Appendix C

Drought Triggers: Development and scenario testing

1 Development of drought triggers

1.1 Introduction

The aim of our drought plan is to demonstrate how we would manage resources and demands through a number of variable but plausible drought sequences, by implementing a range of available management options. The plan does not set out to be prescriptive, as maintaining flexibility in the face of particular circumstances is a key requirement, but presents a framework and timetable of actions to be considered through the most likely drought sequences we might expect. This allows operational managers to make informed decisions and develop action plans to apply in an effective manner. We have developed a suite of drought indicators over subsequent plans, by applying historic parameters which inform the implementation off drought measures.

1.2 Hydrological Monitoring

We collect a range of hydrological data to monitor climatic and water resources conditions.

1.2.1 Rainfall and effective recharge

We maintain a network of rain gauges at selected treatment works, groundwater sources, and service reservoirs. This information is also provided to the Environment Agency. Company rainfall statistics are based on the long term daily data from its gauge at Seedy Mill (1912 to present day). Daily data is also measured at the River Severn Works (1968 to present day).

The Environment Agency (EA) maintains and reports on a comprehensive hydrometric and environmental monitoring network, developed between the 1960’s and 1990’s, for the purposes of its duties to protect and improve the water environment. This information has been made available to water companies by the Agency. We have arrangements to exchange data at selected sites where the EA directly measure rainfall using tipping bucket rain gauges.

Climate data is collected by the Met Office as part of its MORECS service and weekly averaged data of rainfall, evaporation and soil moisture deficit (a measure of how dry the soil is) which we purchase.

1.2.2 River Flows and Reservoir Volumes

Operational data on reservoir level, reservoir storage, abstraction and compensation releases from Blithfield Reservoir are recorded on our telemetry system. Blithfield storage is the main drought trigger within this plan. Inflows from the River Blithe upstream of the reservoir have also been directly measured since 2012. Longer term inflow statistics are determined by mass balance calculation from the operational data, and further estimated by use of a catchment HYSIM model for the long term historic period (1884 to 2014).

We measure river flows on the Blithe in order to manage the River Blithe Pumpback abstraction, and the supporting River Trent abstraction.

River Blithe flows are measured more accurately at the EA flow gauging station at Hamstall Ridware. The EA also measures river flows at a number of sites along the River Trent including North Muskham which is used to regulate the Pumpback abstraction by means of a Hands Off Flow. Data from key EA gauges can be accessed by means of telemetry systems to allow a rapid response to prevailing environmental conditions.

We continuously measure bankside storage reservoir levels as part of the River Severn Works supply system.

The EA collates reservoir level data for Clywedog Reservoir and Lake Vyrnwy and maintains flow gauging station along the length of the River Severn as part its operational management of the River Severn.

1.2.3 Groundwater levels

We maintain an automated groundwater level monitoring system at its groundwater sources, which is linked to telemetry. Information on abstraction rate and pumping water level is recorded, and can be compared to historical records when required.

The EA maintain a number of groundwater observation boreholes across the supply area and in the Shropshire Groundwater Scheme catchments which are used to support River Severn regulation. These are generally manually measured monthly, or use recording equipment which has to be accessed on site monthly.

1.2.4 Environmental data

We installed a number of flow gauging stations and groundwater level piezometers in vulnerable catchments with automated monitoring equipment, as part of the National Environment Programme. Data on these catchments has been collated for a period of between 5 and 8 years so far.

1.3 Drought Indicators

In addition to monitoring the rest water levels at the key indicator sites, we continue to use cumulative recharge deficit as a drought indicator. The recharge deficit is deduced from monthly data provided by the Meteorological Office Rainfall and Evaporation Calculation System (MORECS). We consider that monthly data is adequate for this purpose, given the slow response times of our groundwater sources. Rest water levels are monitored monthly under normal conditions, and both drought indicators are monitored more regularly once a drought sequence seems likely, and during a drought.

Recharge deficit was adopted as a drought indicator following detailed studies undertaken by consultants into appropriate indicators. Prior to this, cumulative rainfall deficit had been used as an indicator, but this was shown by the studies to be a less reliable measure. For example, a summer of high rainfall in between two dry winters, whilst suggesting a low rainfall deficit, gave no indication of the effectiveness of the rainfall in aquifer recharge. Cumulative recharge deficit is calculated from the MORECS data on effective precipitation supplied by the Meteorological Office.

Borehole rest water level (RWL) continues to be used as an indicator of the overall condition of the aquifer during a drought, by comparing it with the long-term average RWL for each indicator site. During a drought sequence recharge deficit increases over time and gives an indication of the length and severity of the drought. Measurement of the cumulative recharge deficit begins in the month when the rest levels at three or more of the six indicator sites fall below their long-term average level and continues until normal conditions have resumed.

A spreadsheet tool allows both indicators (borehole rest water level and cumulative recharge deficit) to be monitored continuously and provides timely warning when trigger levels are exceeded.

1.3.1 Blithfield Reservoir and the River Blithe Pumpback

We will continue to monitor and analyse reservoir storage trends using forecasting tools to advise operational use of Blithfield Reservoir. In addition to this, we utilise statistical tools that indicate the severity of rainfall deficits and low flows observed in any particular year. These will be used as part of its assessment of an exceptional shortage of rain should it need to apply for a drought permit. The cumulative flow and rainfall data for the upper catchment in the calendar year has been developed for this plan as a good indicator of emerging drought conditions.

The availability of the River Blithe pumpback is an important element of operational management for Blithfield Reservoir but is dependent on flows in the lower Trent at North Muskham. There are periods in most years when flows fall below the Hands Off Flow (HOF) so this event is not a drought indicator in itself but extended periods of flows are characteristic of droughts. We monitor river flows on a daily basis and have established a level of concern which alerts the Company to likely failure in 30 days if no rainfall occurs.

1.3.2 The River Severn Works and River Severn

The assessment of hydrological data and prediction of drought conditions is carried out by the Environment Agency who operate the River Severn Regulation Scheme on behalf of the environment and all abstractors.

The EA use a variety of techniques such as analysis of groundwater level and river flow recessions, cumulative rainfall analysis (e.g. Tabony tables) as well as other modelling and forecasting tools.

In all but the wettest of years River Regulation is carried out. The EA provide a regulation prospects forecast at the start of the season and once regulation has started weekly regulation updates. These include their forecasts for the likelihood of regulation using the Clywedog and Shropshire Groundwater Scheme (SGS) and, potentially, the likelihood of application for a River Severn Drought Order.

In addition to this, we have identified statistical tools that indicate the severity of rainfall deficits and low flows observed in any particular year, independent of the regulated river system. These will be used as part of its assessment of an exceptional shortage of rain should it need to apply for a drought order. Single season flow in River Tanat and Met Office rainfall data for the Welsh Mountains area in conjunction with cumulative rainfall deficits and naturalised river flows in the Shropshire Plains have been identified for this plan as good indicators of emerging drought conditions.

1.3.3 Groundwater Sources and the Environment

Indicators of groundwater drought are provided by the Environment Agency observation borehole network. These are reported monthly through its Monthly Water Situation report (Midlands Area) which is generally published on the tenth day of the following month. For groundwater droughts this highlights where groundwater levels are “Below Normal”, “Notably Low” or ”Exceptionally Low” defined as equivalent to an event worse than 1 in 4 years, worse than 1 in 8 years, and worse than 1 in 20 years.

Our groundwater sources are generally resilient to drought with only a couple of sources impacted by low groundwater levels. However flows in some rivers and streams supported by baseflow from aquifers can be very vulnerable to changes in groundwater levels and this may affect our actions, particularly where we have put flow compensation schemes in place.

We have determined that long term (36 - 48 month) cumulative rainfall is a good predictor of groundwater levels in the EA groundwater network. Accordingly, we propose to use daily rainfall data collected at the Central and River Severn Works along with the relevant MORECS data to monitor pseudo groundwater levels across our supply area.

1.4 Drought Triggers

1.4.1 Drought Severity and Drought Triggers

We previously adopted a colour coded system which identified the severity of a drought and aligned with the two control rules we used by the Company to manage a drought situation, at Blithfield Reservoir, and the River Severn (Clywedog). Following a change in guidance from the EA, we have updated our trigger levels and curves to reflect the new level system, as are detailed throughout the plan.

As noted in previously the two critical resources within the Company are the River Severn and Blithfield Reservoir, as our groundwater sources are largely unaffected by drought.

The Environment Agency is responsible for managing the River Severn, and it has developed a set of trigger curves at Clywedog Reservoir in order to manage the river during a drought. These trigger curves have been included in this appendix in figure 1 below.

Drought trigger curves have also been developed by the Company for Blithfield Reservoir, and the chart detailing these is figure 2 in chapter 2.2.1 of the drought plan.

In addition to these control rules we will give due regard to a number of other factors when considering whether to implement its drought management actions. These factors include: the demand for water; sources which may be out of supply; the medium term weather forecast; the soil moisture deficit; the time of year, and; whether the level in Blithfield Reservoir is rising or falling. We reserve the right to use its discretion in the interpretation of the control rules and the implementation of the available actions.

1.4.2 River Severn triggers and actions

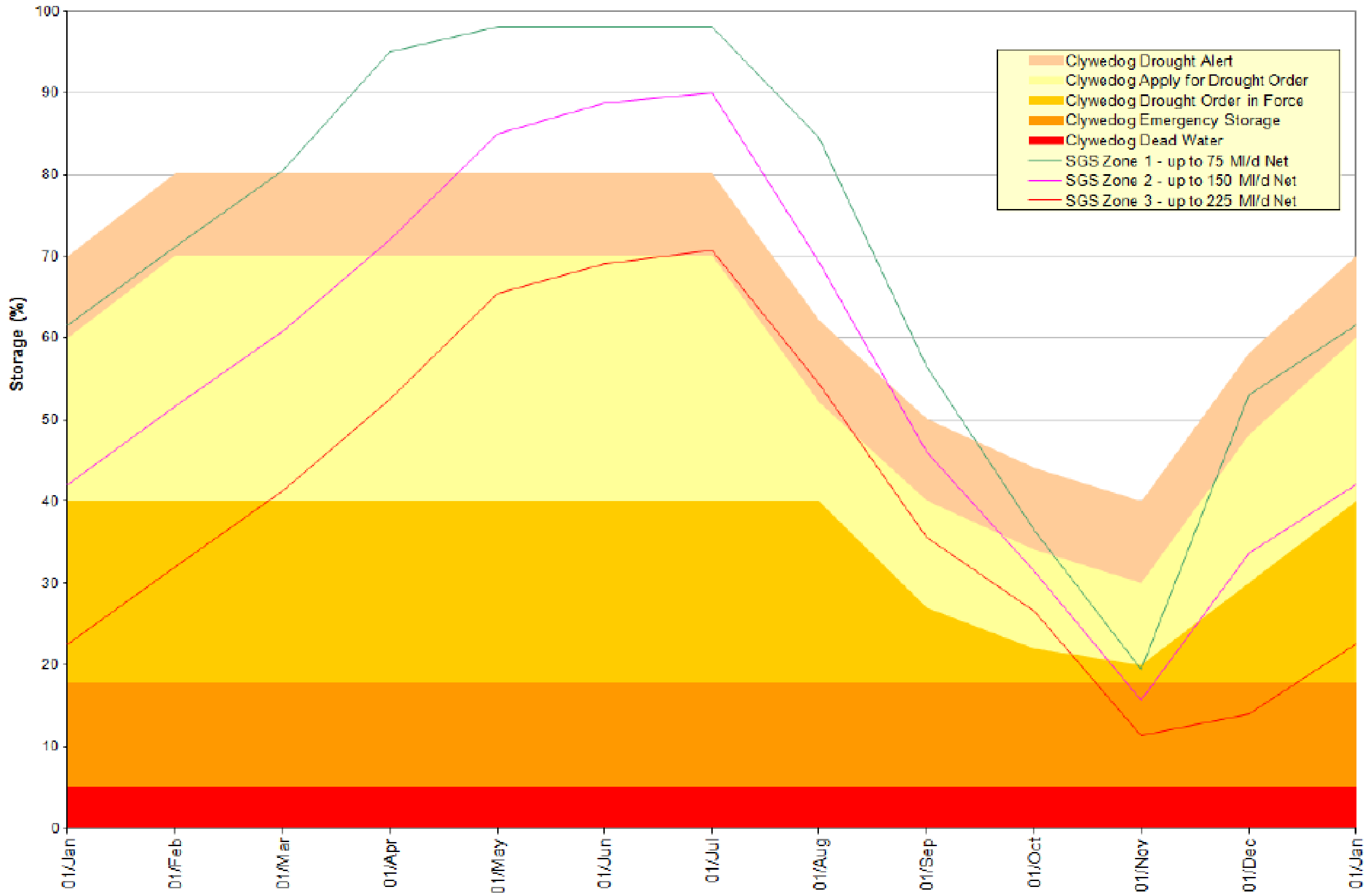
The River Severn is a regulated river that is managed by the Environment Agency. Releases from Lake Vyrnwy and Clywedog Reservoir, and abstraction from the Shropshire Groundwater Scheme are used to maintain the flows in the river. Under the current control rules the Environment Agency is required to maintain a flow at Bewdley of at least 850 Ml/d (as a 5 day average), with a minimum daily flow of 650 Ml/d.

The river is managed by the Environment Agency in order to protect public water supplies and other abstraction rights, to maintain the environmental habitat of the river, to maintain freshwater flows into the Severn Estuary, and to protect navigation rights and the other amenity uses. The Company has no control on the use of the river regulation sources but it assists the Environment Agency in managing river flows.

The West Midlands Area of the Environment Agency also maintains drought plans and the latest versions are available on request from their National Customer Contact Centre.

The control rules for the River Severn are based on storage levels at Clywedog Reservoir (the main source of river regulation). These rules were reviewed by the Environment Agency during the preparation of its last drought plan. South Staffordshire Water, other major public water supply stakeholders on the river (Severn Trent Water, United Utilities and Bristol Water) and other abstractors were consulted by the Environment Agency as part of this process. United Utilities was consulted because the reservoir at Vyrnwy (a United Utilities asset) can be used to regulate the River Severn. The Environment Agency's drought triggers are shown below in figure 1.

Figure 1 River Severn Drought triggers for Clywedog Reservoir and the Shropshire Groundwater Scheme



After River Severn Drought Order Environmental Report (Environment Agency , Version 7 - December 2013)

The graph and control rules shown here still utilise the older terminology and will be updated by the EA in due course.

The main elements of the Environment Agency's River Severn control rules are summarised below:-

- Crossing the Drought Alert trigger initiates a meeting of the Environment Agency and the water companies to discuss the potential drought order. Preparations are made for the potential drought order application and the Environment Agency issues appeals for the public to reduce demand.
- When the Apply For Drought Order trigger is crossed the Environment Agency applies for a drought order to the Secretary of State. Voluntary reductions in abstractions are requested
- When the Drought Order In Force trigger is crossed the drought order conditions become live (see Appendix G). The main condition affecting the Company is a 5% reduction in abstraction licence at the River Severn Works.
- If the Emergency Storage trigger is crossed the minimum flow at Bewdley is further reduced and the releases from Clywedog are constrained even further. Endeavours will be made to maintain flow at Bewdley but releases will be limited to no more than 1.5% of remaining storage. Further reductions in public water abstraction will be sought up to 20%

Use of the Clywedog drought triggers in this plan reflects the importance of the River Severn Works supply to the Company. However, low storage levels at Clywedog alone will not necessarily trigger action by the Company and this will also be dependent on the storage situation at Blithfield. For example if Blithfield is in a healthy position then drought management actions are likely to be delayed. If Blithfield storage is approaching a trigger (2-3 weeks away) then actions may be initiated immediately.

The potential effect of low storage levels at Clywedog is therefore to accelerate drought management actions linked to Blithfield by 2-3 weeks and ultimately to trigger a drought order application for the River Severn Works.

1.4.3 The River Severn Collaborative Modelling

Severn Trent Water first developed a water resources simulation model for the River Severn (& River Wye) using a modelling package called RESSIM. This model was later updated in AQUATOR. This is currently the most advanced model available for examining different water resource scenarios on the river. The model simulates river flows, reservoir storage, and the amount of water available to meet different demand scenarios. The model has been used directly by the Environment Agency (by agreement with Severn Trent Water) for the purposes of investigating the impact of water company and EA drought orders. It has also been used to provide river flow and regulatory assumptions for more detailed assessment of the South Staffs Water supply system. The Severn Trent Water model is a potential tool for advising drought strategy at the start of the regulation season but its complexity and the resources required to carry out model runs means that it is unlikely to be used as an operational tool in drought management.

1.4.4 Use of Bankside Storage to Assist River Regulation

We have bankside storage at the River Severn Works on the River Severn. This provides the facility to assist the Environment Agency with the regulation of the river. The Environment Agency can request for us to adjust our proposed daily abstraction from the River Severn when it is considered that there is a risk that minimum flows at Bewdley will not be maintained with the regulation releases which have been made. In these circumstances the Company can take water out of bankside storage to maintain its volumes of water production thus leaving more water in the river.

We comply with such requests from the Environment Agency on a best endeavours basis. In the event of operational constraints the Company is not required to comply. At all times the Company ensures that there is no risk to the provision of public water supply.

Assistance with river regulation in this way is in the interests of all parties as it helps improve the efficiency of regulation releases and the maintenance of supplies for continued regulation in the event of on-going dry weather.

It will be essential that there is co-ordination between the operations of South Staffordshire Water and the Environment Agency during a drought period.

1.4.5 Co-ordination of Drought Management on the River Severn with Severn Trent Water

South Staffordshire Water's abstraction licence at the River Severn Works is a joint licence with Severn Trent Water, and up to 1/3 of the licence can be used to supply Wolverhampton (Severn Trent supply area). In addition, the licence at the River Severn Works is linked to Severn Trent Water's abstraction licence at its own works, further downstream on the River Severn. The total abstraction from the two sites cannot exceed 431 Ml/d.

These complex joint licences mean that it is essential for close co-operation between the two companies during a drought to ensure that licence conditions are not breached. The two companies have discussed alignment of their respective Drought Plans, and this is reflected in the communication strategy in this plan.

The control curves for Blithfield reservoir are shown in figure 2 in chapter 2.2.1. These have been updated to reflect the new level system. The level 3 curve is used to illustrate when the drought permits would be operational.

If the level in Blithfield continues to fall then the Company will consider the need for and likely benefits of an Ordinary Drought Order to restrict non-essential uses of water at commercial premises. If this is deemed appropriate and beneficial then an application will be made.

The Emergency Storage Curve is 4% above the dead storage curve. This water will only to be used as a last resort and is a buffer before dead storage is reached. Dead storage (25%) represents the level of storage below which it is difficult to abstract water because of the hydraulics of the system and the quality of the water would decline such that treatment may have to be curtailed at times. The Company is currently investigating ways it can make better use of the unused storage in the reservoir and what works and /or treatment measures might be required. This control curve review was completed, by Mott McDonald, to inform WRMP19 and the output of the review showed that there was no benefit to altering the profiles of the curves.

1.4.6 Triggers and Actions for Groundwater Sources

As described previously, we have adopted regional groundwater levels as early indicators of the onset of drought where these are linked to baseflows which influence the River Severn and River Blithe flows. Analysis of reservoir levels and surface water flows are best used to monitor the development of droughts and it is triggers associated with these which have specific actions associated with them. There are no groundwater specific triggers recommended for these sites.

For our own operational boreholes, we have proposed the trial of triggers based on groundwater levels below normal, and the related actions are as follows:

- Groundwater levels below normal – enhanced monitoring. Ensure transducers are functioning in all operational boreholes and institute manual check dips where appropriate. Update site reviews of baseline performance and highlight contingency actions. Provide forecasts and lead times for actions and ensure site specific monitoring and triggers in place.
- Groundwater levels notably low – operational readiness. Actions such as the partial reduction in output from drought vulnerable boreholes or wells are implemented based on site specific triggers such as pumping water levels or turbidity levels. Other actions may be reactive based on problems with local pump performance or design.
- Groundwater levels exceptionally low – further reactive measures may be required and will be prioritised to ensure supplies maintained.

1.4.7 Triggers and Actions for Environmental Schemes

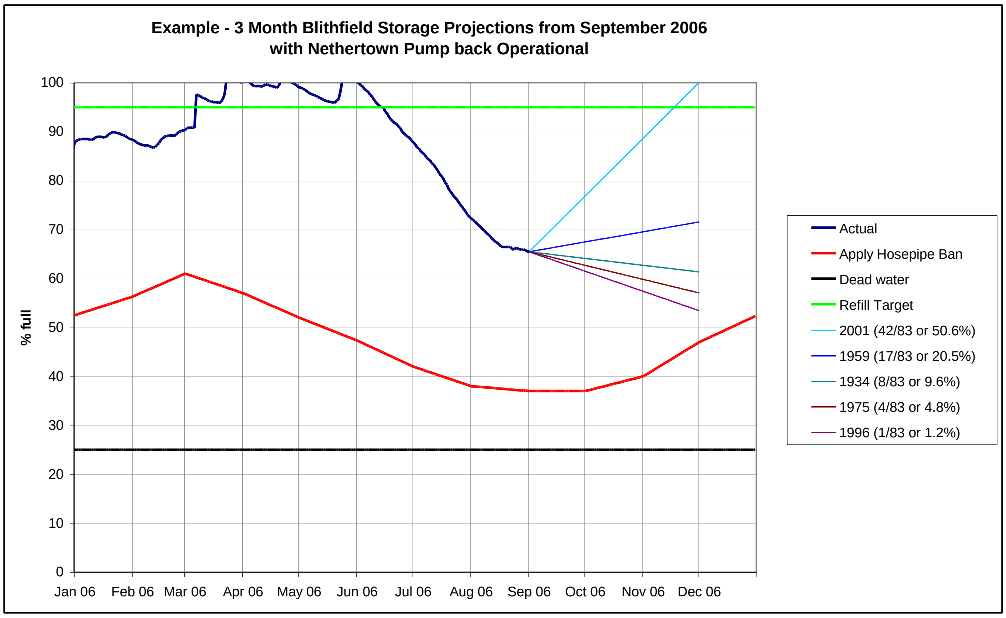
Groundwater levels influencing baseflow are a major issue to vulnerable rivers and streams in our supply area. These will be used to trigger operational readiness to implement environmental support schemes such as Shaft 20/Stowe Pool and Broome Lodge Farm/Windmill Pool. At these specific sites there are separate triggers used for implementation purposes. Accordingly the hierarchy of actions below, whilst closely aligned to Environment Agency reporting, is for general guidance only:

- Groundwater levels below normal – enhanced monitoring. Liaise with Environment Agency local officers to ensure site specific monitoring and triggers in place. Provide forecasts and lead times for actions to operational staff.
- Groundwater levels notably low – operational readiness. Ensure resources in place to implement mitigation schemes e.g. manpower and plant
- Groundwater levels exceptionally low – implement mitigation measures according to agreed site specific triggers

1.5 Forecasting the Impact of Drought

In the absence of accurate long range weather forecasts, we need to understand the potential impact of a range of drought scenarios, at different stages in a drought. We will do this by considering each of the 3 main water resources in the following way:

- Our groundwater sources are largely unaffected by drought, due to the nature of the Sherwood Sandstone aquifer (groundwater levels only fluctuate by a few meters), and therefore no specific scenario analysis is required.
- The availability of water from the River Severn at the River Severn Works is determined by flows at Bewdley, by reservoir storage at Clywedog and by the level of River Regulation. The River Severn Drought Management Group will be convened by the Environment Agency once the Drought Alert trigger is crossed at Clywedog and will enable scenario analysis to be undertaken using the joint Environment Agency/ Severn Trent Water AQUATOR model. This will include different scenarios for abstraction, other river demands, and different rainfall - runoff (inflow) sequences. The results will be made available as part of the Severn Drought Management Group.
- Storage level scenarios at Blithfield Reservoir will be examined using our prediction tool. This is a spreadsheet model which contains 80 years of simulated inflows to the reservoir, and allows different abstraction, compensation release, and quantities of water pumped back from the River Blithe Pumpback Scheme to be specified. By varying the inflow to the reservoir in the spreadsheet we can simulate reservoir storage levels based on a range of different droughts, and allocate a return period (probability) to the event. An example of the output of the spreadsheet model is shown below.



By considering the modelling outputs from the River Severn Drought Management Group, and the Blithfield Reservoir storage scenarios, along with a range of additional information, including the short-medium term weather forecast, the soil moisture deficit, the demand profile and forecast, and the available supplies, decisions can be made on the best way to manage the drought in question, using the triggers and options within the plan.

2 Drought Scenarios

2.1 Drought Scenarios Covered by this Plan

In order to demonstrate how our proposed drought actions would be implemented and to test the associated triggers, different scenarios have been examined to show how a range of historic droughts would be managed, given current water demands, operational practice and supply infrastructure. Within the drought scenarios planned outage is assumed to be managed in line with our approach described in chapter 3.3.1, but there is also an assumption that unplanned events contribute to an average loss to supply of 10 Ml/d (in line with the WRMP14 outage allowance) over the periods in question. This work makes use of the latest Company Aquator model which has been updated for use in the forthcoming Water Resources Plan (WRMP24).

We operate a single integrated resource zone, supplied by the River Severn, by Blithfield Reservoir, and by 26 groundwater sources.

In general our groundwater sources are not significantly affected by droughts. This is because all of our groundwater sources abstract from the Sherwood Sandstone aquifer. During drought periods, regional groundwater levels in this aquifer typically only fall by 1-3 metres. For the majority of our sources this does not affect our ability to supply. As a result we do not consider it necessary to examine specific groundwater drought scenarios.

The River Severn is susceptible to a single season drought, as evidenced by the 1976 drought. This is because river flows can fall quickly, especially following a period of low rainfall and low groundwater levels. Low groundwater levels can result in a reduction in groundwater baseflow from the Triassic Sandstone aquifer in Shropshire, which is an important component of river flow on the Severn, especially during low river flows.

The River Severn is regulated (supported) by releases from Clywedog Reservoir, from the Shropshire Groundwater Scheme (SGS), and to a lesser extent by releases from Lake Vyrnwy. Releases are made in order to maintain a minimum flow on the river as determined by the gauging station at Bewdley. River regulation is managed by the Environment Agency. Storage levels at Clywedog are the key measure for the Environment Agency for drought severity and for triggering actions, as mentioned previously.

Blithfield Reservoir is considered to be two season critical, as its lowest storage levels occur in the second year of a drought if the reservoir has failed to refill over the winter. The critical period on record is 1975/76, although other significant droughts on the record occurred in 1892/97, 1933/34, 1995/96 and 2010/11.

The period 2010/11 was marked by an exceptional shortage of rain in our supply area which led to notably low groundwater levels and periods of notably low river flows in the Trent catchment. Storage levels in Clywedog Reservoir were not exceptionally low helped by summer rain in Wales and regulation was maintained through 2011 without use of the Shropshire Groundwater Scheme. Accordingly we were able to manage demand by the deployment of its relatively drought-resistant groundwater sources and maximisation of River Severn resources. This combined with suppressed summer demand meant that the drought was not as severe as the 1995/96 event. The drought broke in December 2011 and was followed by an exceptionally wet spring and summer 2012.

We have not identified a separate summer and winter drought scenario as the control curves cover the entire year. It is possible that where a hosepipe ban may be indicated by the trigger curves, this may not be appropriate during winter months, and in any case it is assumed when modelling scenarios that there is no benefit outside the spring/summer period based on national studies. We will consider the implementation of such options in the context of the time of year when the trigger curve is crossed.

The response of our water resources system to a range of historic droughts has been examined using AQUATOR, our water resources model. The model simulates the previous 133 years of climate data and examines how we would meet current demands for water. This modelling has confirmed that the most severe droughts from the historic record that would affect us are 1892/97, 1975/76 and 2010/11, and their rainfall characteristics are tabulated below. These drought periods also include the most severe single season droughts on record (e.g. 1976) and are therefore considered the most appropriate scenarios to test this drought plan. Each of these scenarios is considered in more detail below.

Drought	Duration (years)	Total rainfall (mm)	% of LTA	Deficit from LTA (mm)
1893-98	5	3398	84	635
1974-76	2	1341	83	273
2009-11	2	1330	82	284

Modelled storage at Clywedog has been provided by Severn Trent Water/Environment Agency, and was derived from Severn Trent Water's water resources model.

The AQUATOR model has also been used to explore the resilience of our resources against a more extreme 200 year drought scenario. This has been carried out by adjusting the rainfall and flow data for four time periods, two annual (1933-1934 and 1995-96) and two 2-year (1975-76 and 2009-2011). The rainfall and flow data for the Blithfield Reservoir catchment was evaluated statistically to establish the likely 200 year outturn and the model data for each time period adjusted accordingly. Model data for the Trent and Severn was also adjusted to ensure its consistency with the adjusted Blithfield data, in accordance with long term statistical relationships.

All model results consider a conservative (high) demand case. They use a profile of surplus summer demand over winter background water consumption based on the exceptional demands observed in 1995. Modelling was also carried out assuming a 2006 profile when high summer demands were of much shorter duration and these consistently show less impact. This supports the observation of a reduced impact of the 2010/11 drought when summer demands were very low.

2.2 Resilience against Historic Droughts

In the sections below, the graphs denote the old terminology for trigger levels as they were produced prior to the new levels being produced. To avoid confusion, the narrative uses the same terminology as the graphs.

The table below details the translation of the old terminology into the new level system in use today:

Previous Terminology	Corresponding level in current terminology
Drought Alert curve	Level 1
Drought Order curve	Level 2
Drought Order in Force curve	Level 3
Emergency Storage curve	Level 4

2.2.1 Repeat of 1974 to 1976 Drought (two season drought)

The 1975/76 drought was a two season drought which was characterised by a very dry winter. In addition, 1976 was one of the driest single years on record, and it represents the critical single year for the River Severn. The modelled storage at Clywedog (River Severn) and at Blithfield is illustrated in figures 2 and 3 below.

Clywedog Reservoir levels fall to 60% but above any trigger levels in 1975 and recover in the winter of 1975/76. In 1976 there is an early and very rapid recession between May and September with lowest levels at around 25%. The 1976 recession drops below the Clywedog Apply for Drought Order curve in late June and the Clywedog Drought Order in Force curve at the beginning of August. Recovery starts in mid-September but levels remain in the Clywedog Drought Alert zone for the remainder of the year. Similarly SGS triggers for 75 Ml/d, 150 Ml/d and 225 Ml/d are rapidly crossed between May and June and it is anticipated that the Severn would be under Maximum Regulation prior to imposition of a drought order in the autumn.

Blithfield Reservoir storage falls below the drought monitoring curve in 1974 and 1975 and does not fully recover in the winter of 1975/76. There is a rapid recession in 1976 between April and September and thereafter the reservoir levels rapidly recover. Minimum reservoir storage is 50% which is above the Apply for Drought Permit curve.

Figure 1 Modelled Storage at Clywedog 1974 to 1976

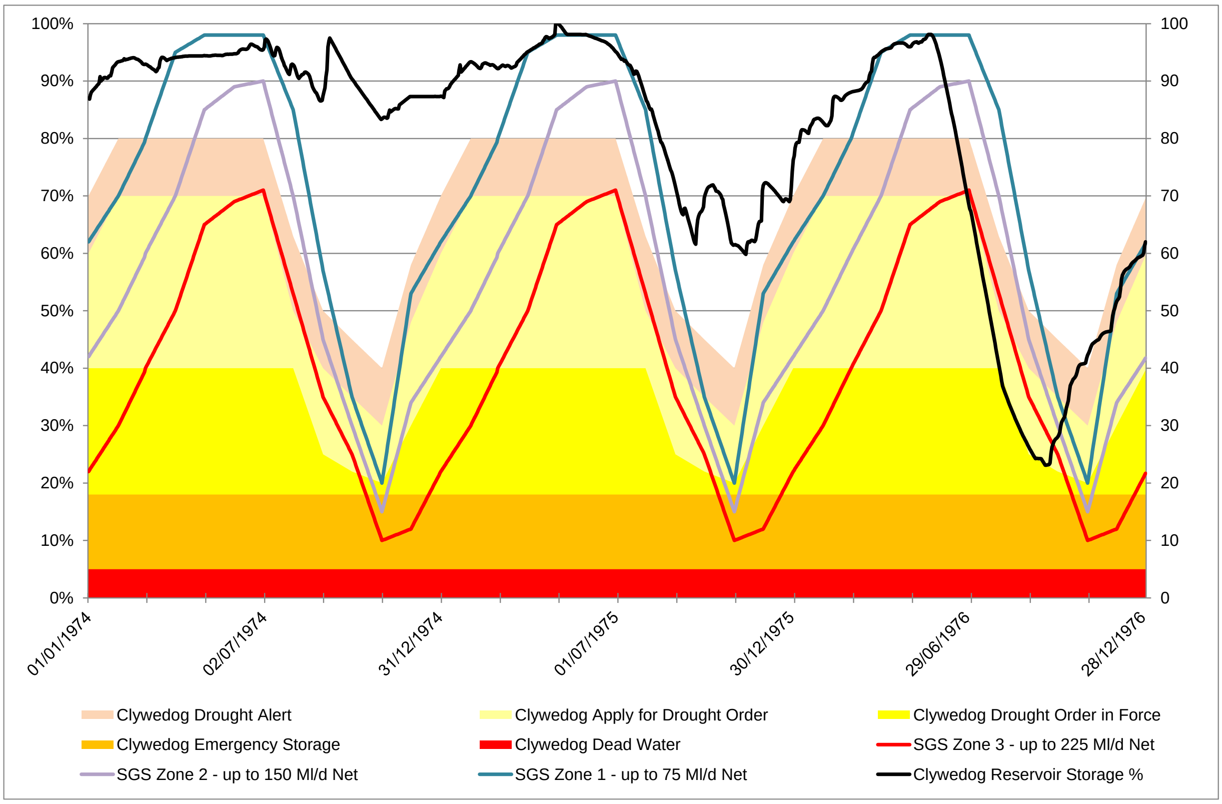
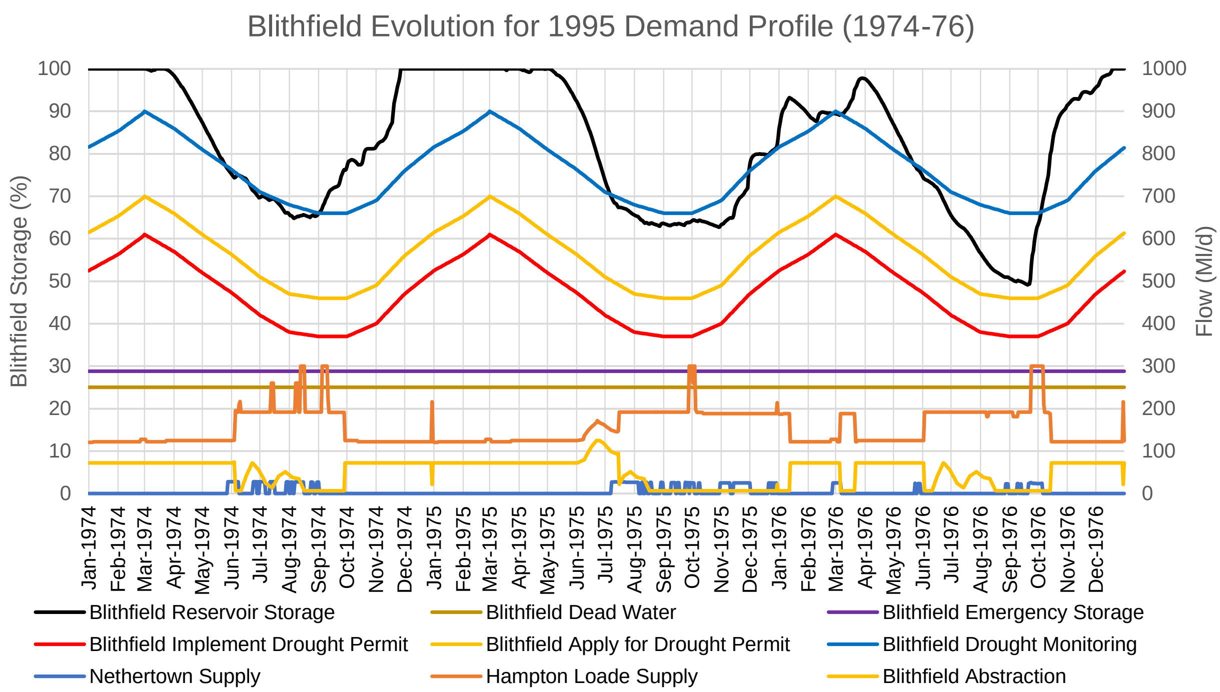


Figure 2 Modelled Storage at Blithfield 1974 to 1976



2.2.2 Repeat of the 2010 to 2012 drought (two season drought)

2010/11 was a severe two-year drought and is the most recent event for which we have operational experience. Although rainfall was exceptionally low over the two year period, summer temperatures were seasonally low to moderate and regional customer demands in the summer peak period unremarkable. As a consequence the event did not precipitate any significant demand management measures. A hosepipe ban was called by a number of water companies in the South East in 2012 but was lifted after a short period after the start of an exceptionally wet spring and summer. Low flows were encountered in Blithfield Reservoir leading to low reservoir levels in summer and autumn 2011; and groundwater levels were also low and led to minor output reductions in our few drought sensitive boreholes. In contrast summer rainfall in Wales contribute to River Severn flows and reduce 2011 releases from Clywedog. Clywedog levels do not fall below 80% in 2010 and recover over the winter. Storage falls sharply during July and August 2011 but recovers in September and the reservoir starts to refill in November. The Clywedog trigger curves are not crossed during the event although there are extended releases for regulation purposes from the reservoir and SGS.

Blithfield levels recede to below 70% and below the drought monitoring curve in 2010 but are stabilised by conservation measures. Levels briefly recover over winter 2010/11 but recede sharply in spring 2011 following a period of exceptionally low rainfall. They reach a minimum of 57.5% and require extensive conservation measures to stabilise above the Apply for Drought Permit curve. Levels start to recover in December.

Figure 3 Modelled Storage at Clywedog 2009 to 2011

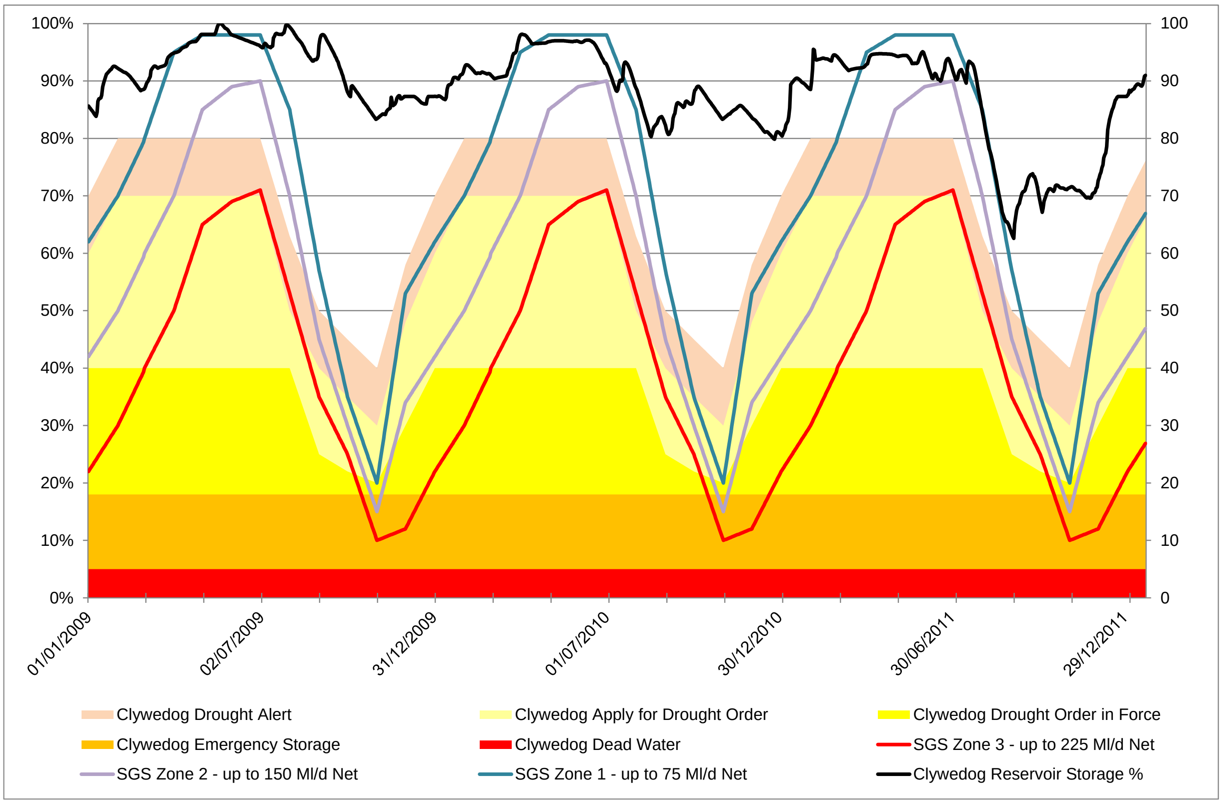
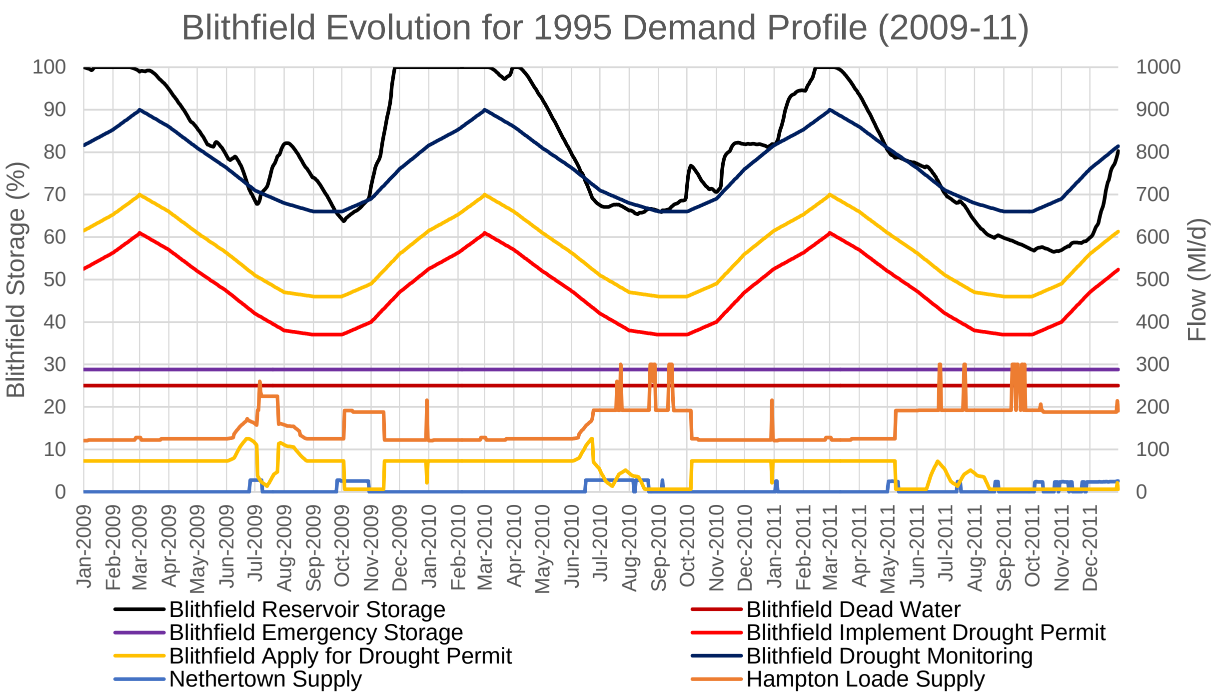


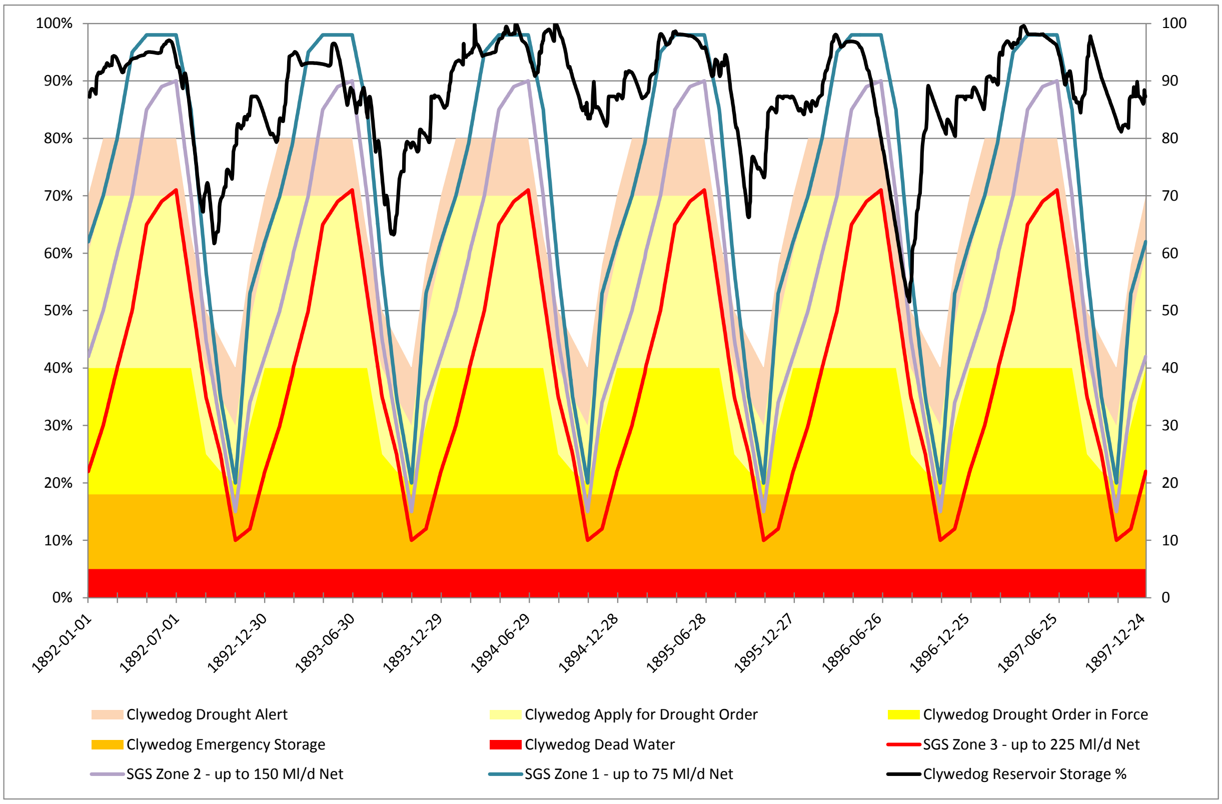
Figure 4 Modelled Storage at Blithfield 2009 to 2011



2.2.3 Repeat of 1892 to 1897 Drought (multi-season drought)

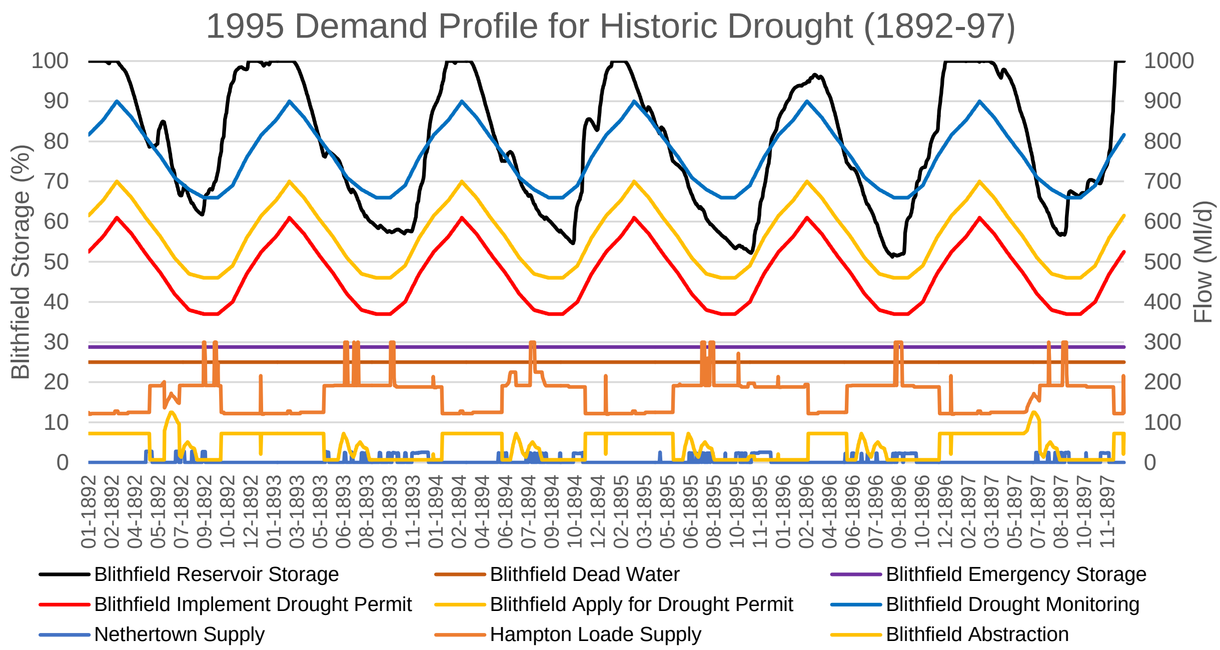
The 1892/97 period was a series of successive dry summer droughts of moderate to severe intensity. Contemporaneous accounts record some problems with high demand and water shortages in the years 1895 and 1896. This sequence of years has been analysed to consider supply system vulnerability in multiple year drought sequences as most of the sequences previously studied have not exceeded two years.

Figure 5 Modelled Storage at Clywedog 1892 to 1897



Clywedog reservoir levels fall to below 70% in four of the six years and would be accompanied by extended periods of river releases. The reservoir levels fall below the Shropshire Groundwater Scheme (SGS) 70 Ml/d curve in every year during the early spring. In two years, 1893 and 1896, early recessions mean reservoir levels fall below the SGS 150 Ml/d curve and in 1896 levels run parallel to the Clywedog Drought Alert trigger for two months in the summer.

Figure 6 Modelled Storage at Blithfield 1892 to 1897



Blithfield reservoir levels fall below the drought monitoring curve in each of the six years and fall to 51.2% in 1896 but do not trigger the apply for drought permit curve. It is likely that appeals for restraint would be requested from customers. Notably reservoir levels refill in each year apart from winter 1895/96.

2.2.4 2018-2020

The 2018 period was marked by a prolonged period of dry weather of moderate intensity. There were short bursts of intense high demand which coincided with high temperatures; however this did not affect the system and generally demand was not an issue in the period. The level in Blithfield did drop below the drought monitoring line in mid-July but critically did not cross the drought permit line. A drought permit was not applied for as the apply for drought permit line was not crossed until mid-November at which point demand saving measures associated with TUBs were deemed not to be relevant for that time of the year and generally entering the winter period where recovery of the reservoir would be observed. Indeed a steep recovery of the level is observed form the start of December through to the New Year.

The 2020 period was marked by a generally warm dry spring period and notable increases in demand associated with the national lockdown linked to the Covid-19 pandemic. The preceding relatively wet 2019 resulted in a good recovery of both surface water and groundwater, which allowed for good baseline storage prior to the high demand periods of the year. Whilst only the drought monitoring line was crossed, appeals for restraint were issued to customers with the onset and development of the lockdown due to a lack of data of a potentially new demand profile that had not yet been observed.

2.2.5 Summary of Resilience of Drought Plan to Historic Drought Scenarios

The simulation of the operation of the system during the historic droughts under the current scenario of demand shows that:

- The system is resilient against historic droughts at the current level of baseline demand, using conservative demand assumptions for summer peaks based on the 1995 profile.
- Modelling suggests there would be a need to activate appeals for restraint for relatively short periods during these events even when using conservative (high) demand assumptions.
- A future occurrence of a drought like that of 1975/76 would lead to the lowest stored volume in Blithfield, which would nonetheless be close to 50%. A slightly higher minimum volume would occur with a drought like that in the 1890s, while 2010/11 is slightly less severe.

2.3 Resilience against more extreme droughts

The system has been tested using a simulated 200 year drought event. Four temporal patterns, two annual (1933-1934 and 1995-96) and two 2-year (1975-76 and 2009-2011) have been studied based on a thorough statistical treatment of their likelihood and the ability to extrapolate more extreme events . No pattern from the 19th century was considered as the uncertainty with the base data is significantly higher. The Blithfield inflows (in Ml) relating to a 200-yr return period previously estimated have been distributed based on these sequences as follows:

Drought	Historical	200-yr
1934-35	34,371	20,512
1974-76	57,100	47,085
1995-96	24,399	21,339
2009-11	51,085	42,384

The rainfall distributions are tabulated below for comparison with the historic droughts. In all cases the pattern of rainfall has been taken from observed historical sequences but adjusted downwards so that it matches the 1 in 200 year calculated event.

Drought	Duration (months)	Total rainfall (mm)	% of LTA	Deficit from LTA (mm)
1934-35 1994-95	12	518	64	290
1974-76 2009-2011	24	1215	79	322

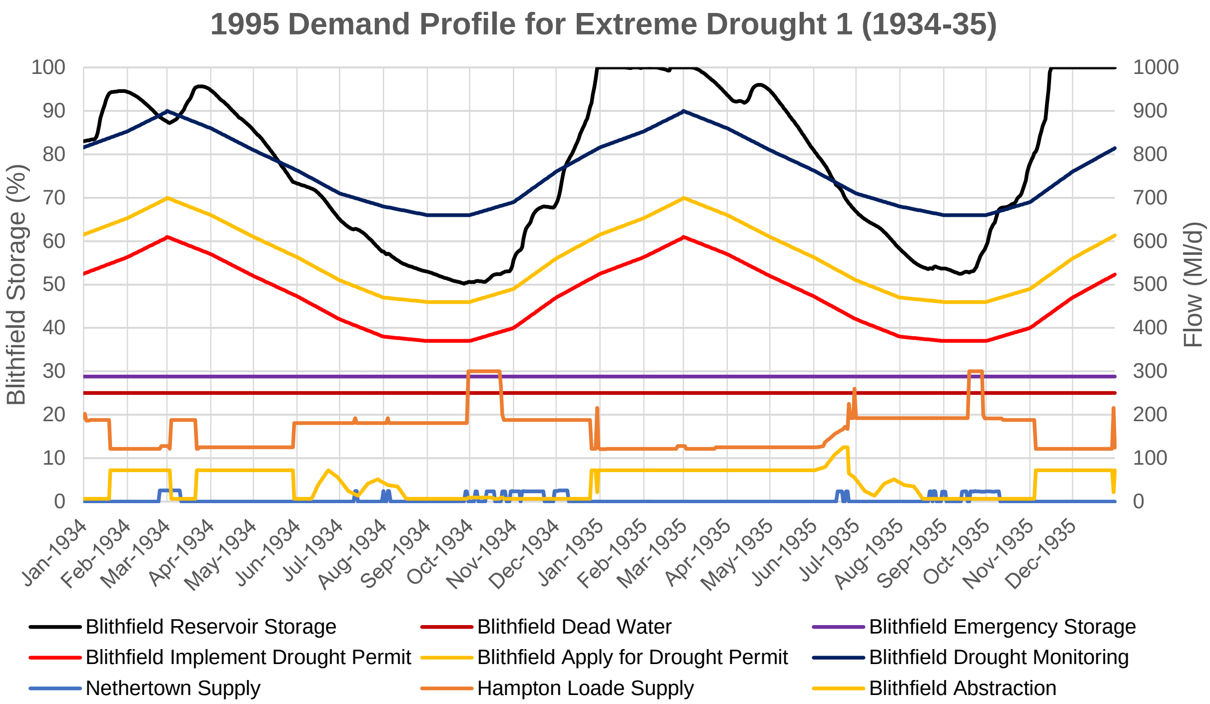
The results of the modelled scenarios are shown in figures 8 and 9 below. All scenarios, as expected, reveal lower resulting reservoir levels against the original unperturbed scenarios discussed in the sections above. However in no cases is there either a requirement for a temporary use ban or any further management measures that put the supply system under stress. The main effect is in an increased number of days where appeals for restraint are required to help manage summer demand.

2.3.1 Summary of resilience of drought plan to extreme drought scenarios

The simulation of the operation of the system during the 200-yr droughts under the current scenario of reduced baseline demands (using high summer peaks as observed in 1995) shows that:

- The system is resilient against potential future 200-yr droughts.
- Modelling suggests there is an increased need to activate appeals for restraint for extreme droughts. Water conservation in Blithfield is deemed sufficient to avoid crossing the level 3 trigger. As discussed in Section previously, in practice a customer campaign would be initiated in the spring if there was good evidence of severe drought conditions emerging.
- If demand is maintained at the current level there is no risk of TUBs or drought permits/orders during the extreme droughts studied. There would, however, be a risk if demand approached the deployable output of the system or there was a significant degradation of supply infrastructure.
- A future occurrence of a 200-yr drought with a temporal pattern similar to that of 1975/76 would lead to the lowest stored volume, which would nonetheless be close to 50%.

Figure 7 Modelled scenarios for extreme drought Part I



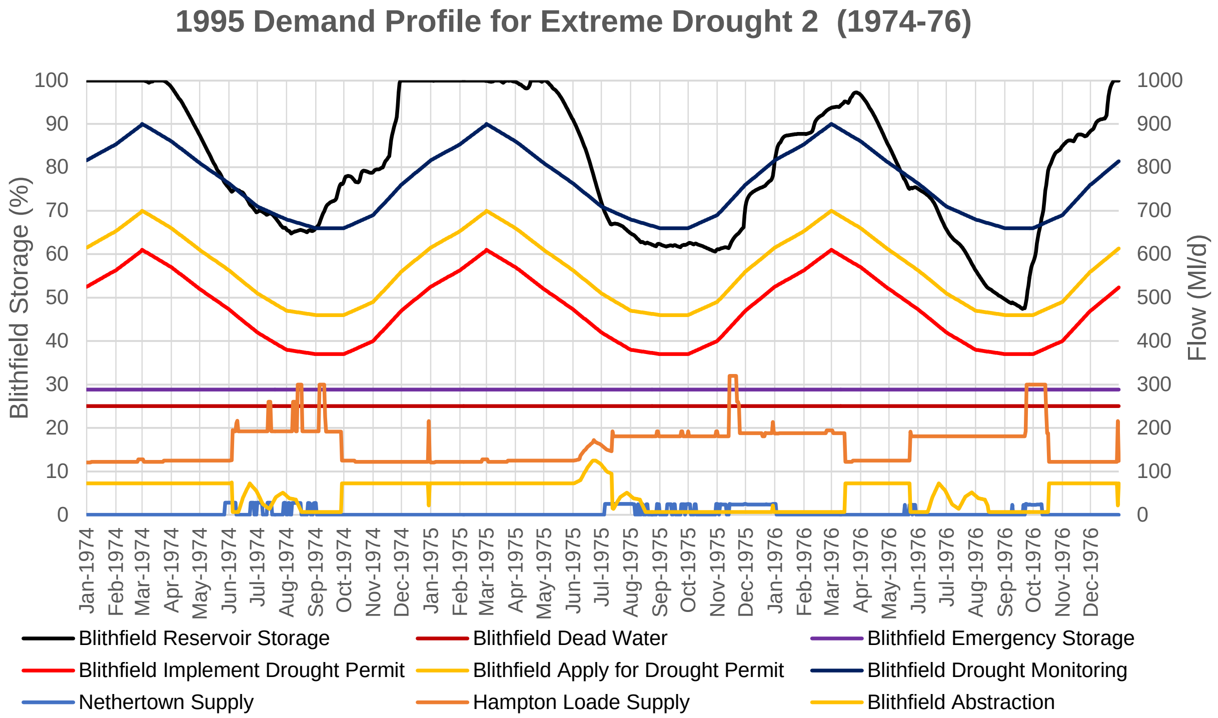
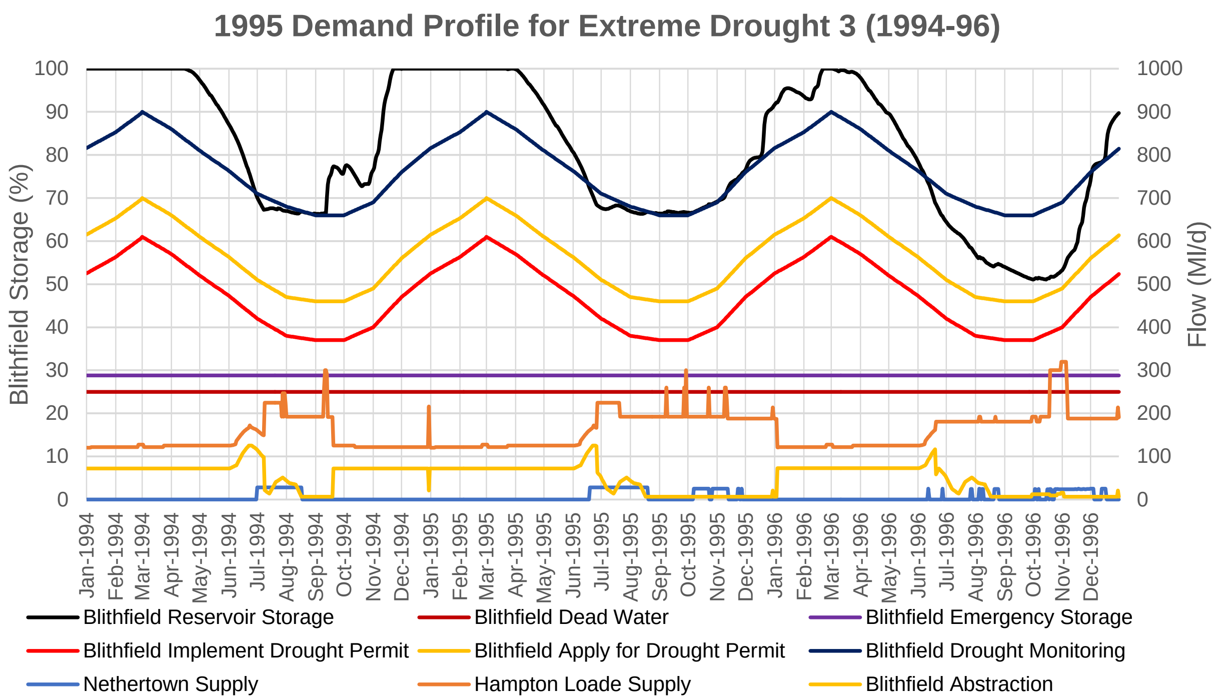
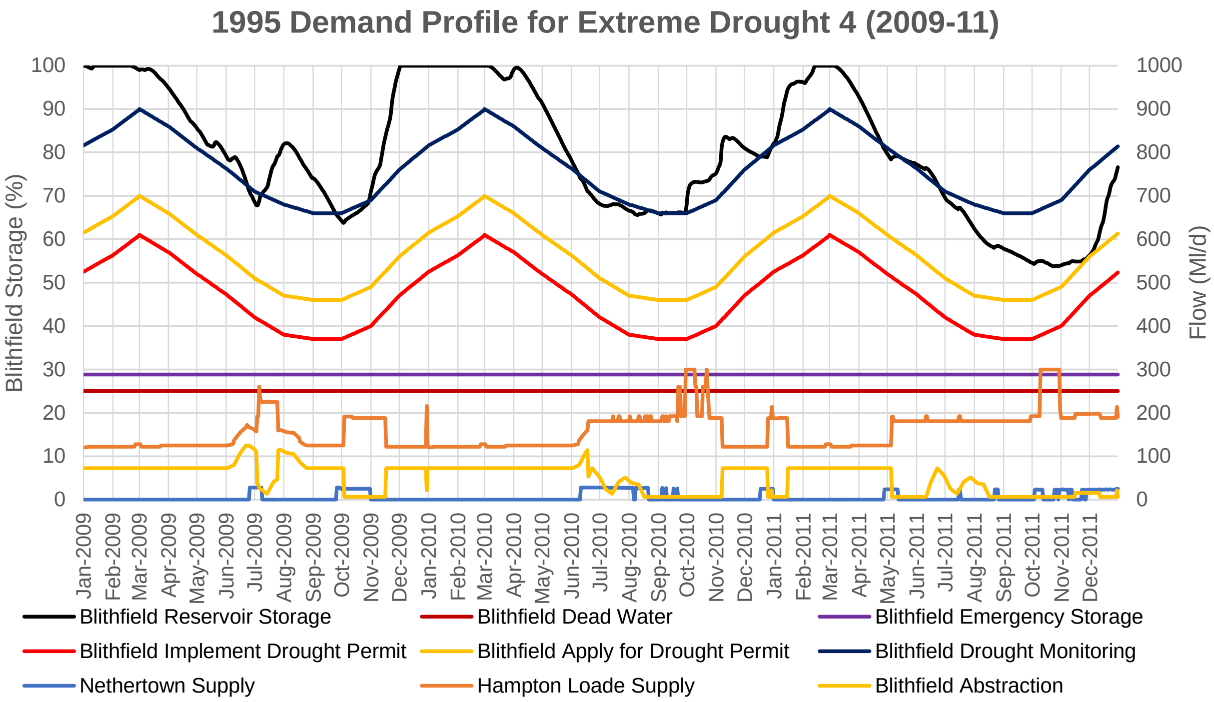


Figure 8 Modelled scenarios for extreme drought Part II




1995 Demand Profile for Extreme Drought 4 (2009-11)
Blithfield Storage (%)
Flow (Ml/d)
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500
600
700
800
900
1000
Jan-2009
Feb-2009
Mar-2009
Apr-2009
May-2009
Jun-2009
Jul-2009
Aug-2009
Sep-2009
Oct-2009
Nov-2009
Dec-2009
Jan-2010
Feb-2010
Mar-2010
Apr-2010
May-2010
Jun-2010
Jul-2010
Aug-2010
Sep-2010
Oct-2010
Nov-2010
Dec-2010
Jan-2011
Feb-2011
Mar-2011
Apr-2011
May-2011
Jun-2011
Jul-2011
Aug-2011
Sep-2011
Oct-2011
Nov-2011
Dec-2011
Blithfield Reservoir Storage
Blithfield Dead Water
Blithfield Emergency Storage
Blithfield Implement Drought Permit
Blithfield Apply for Drought Permit
Blithfield Drought Monitoring
Nethertown Supply
Hampton Loade Supply
Blithfield Abstraction