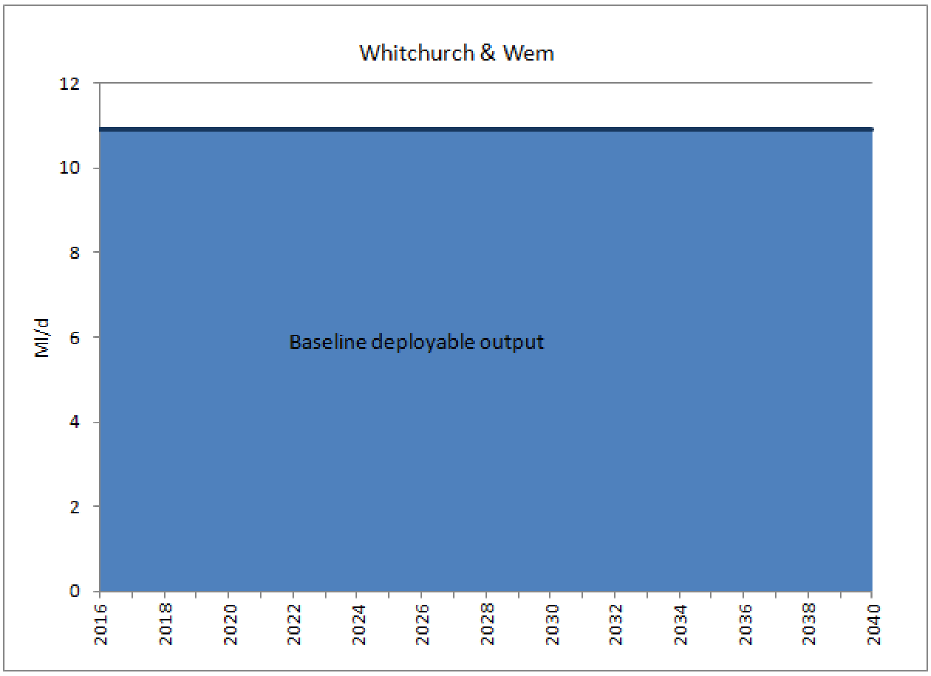
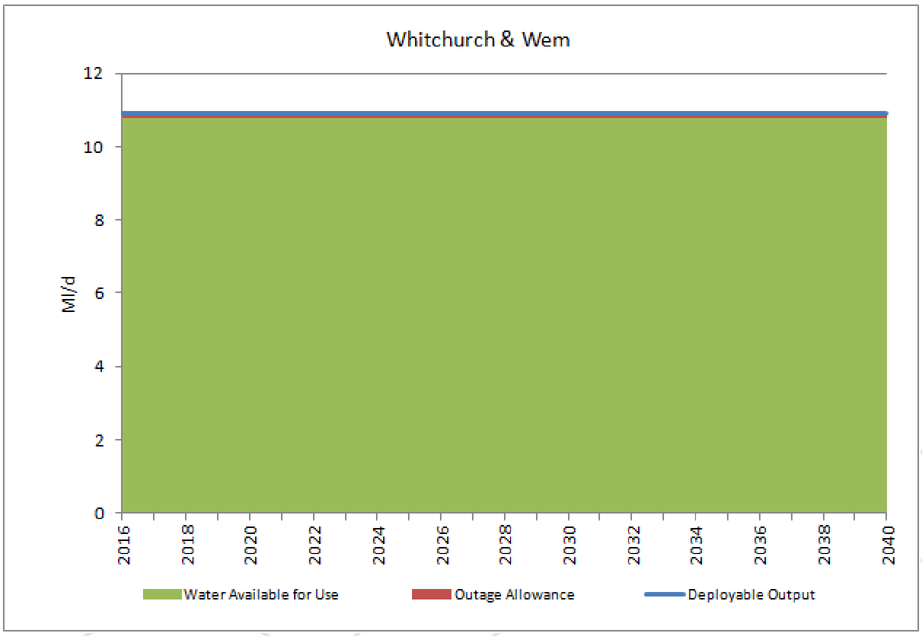


Figure A7.28: Whitchurch and Wem baseline water available for use



Wolverhampton zone

Figure A7.29: Wolverhampton baseline deployable output

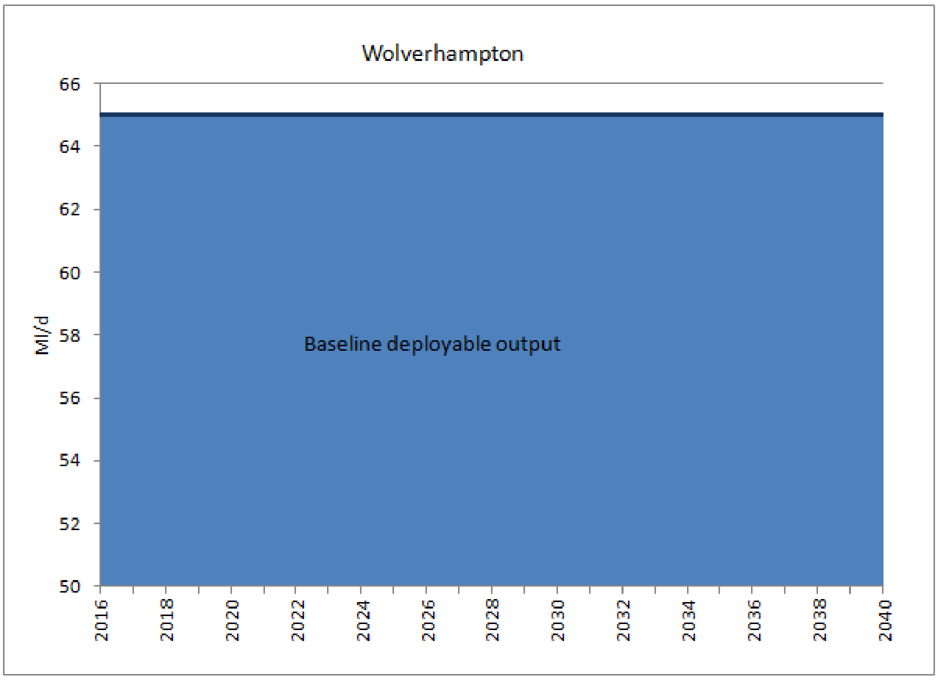


Figure A7.30: Wolverhampton baseline water available for use