Cambridge WRZ Outage Analysis

Water Resource Management Plan 2019

21 November 2017

Cambridge Water

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Contents

Executive summary

This document summarises the Outage allowance assessment carried out for the Cambridge Water Resource Zone, forming part of the South Staffs Water WRMP19 planning process.

Outage is defined as a temporary loss of deployable output due to planned maintenance and capital work (planned outage) or due to unforeseen events such as power failure, source pollution, system breakdown etc (unplanned outage). The outage allowance is calculated according to a standard methodology developed and published by UKWIR (Outage Allowances for Water Resource Planning, UKWIR/EA, March 1995).

The 1995 methodology advocates the use of a probabilistic approach, based on Monte Carlo analysis. The analysis involves defining probability distributions for magnitude and duration for all identified outage events and combining these to give an overall probability distribution for the outage allowance.

Historic events have been analysed and included from 2004 to 2016. The list of events was first reviewed to identify if events were legitimate outages. Non-legitimate events were excluded from the data. The data were then grouped by source and by category, and categorised as planned or unplanned events, to produce distributions. The events were also reviewed to ensure that where two or more events were recorded as occurring at the same time and the same site, these were only counted as one event.

Events at sources no longer in supply were excluded to avoid overestimating overall magnitude (if DO has decreased) and prevent systematic biases in Outage. The frequency value for the events is calculated by the total number of events divided by the time covered by the dataset (in this case 15 years). This is then used as the outage frequency value for the Poisson distribution used in the model.

For supply/demand balance modelling, the 70th percentile values for Outage at both DYAA and DYCP are considered to be most appropriate for capturing a suitable level of risk to the Cambridge Water Resource Zone to protect its level of service. This is consistent with WRMP14 assumptions. The corresponding values for DYAA and DYCP Outage are 7.27 Ml/d and 3.80 Ml/d respectively. These are equivalent to 7.3% and 3.3% of base year deployable output for DYAA and DYCP respectively. The lower DYCP outage is due to most legitimate outage events occurring outside of peak times, and the fact that DYCP D.O. is higher than DYAA D.O., such that the peak period events are proportionally less important for DYCP than for DYAA supply/demand balance.

1 Introduction and background

Water Companies in England and Wales have a statutory duty to prepare and submit Water Resources Management Plans (WRMP), including Supply Demand Balance (SDB), to the Environment Agency (EA) and Ofwat. A key component of these WRMPs is the outage allowance.

Outage is defined as a temporary loss of deployable output due to planned maintenance and capital work (planned outage) or due to unforeseen events such as power failure, source pollution, system breakdown etc (unplanned outage). The outage allowance is calculated according to a standard methodology developed and published by UKWIR (Outage Allowances for Water Resource Planning, UKWIR/EA, March 1995) and referred to in the WRMP guidelines (EA, 2016).

Mott MacDonald (MM) has been engaged by South Staffordshire Water to assess the outage allowance for Cambridge Water for the 2017 Draft WRMP.

1.1 Objectives and scope of work

The objectives of the project are:

- to analyse historical data recorded by Cambridge Water, to identify legitimate outages and produce appropriate probability distributions for the events where there is sufficient data; and
- to assess Cambridge Water's outage allowance under average and peak conditions.

In addition, the scope of work includes the actions below:

1. review the historical outage record events to identify any possible non-legitimate events recorded, analyse the data and produce appropriate distributions;
2. produce summaries of the results by source, outage type and impact;
3. produce a report outlining the methodology and assumptions used and presenting the results of the analysis.

1.2 Background to outage

1.2.1 Why assess outage

At any given point in time a water company should expect to find that the achievable output from some of its treatment facilities is below the normal deployable output. This can be for a variety of reasons, including unplanned events (such as raw water quality failures or asset failures in the treatment plant itself), or planned events (such as scheduled maintenance or capital schemes). When this reduction in deployable output is of a temporary nature (i.e. the situation is recoverable in time), it is known as an outage.

It is therefore important that water companies make sufficient allowance in their water resource planning for such temporary reductions to ensure that, for each resource zone, the risk of a supply-demand deficit in critical periods is eliminated or reduced to an acceptable level. This is done by calculating and incorporating in the supply-demand balance an outage allowance.

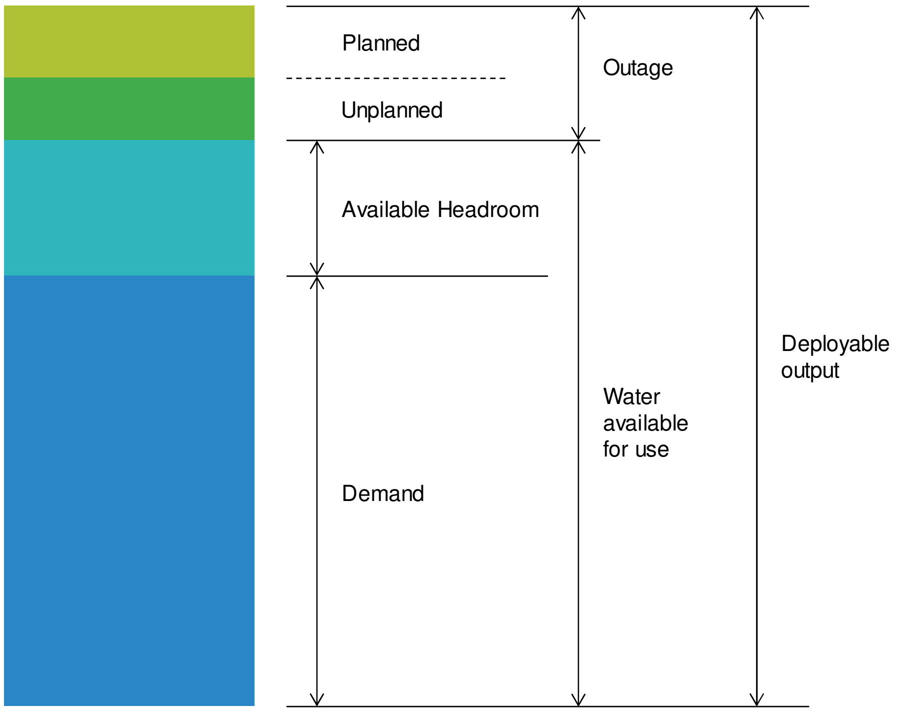
Water companies must show evidence that they have taken this into account when they submit their WRMPs as part of the periodic review process. The last WRMPs were submitted to the

Environment Agency in 2014 and 2015 and these also formed the companies' supply-demand balance submissions to the Office of Water Services (Ofwat) as part of PR14. These plans take a long-term view and demonstrate how the company intends to maintain an acceptable balance of supply and demand into the future. The last plans considered the planning period 2012 to 2040 whilst the PR19 planning period will cover the years 2017 to 2045.

1.2.2 Outage in the Supply Demand Balance and Accepted Definitions

A schematic in Figure 1 shows how the outage allowance calculated by water companies relates to the other components of the Supply Demand Balance (SDB).

Figure 1: The Supply Demand Balance



The SDB is calculated as the difference between Water Available for Use (including imported water if applicable) and demand at any given point in time by comparing DO with water demand, after allowing for outage and target headroom.

In assessing the supply demand balance, the following equations are normally adopted:

1. Water Available for Use (WAFU) = Deployable Output (DO) – Outage
2. Available Headroom = WAFU – demand
3. Available Headroom ⩾ Target Headroom needed to satisfy given standards of service

Deployable Output is generally considered to be the output of a source allowing for all constraints, whether physical, licence or environmental for a given level of service. As such it is the volume of water that can be deployed into supply. Outage is defined at its simplest as a temporary loss of deployable output.

The term Allowable Outage is defined in order to distinguish between events that can legitimately contribute to the outage allowance and those that cannot. The issue of what does and does not constitute a 'legitimate' outage event is discussed further in Section 2.4.2.

Available Headroom is defined as the margin between Water Available for Use (WAFU) and demand at a given point in time and in theory is a measurable quantity of water. Target Headroom is a derived value which represents the minimum acceptable Headroom required for planning purposes to cater for uncertainties (excluding outages) in the overall supply-demand balance.

1.3 Environment Agency Water Resources Planning Guidance

The guidance on outage for the 2013 Draft Water Resources Management Plan is found in the Water Resources Planning Guideline issued by the Environment Agency in June 2012 and updated in May 2016. In Section 3.4 the guideline states:

"A water company should justify its outage allowances in relation to the likelihood of events recurring, given the magnitude, duration and timing of actual outages. This should be supported by recorded data. Where a water company does not collate data to support outage assessments, it should provide a plan to implement the collection of outage data and report on progress in its annual reviews.

Outage allowance should be reassessed across the planning period where significant changes to the supply system are planned. A company should also include specific ways of addressing its particular supply-demand balance problem in its assessment of all its water management options. Where appropriate, this should include options to reduce the outage allowance.

The company should justify the determined outage allowances and provide a clear audit trail in its water resources management plan. Definitions for technical outage terms have been clarified since previous guidelines and companies should use these technical terms (outage, planned and unplanned outage, legitimate outage, allowable outage and outage allowance) where applicable. Outage should be considered separately from target headroom."

The methodology used to assess outage for Cambridge Water has been designed to comply with this guidance as it is based on the 1995 UKWIR methodology and an analysis of historic outage data.

Table 1: Definitions (Water Resources Planning Guidelines, 2012)

Deployable Output	The output for specified conditions and demands of a commissioned source, group of sources or water resources system.	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 main, treatment, water quality, and levels of service.
Outage	General reference to any outage impacting on a sourceworks resulting in a temporary loss of Deployable Output	Outage events are always temporary (up to 3 months) and include: observed events and perceived risks; result in either partially reduced output or complete closure; and include both legitimate outages and those which are not considered to be legitimate.
Unplanned outage	An outage caused by 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 risk.	The definitive list of unplanned outage events is: • pollution of source • turbidity • nitrate • algae • power failure

		• system failure Extreme events should not be considered in the methodology. Extreme events are occasional, unpredictable events that cannot reasonably be foreseen, but which reduce the deployable output. Utilities would not normally plan investment to prevent outages for such extreme events.
Planned outage	A foreseen pre-planned outage resulting from a requirement to maintain sourceworks asset serviceability.	Planned outages must result directly from programmes declared by Utilities under the general headings of maintenance, capital or revenue in accordance with a utility's policy
Legitimate outage	An outage event is legitimate if it affects the water available for use to the extent that it contributes to a supply shortfall. (For example, during dry year annual average, peak week or other critical resource planning period).	Whether an individual outage is legitimate or not will often depend on the wider resource zone infrastructure and any constraints on the supply system.

Source: Water Resources Planning Guidelines, 2012

2 Methodology

The methodology for this outage analysis follows the best practice guidance set out in the 1995 UKWIR "Outage Allowances for Water Resource Planning". It builds on the outage analysis models used by South Staffs Water to calculate their outage allowance for previous WRMPs.

2.1 The 1995 UKWIR Methodology

2.1.1 Overview

In 1995, UKWIR published its general methodology for the calculation of outage allowances. Their research showed that before this time water companies had been using a variety of approaches to calculating 'outage allowances', including the use of blanket allowances, simple estimates from available data, risk matrices and, in many cases, no allowance at all; hence the need for an accepted methodology for use across the industry.

The 1995 methodology advocates the use of a probabilistic approach, based on Monte Carlo analysis. The analysis involves defining probability distributions for magnitude and duration for all identified outage events and combining these to give an overall probability distribution for the outage allowance. A "lotus notes"-based spreadsheet with an add-in Monte Carlo analysis tool called @RISK was produced as part of the project.

2.1.2 Determining if the methodology can be applied

The methodology starts with an optional screening process to identify whether DO in the Resource Zone is at least 25% greater than demand. This percentage is the same as that applied to the filter in the headroom methodology. This screening process will determine whether a probabilistic analysis of outage uncertainty is appropriate. A simpler method could be applied if there is evidence that any failures are unlikely to affect supply or DO. An example of this more simplistic assessment of outage may be a fixed percentage allowance for the resource zone. However, even if there is a significant resource surplus, a full outage assessment may still be advisable in order to provide a better level of understanding of issues within the resource zone.

2.1.3 Identify historic outage events

Having decided to apply the outage methodology to a water resource zone, the next task is to identify any historic failures of supply. Ideally a record of all the required pieces of information such as magnitude and duration of loss during each event, as well as reason for the loss, should be included in the record. Interviews with water resources and operational staff, or interrogation of operational data are also likely sources of this failure information and provide a useful sense-check of any data available.

Once the Legitimate Outage events have been identified, then the outage issues data-form can be completed. This contains information associated with outage dependency, and the frequency, magnitude and duration of the events. In general, the outage events will be independent, but sometimes one event will be the result of another, therefore they may be correlated, dependent or they may be mutually exclusive (i.e. one or the other will apply at any one time, but not both).

This process needs to be repeated for each of the resource zones within the region.

2.1.4 Construct the model

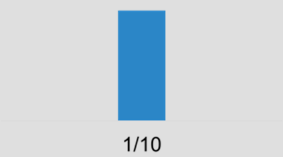
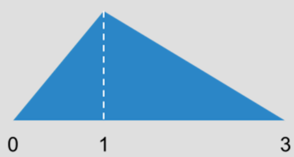
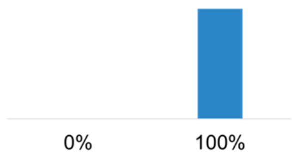
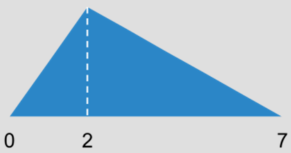
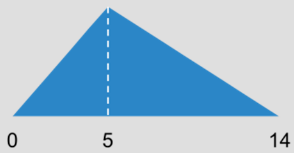
The Monte Carlo model is then constructed in @Risk to combine the estimates of frequency, duration and magnitude for each of the events to determine the overall distribution of legitimate outage. The Outage Model sets out a series of spreadsheets in a way that is auditable and easily combined to calculate this distribution. Each Outage component in the model is cross-referred to the Outage issues proforma so that the origin of the data is clear.

The Monte Carlo model is run to derive the distribution of Legitimate Outage and the output presented in tabular and graphical form. The Outage Model has established formats for the graphical and tabular output.

This methodology requires the uncertainty surrounding the frequency, magnitude and duration of each outage issue to be defined as a probability distribution. All the issues are then combined using Monte Carlo simulation to give overall outage uncertainty.

First of all, each outage issue is broken down into a set of three probability distributions. This might take the form of a triangular distribution or a fixed value for frequency, a triangular or discrete distribution for magnitude, a triangular distribution for duration or if sufficient data any distribution that best fits the available data. An example is given in Table 2.

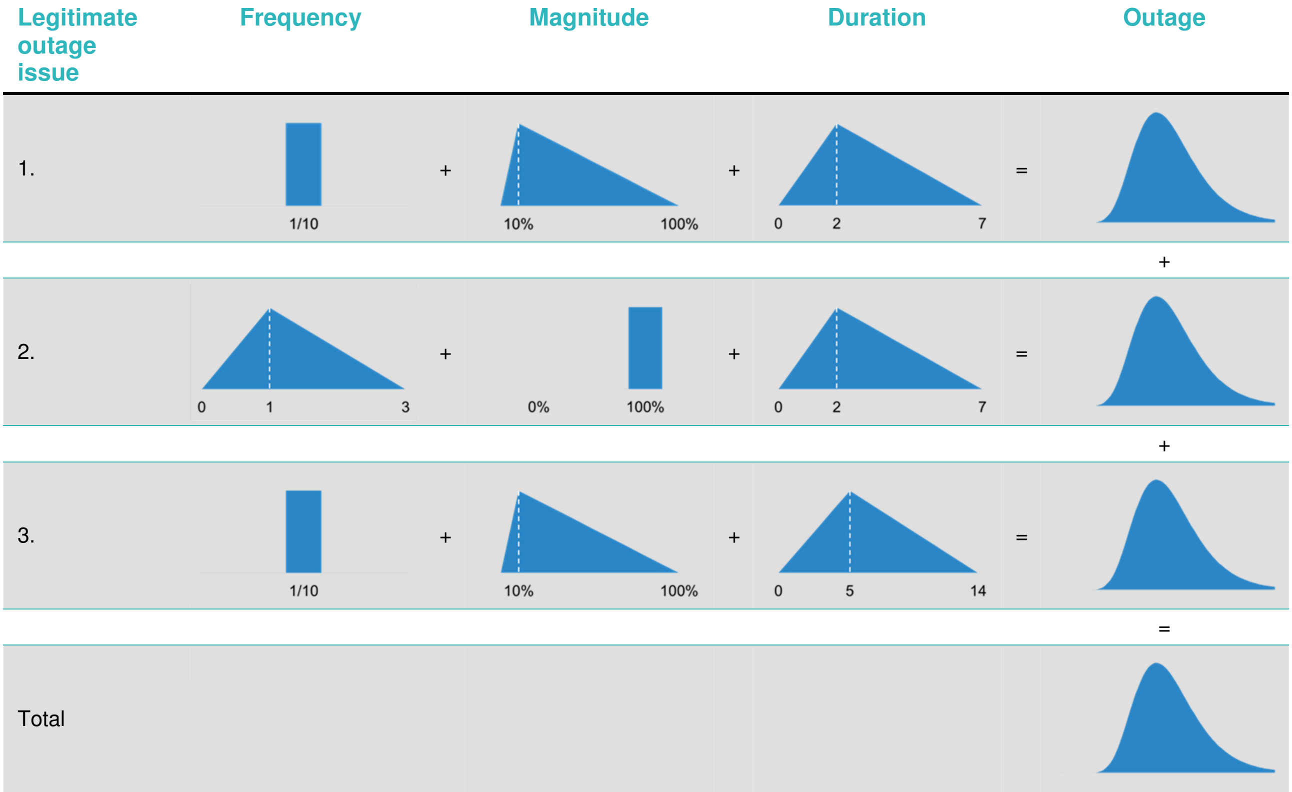
Table 2: Example of outage probability distributions

Frequency		One failure recorded in 10 years. It is not possible to assign a distribution with one datum. Use a fixed distribution with value 1/10.		Up to 3 events recorded in a single year over a 20 year period, but on average, only 1 event a year.
Magnitude		If an event occurs, it could have no impact or cause complete shutdown, however, the most likely is a 10% reduction		If an event occurs it would result in a complete shutdown
Duration		The event could last up to a week, but repairs should be made within 2 days		The event could last up to 2 weeks, but the works is normally operational be the end of the first week

For each outage event type, these distributions are then summed to generate one overall probability distribution for the event outage, as shown graphically in Table 3.

An inherent assumption in this methodology is that the outage issues are independent. Generally this is the case, but some can be inter-related. Two issues may affect the same source but only result in one outage. In this instance, it is necessary to modify the Monte Carlo analysis to allow for these inter-relationships.

Table 3: Summing outage issues



2.1.5 Software and simulations

Various software packages are available for performing Monte Carlo analysis. This methodology has been tested using @RISK, an add-in software package which operates within a spreadsheet environment. When a Monte Carlo simulation is run, the software randomly selects numbers from each probability distribution assigned to each component of an outage event (frequency, magnitude and duration). Each set of random numbers effectively simulates a single 'what-if' scenario for the spreadsheet model. As the simulation runs, the model is recalculated for each scenario and the results are presented as a series of forecast charts for Outage Uncertainty.

The simulation stops according to criteria set by the user, which is normally a number of iterations or trials. The number of trials must be set to give an acceptable mean standard error for the simulation results, whilst controlling the processing time to workable limits. A typical number of trials might be 1,000 to 10,000.

3 Model development

The Cambridge Water outage model has been developed following the best-practice UKWIR methodology, and builds on previous iterations used for WRMP14 and WRMP09.

3.1 Identifying time periods for analysis

The outage modelling aims to calculate the outage allowance during peak and off-peak periods. Previous iterations of the outage model have taken a month-by-month approach. However, the outage data does not currently support this level of granularity. It was therefore decided that just two time-periods should be considered: an off-peak season (including planned events) and 3 month peak season (unplanned events only).

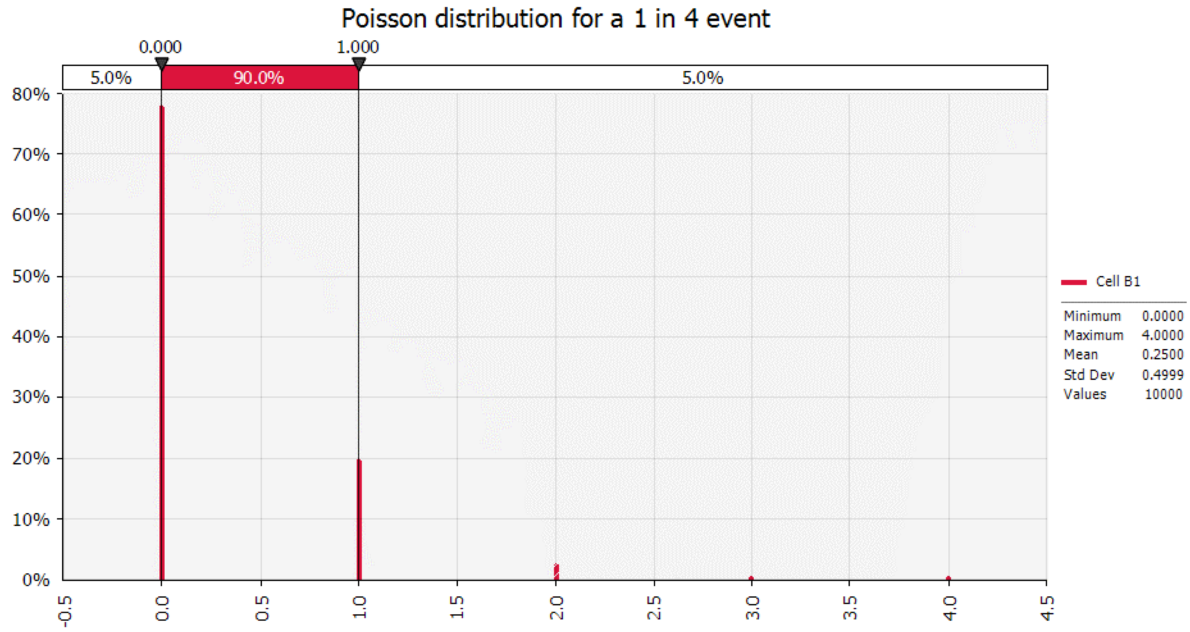
3.2 Assessing the impact of frequency on uncertainty

One of the largest sources of uncertainty in outage analysis is the number of times an event occurs in a year. This is always a discreet number, as it is not possible for half an event to occur. This can be modelled using a Poisson distribution, which will give the probability of several events occurring within a specified time period, given the expected number of events to occur. In special cases, for example algal blooms, where it is only possible for the event to occur once, a Bernoulli distribution can be used instead of a Poisson distribution.

This is a change from the WRMP14 methodology, where frequency was generally considered using a fixed value. However, there is a risk that this discrete approach tends to underestimate the outage uncertainty.

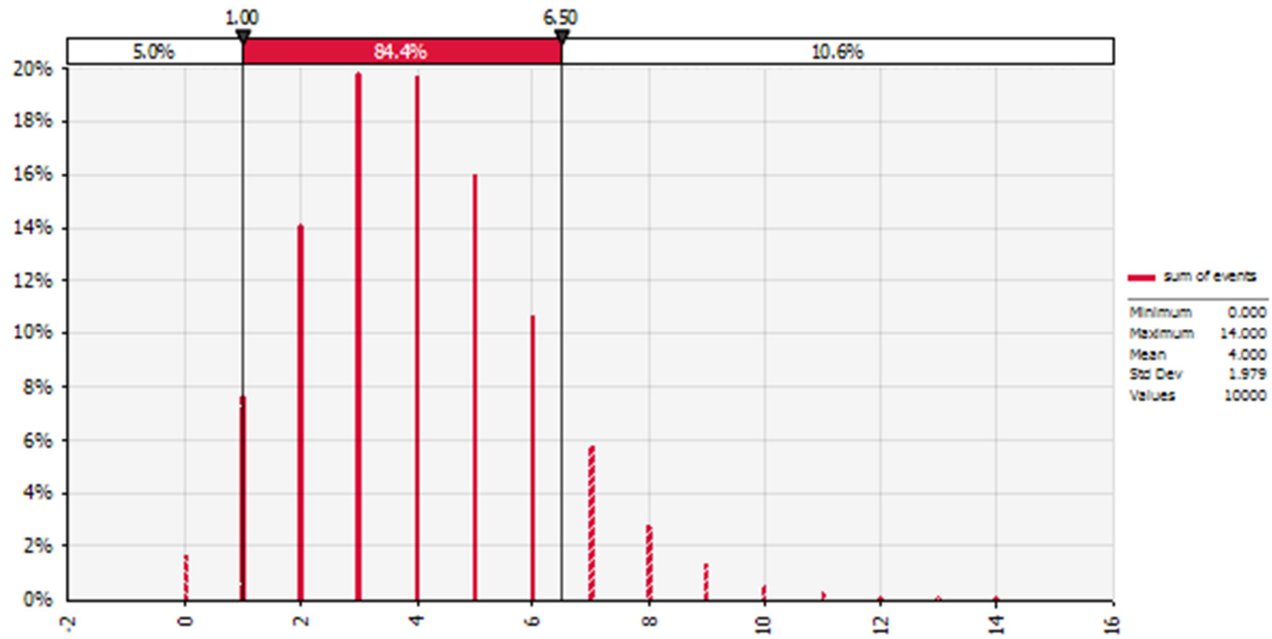
For example, if an event was observed to occur once every four years, a discrete frequency value of 0.25 would be used. This is multiplied by the outage severity (magnitude x duration) to give the overall outage distribution. In this example, the outage allowance would be one quarter of the expected loss due to the outage event, which is perfectly acceptable for the median outage value but risks underestimating outage at higher probability percentiles.

Figure 2: Example Poisson distribution



As another example, if there are 16 sources with an outage once every four years, the most likely case is that there are 4 outages across the sources, but it is possible that some years there will be more than 4, and some years less.

Figure 3: Output distribution showing the sum of Poisson distributions



To be 80% certain that our outage allowance covered the number of outages, the sum across the 16 Poisson distributions shows it would be necessary to allow for six outage events. That gives a value 50% higher than using a fixed multiplier for frequency. Or to look at it another way, if only four outage events were allowed for (as would be the case using fixed values), then our outage allowance would be insufficient in more than one out of every three years.

Our adoption of a poisson distribution for frequency resolves these issues.

3.2.1 Combining uncertain number of events with uncertain magnitude and duration

To combine the number of events with the magnitude and duration of each event, it is necessary to evaluate the magnitude and duration each time an event occurs. There are two options to do this:

1. Using @Risk's built-in 'risk compound' function.
2. Create multiple distributions, allowing one distribution per possible event

Of these, the risk compound function is preferred due to its greater flexibility and efficiency.

A third option is to not evaluate the magnitude and duration each time. However, this approach overestimates the outage uncertainty by assuming every event in any given year is identical.

We therefore adopt the risk compound function for combining all events.

3.2.2 Limitations

Where events have particularly long durations, the risk compound method may overestimate the total outage, particularly if the distribution used for duration is triangular, which tends to overestimate the number of extreme events. This will make it possible for the total duration of the events to exceed the total duration of the time period. To limit the potential impact of this, care was taken when developing the magnitude and duration distributions from the historic data. A separate model file was created to assess the total duration of events to check that the distributions created from the raw data were producing feasible outputs. Where necessary the inputs were adjusted before carrying forward into the final model.

3.3 Creating input distributions from historic events

Historic events have been analysed and included from 2004 to 2016. The list of events was first reviewed to identify if events were legitimate outages. Non-legitimate events were excluded from the data. The data was then grouped to produce distributions. The events were also reviewed to ensure that where two or more events were recorded as occurring at the same time and the same site, these were only counted as one event.

Events at sources no longer in supply should generally be excluded. Including disused sources in outage risks overestimating overall magnitude (if DO has decreased), as well as the fact that disused sources are likely to have suffered anomalously high levels of outage, contributing to their failure. For Cambridge Water, the following considerations were included in deciding legitimate outage.

- HOPW2 is now in supply, but hadn't been for some time due to cryptosporidium risk, so there are no recorded outage events pre-2014. Upgraded treatment means that the post-2014 events should be representative (mainly turbidity failure).
- FD12PW is currently out of service but should be reinstated later in this AMP as a raw source to the treatment works at FD36PW so its outage events have been included, with the exception of treatment, which would be encompassed by FD36PW treatment outage events. The long-duration treatment works failure at FD36PW was due to microbial contamination

and is considered to be a legitimate possible outage in the future, so is included but with a duration distribution that reflects the low probability of top-end durations.

- KIPW2 and CRPW2 are both out of supply at the moment due to inadequate sand filters. They are likely to be included in WRMP19 as AMP 7/8 schemes. The filter failure events are not included because the treatment upgrades at both sites are considered sufficient to mitigate similar events in the future.

Event magnitudes were cross-checked against current DO for each site, to ensure any changes in DO since an event occurred are captured: for events at sources where DO has decreased for any reason, current DO is used to calculate outage rather than DO at the time of the event, in order to avoid over-estimating outage.

3.3.1 Grouping events

Events were grouped by site and by category (event type). Alternative options considered included grouping by type only and applying across all sites, or grouping by site only (effectively ignoring category). These options would result in a loss of granularity in the results and could affect the upper and lower outage percentiles. They also would mean a loss of detail in the results: i.e. which sites are contributing most to outage, and any possible mitigations to reduce outage in the future .

3.3.2 Calculating frequency

The frequency value for the events is calculated by the total number of events divided by the time covered by the dataset (in this case 15 years). For example, if 15 planned events had occurred at one site over the last 15 years, the frequency would be 1 event per year. This is then used as the frequency value for the Poisson distribution used in the model

3.3.3 Duration and magnitude

The distributions for duration and magnitude are by default created as triangular distributions using the minimum, modal and maximum values to create the distribution.

3.3.4 Correlation and Dependency of Events

Dependency is not generally an issue for Cambridge' sources, but on some occasions more than one event may impact on the same volume of resource at a sourceworks, at the same time. For example, a turbidity incident can often occur at the same time as a crypto event. An analysis should be able to ensure that a resource loss is not double counted, i.e. once for the turbidity issue and once for the crypto issue. The model does not test for simultaneous occurrence of multiple causes of outages, which could lead to double counting. However, this is counter-balanced by the analysis and recording of the historic data. Events are only recorded as one type, and if another event occurs that would otherwise lead to an outage, this will not be captured. For example, if a site has a planned outage, and while it is out there is an issue with the raw water which would lead to an outage, this second event would not be captured.

Where sites are linked in the specific case of blending low and high nitrate sources, the outage event at the low nitrate source may be given the magnitude of the sum of both sources to account for a resulting blend failure. Cambridge Water monitor 13 distinct nitrate blends. However, at none of these is any one low nitrate source considered so critical to the blend that its failure would result in a compounded failure for the blend as a whole. Therefore, no increase in event magnitudes at low-nitrate sources has been applied.

3.3.5 Extreme Events

Extreme events can fall into one of two categories:

- Rare events which will occur infrequently, if at all during the planning period; and
- Events which may occur with a limited impact, but there is a small chance that the impact could be much more significant.

For isolated zones, there is a risk that such events are under-represented using the standard frequency-magnitude-duration approach: a failure would have a major impact on the supply/demand balance, even if this occurs infrequently. In this case it would be appropriate to remove frequency from the analysis.

For Cambridge Water, the resource zone is generally well enough integrated that this issue does not apply: extreme events can be included in the analysis in the usual way by combining frequency, magnitude and event duration. As the chance of occurrence is small, the frequency will be low, reducing the impact of the event on the overall outage uncertainty.

3.4 Analysing the data

Once the distributions are selected, they are built into the @Risk model. The model is then run for 10,000 iterations to produce the combined outage. The in-built sensitivity functions are used to analyse which inputs have the greatest impact on the result.

4 Results and conclusions

4.1 Results of Outage Assessment

The results of the runs performed for both average and peak conditions are set out in this chapter. The results have been calculated from simulations using 10,000 iterations. It is deemed that this number of iterations is sufficient to ensure repeatability of the results of the analyses.

The results of both analyses are presented both in Ml/d and as percentages of the company's deployable output for various percentiles of risk.

4.1.1 Results of the Analysis under Average (DYAA) Conditions

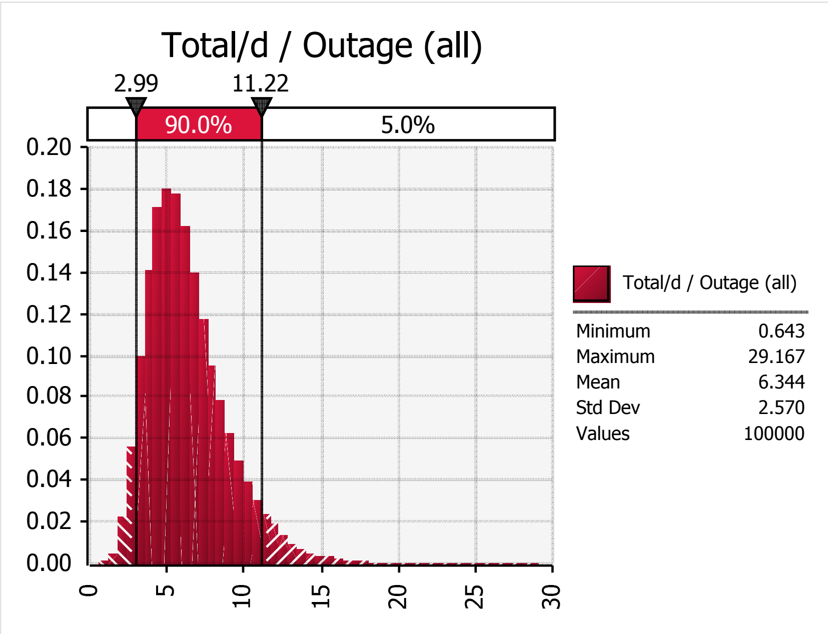
The result for dry year annual average conditions are shown in Table 4 and Figure 4.

Table 4: DYAA Outage results by percentile

Risk Percentile	Outage (Ml/d)	% of Base Year DO
5%	2.99	2.99%
10%	3.50	3.50%
15%	3.88	3.88%
20%	4.21	4.21%
25%	4.50	4.50%
30%	4.78	4.78%
35%	5.06	5.06%
40%	5.34	5.34%
45%	5.61	5.61%
50%	5.90	5.90%
55%	6.20	6.20%
60%	6.52	6.52%
65%	6.88	6.88%
70%	7.27	7.27%
75%	7.72	7.72%
80%	8.25	8.25%
85%	8.91	8.91%
90%	9.81	9.81%
95%	11.22	11.23%

Source: Mott MacDonald

Figure 4: DYAA Outage Distribution



Source: Mott MacDonald

4.1.2 Results of the Analysis under Critical Period (DYCP) Conditions

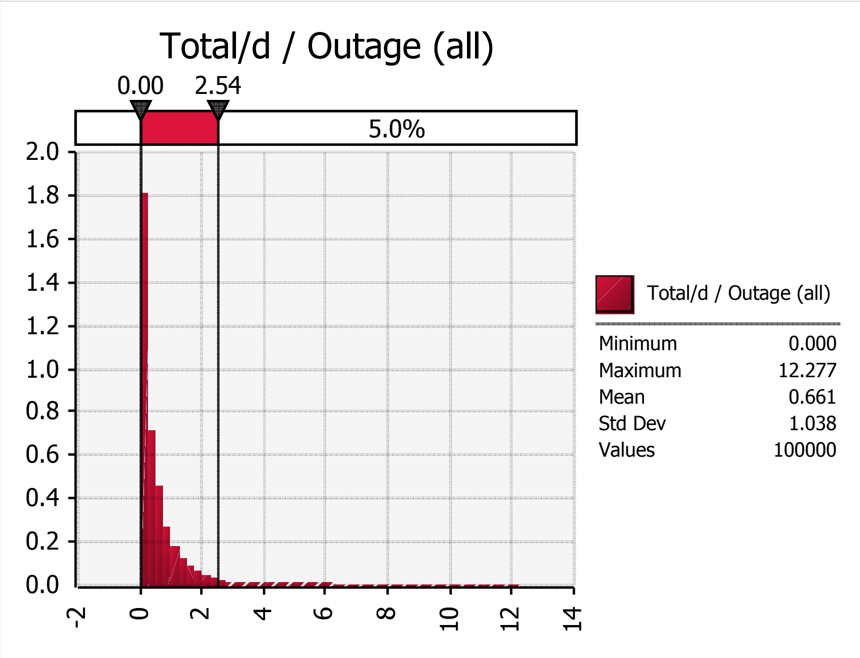
The result for dry year critical period conditions are shown in Table 5 and Figure 5.

Table 5: DYCP Outage results by percentile

Percentile	Outage (Ml/d)	% of Base Year DO
5%	0.07	0.06%
10%	0.18	0.16%
15%	0.31	0.27%
20%	0.44	0.38%
25%	0.62	0.53%
30%	0.80	0.68%
35%	1.00	0.86%
40%	1.25	1.07%
45%	1.56	1.34%
50%	1.86	1.60%
55%	2.21	1.90%
60%	2.59	2.22%
65%	3.11	2.66%
70%	3.80	3.26%
75%	4.77	4.09%
80%	6.13	5.26%
85%	8.06	6.91%
90%	10.99	9.42%
95%	16.91	14.50%

Source: Mott MacDonald

Figure 5: DYCP Outage Distribution



Source: Mott MacDonald

4.1.3 Percentile Risk Selection

For supply/demand balance modelling, South Staffs considered the 70th percentile values for Outage at both DYAA and DYCP to be most appropriate for capturing a suitable level of risk to the Cambridge WRZ supply system.

The corresponding values for DYAA and DYCP Outage are 7.27 Ml/d and 3.80 Ml/d respectively. These are equivalent to 7.3% and 3.3% of base year deployable output for DYAA and DYCP respectively. The lower DYCP outage is due to most legitimate outage events occurring outside of peak times, and the fact that DYCP D.O. is higher than DYAA D.O., such that the peak period events are proportionally less important for DYCP than for DYAA supply/demand balance.

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