Final Drought Plan

2022

Appendix E: **Drought scenarios and testing of the plan**

United Utilities

Water for the North West

1 Introduction

As outlined in Appendices A and J, since the last drought plan we have put considerable effort into improving our understanding of droughts. We collated new data, developed new tools and adopted new techniques. This new understanding underpins our drought plan and has been used to derive some of its key features, for example the new drought levels (main document, Section 2.3). In this appendix we describe the testing undertaken to demonstrate that our drought actions and levels, and drought plan as a whole, are robust and will ensure an effective response to drought. This testing has taken two forms:

1. **Stress-testing of the new drought levels to future uncertainties (Section 2)**
2. **Event-specific scenario modelling (Section 3)**

2 Drought levels stress testing

For the Strategic and Carlisle Resource Zones (RZ) the new drought levels were created with the aid of computer models and sophisticated optimisation techniques (Appendix A). Even within the relatively short five-year timeframe of this drought plan there is considerable uncertainty about the conditions that could occur. The dominant factor leading to customer restrictions is the weather but other aspects such as changing patterns in customer demand for water can play a key role too.

In the drought level optimisation process uncertainty in weather conditions was well represented. The primary objective of a water resource model has long been to test the supply network under a wide range of historical hydrological conditions. Other uncertainties, such as longer-term climate change effects, are less well represented. This is in part due to limitations in our understanding of these areas relative to hydrology but is also governed simply by the amount of data we can simulate using today's computers. Therefore, for the optimisation process we made a series of conservative assumptions about what conditions could occur in the drought plan period. For example, we set demand levels above those experienced in the 2018 dry weather event to ensure our plan is resilient to high demand.

In previous drought plans, at this point we would have cemented our assumptions and moved on to testing event-specific scenarios. For this drought plan we introduced a new step that goes beyond the standard industry approach and was facilitated by our recent advances in modelling. We stress-tested our new drought levels against a wide range of future uncertainties and the corresponding risk levels are summarised in Table 1 for the Strategic RZ and Table 2 for the Carlisle RZ. It is important to note that the risks presented in the tables are relative to the drought plan baseline rather than to our levels of service (i.e. higher risks do not indicate an expected levels of service failure). We explored a greater number of uncertainties in the Strategic RZ where the drought risks are higher. The key findings were:

- The stress testing highlighted that the new drought levels are robust to a range of future uncertainties, beyond the core assumptions used in their derivation.
- The risk of non-essential use bans (NEUBS) or emergency drought orders remains extremely low under all future uncertainties tested. Any simulated increase in risk was a very small fraction of the starting risk.
- Shaded in amber, the highest simulated increases in the risk of temporary use bans (TUBS) and drought permits were due to "extreme" climate change and demand. However, the levels simulated here were well outside of our normal planning envelope with 95th percentile climate change severity and 150 Ml/d (Strategic RZ) / 1.5 Ml/d (Carlisle RZ) of additional demand on top of 2018.
- We saw increases and changes in the spatial distribution of demand in 2020 due to Covid-19 (for example due to people working at home in residential settings). During the development of this plan we were still analysing these effects and in 2022 it remains challenging to forecast the short to medium term impacts on demand.

- “Severe” climate change impacts and demand increases, as well as poor leakage performance and more frequent water quality issues, led to slight increases in the simulated risk of restrictions (yellow shading).
- Some features of the optimisation process created extra resilience to some of the uncertainties. For example, the minimum time requirement for the Environment Agency to grant drought permits was set at 12 days. However, an optimisation objective of the drought levels optimisation process was to provide as much flexibility as possible around the timing of actions. This meant that in the vast majority of simulated events, there was already 28 days available for drought permits to be granted. As shown in the Strategic RZ table (there are no drought permits in the Carlisle RZ), there was therefore limited additional risk associated with extending the minimum required period from 12 to 28 days. In our drought plan scenario runs, we only implemented permits that we anticipate would be granted in the conditions simulated, based on local rainfall and impounding reservoir levels. Of course, in reality all drought permits are subject to Environment Agency approval.
- Along similar lines, using a very large hydrological dataset in the optimisation, with hundreds of different drought patterns, provided a very high overall level of resilience which then gave secondary benefits in terms of dealing with other future uncertainties. This is especially true in comparison with previous drought plans where our modelling utilised only a handful of droughts.
- There is a high degree of overlap between resilience to general weather variability, as mainly reflected by our stochastic dataset, and longer-term climate change as reflected by the UKCP09 perturbations we applied in this stress testing. Demand is also closely linked to the weather and we used understanding from our weather-demand model, developed by the Met Office, to inform our core demand assumptions and stress-testing scenarios. There are other elements of demand that are far harder to predict, for example changes in customer behaviour and the economy (which directly affects our business customers). As evidenced by the recent past these trends can now change much more quickly than previously had been the case. This inevitably leads to larger uncertainty bounds and greater use of scenarios in our demand forecasts. During the development of the plan Covid-19 was having a profound effect on our lives and this is translating to significant changes in demand for water, for example due to people moving from office to home based working. This is a complex situation to understand, especially with regards to separating the shorter and longer term effects on demand. This risk have been covered by increasing levels of demand in our stress testing process.
- As an industry we have focussed heavily on the risk posed by weather variability but in the future we will need to improve the way that other risks are accounted for. There are several factors that affect the likelihood of customer restrictions occurring and as many as possible of these should be explicitly included in the calculation of risk. The stress-testing approach taken is our current best way to account for this but the next time we update the drought levels we hope to be able to include, for example demand uncertainty, in the optimisation process itself.

Table 1 - Strategic RZ stress-testing results. Green shading indicates a similar level of risk; yellow a slightly higher level of risk; and amber a higher level of risk.

Aspect	Specific stress test	Simulated additional risk relative to baseline: Temporary use ban	Drought permits	Non-essential use ban	Emergency drought orders
Customer behaviour (demand saving)	Customers save half as much water as expected in a temporary use ban				
Drought permits	The Environment Agency takes longer than expected to grant drought permits (28 days)				
Demand higher than expected	150 Ml/d higher than 2018 (average across the year)				
	100 Ml/d higher than 2018 (average across the year)				
Leakage performance below target	Leakage not reduced below levels recorded in 2019-20				
Water quality outage	Water quality issues occur at water treatment works periodically[1]				
Climate change	The impact of climate change on supply in the 2020s is severe (75th percentile)				
	The impact of climate change on supply in the 2020s is extreme (95th percentile)				

Table 2 - Carlisle RZ stress-testing results. Green shading indicates a similar level of risk; yellow a slightly higher level of risk; and amber a higher level of risk.

Aspect	Specific stress test	Simulated additional risk relative to baseline: Temporary use ban	Non-essential use ban	Emergency drought order
Customer behaviour (demand saving)	Customers save half as much water as expected			
Demand higher than expected	1.5 Ml/d higher than 2018 (average across the year)			
	1 Ml/d higher than 2018 (average across the year)			
Climate Change	Climate change in the 2020s is severe (75 percentile)			
	Climate change in the 2020s is very severe (95 percentile)			

[1] Specifically this scenario corresponds to removing water quality issues from the outage allowance (which was added to demand in all simulations) and assuming that they would constrain supply in every single drought event.

3 Scenario modelling

Considerable effort has been put into designing the drought actions and levels that form the backbone of this drought plan. Knowledge and expertise from across our teams and consultants has been combined with the latest technology. This section outlines scenario modelling which formed the last step of this process. Using our sophisticated water resources models we selected specific drought events to help test the effectiveness of our drought plan.

We simulated a range of both historical and synthetic drought events. Simulating historical events allows us to test what would happen if the hydrological conditions were to re-occur with today's supply system and this drought plan in place. Simulating synthetic events is also important as it allows us to test the plan against droughts that are more severe and/or different in nature to historically recorded droughts. In the past we created synthetic events by joining together data from different historical events. These scenarios provided an effective test but it was difficult to know their plausibility or likelihood of occurrence. For this drought plan we used plausible droughts created using a stochastic "Weather Generator" as described in Appendix A. Furthermore, rather than simply selecting events based on simple metrics such as the amount of rainfall we simulated hundreds of droughts to find those that would actually pose a risk to customers, i.e. we based drought severity on the type of restrictions that would be implemented. This process, which we refer to as drought characterisation (Appendix J), ensures that our drought plan has been tested against the drought patterns that we are most vulnerable to. Failing to do this could leave us with blind spots.

We plotted simulated storage for Haweswater and Dee to assess the severity of the impact in terms of minimum reservoir storage levels reached, drought levels crossed and actions taken. We also examined the time taken to pass through each level to ensure there was sufficient time to implement the actions required and flexibility for the decision making process. To help show the benefits of drought permits, and how these can vary from event to event, we plotted simulated storage with and without the permits in place (blue dashed line).

As outlined in Appendix A, the operation of sources in the Strategic RZ is complex and adapted day-by-day based on a wide range of variables. Our water resources models have sophisticated algorithms to emulate this process, as an example Windermere is used by the model in the following circumstances:

- Haweswater Reservoir is below its resource curve.
- The downstream River Leven is above its "hands-off flow[2]" condition.
- There is a surplus of demand that can be met by Windermere once other network requirements, in particular asset minimum flow[3] requirements, have been satisfied.

To help reflect the more operational nature of this drought plan compared to previous plans we have labelled the scenario simulation outputs with key operational activities. It is important to reiterate that use of these sources is

[2] "Hands-off flow" conditions are sometimes included in abstraction licences. They stipulate a flow level below which abstraction cannot cause the river to drop. Windermere is a natural lake which spills in the River Leven hence there is a direct relationship between lake and river levels (this "spill equation" is also included in our models).
[3] Many assets, in particular water treatment works, have a design requirement to maintain a minimum flow throughput either continuously or for set periods. We must use water from these assets in preference to Windermere to maintain a supply of water.

not based on simple rules that can easily be presented here (Appendix A). We need to interrogate the modelling results to find out when these assets are used in each event.

The results shown in the following sections are for the Strategic and Carlisle RZs. The North Eden and Barepot RZs have no plausible drought risk as explained in Appendix J, although we in-effect ran some extreme scenarios in North Eden to help demonstrate this point by assuming peak week demands (i.e. the week of the year with the highest level of demand) would occur in every week of the year (Figure 1).

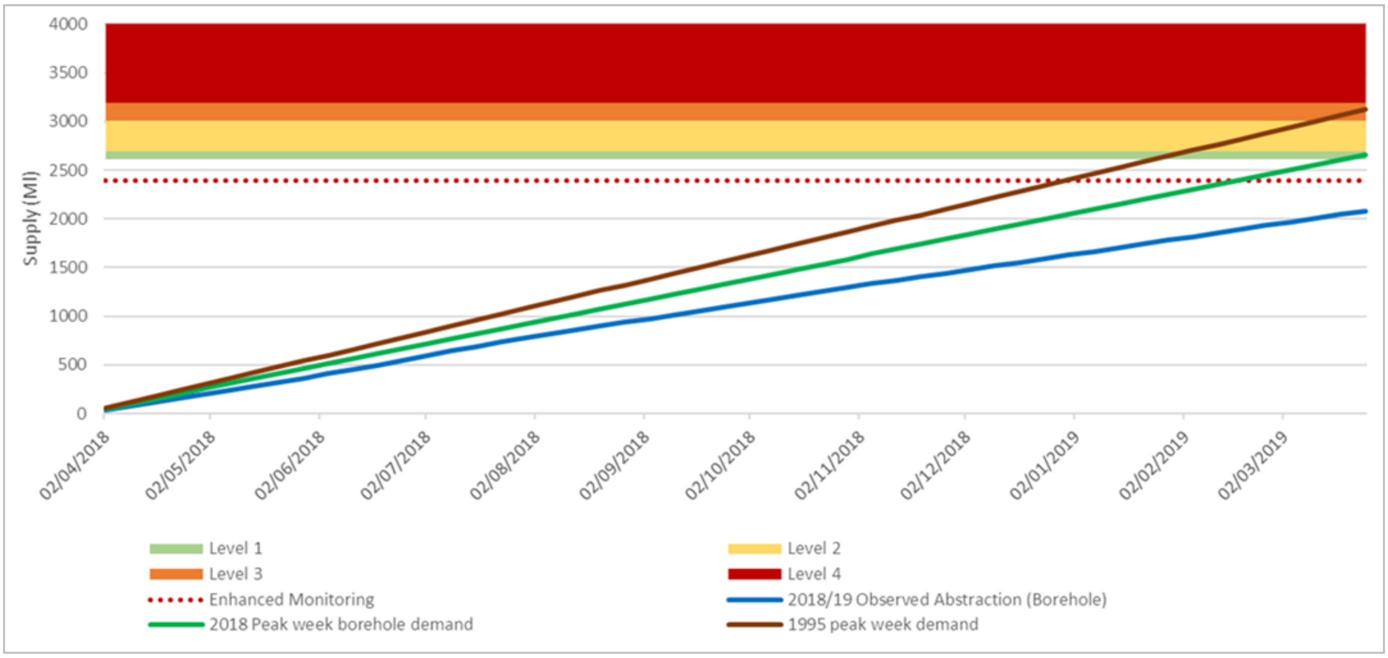


Figure 1 – Scenario testing used to help demonstrate the lack of plausible drought risk in the North Eden RZ. The green and brown lines correspond to demand which has been artificially raised to equal peak week demand in all weeks of the year. Further information is provided in Section 5.2 of Appendix J.

3.1 Strategic Resource Zone

3.1.1 1984 Historical Event (One Season)

Rationale

In terms of simulated storage levels, 1984 is the most severe historical event affecting the Strategic RZ. This does not mean that it had the highest impact historically but that the hydrology from 1984 has the biggest impact on the current supply system.

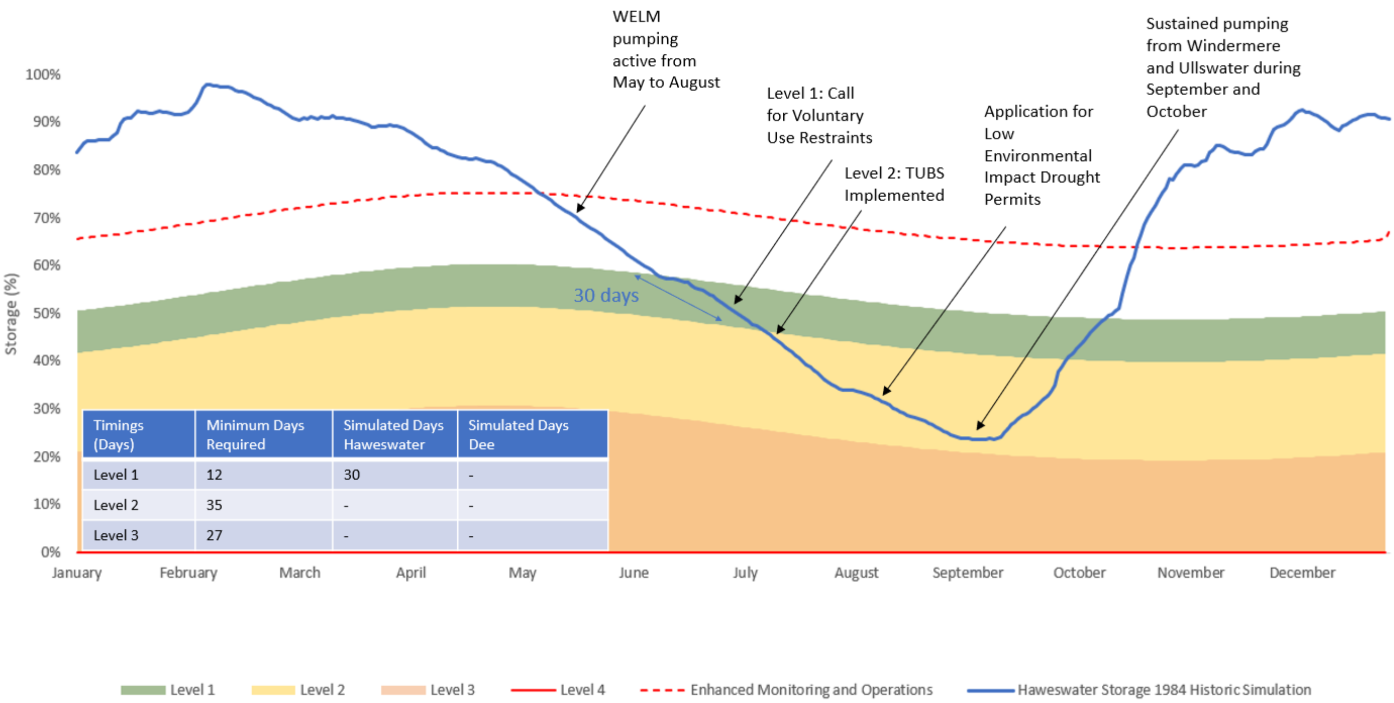
Event Description

This drought scenario is based on a repeat of the climatic and hydrological conditions experienced in our region in 1984, and has the following characteristics:

- Single season summer drought of duration approximately 7 months.
- Impacts occurred particularly in the north of our region but including the Pennines.
- Historically, a range of drought permits and orders were applied for from mid-May onwards and implemented between June and September 1984.
- Rainfall at Burnbanks rain gauge (Haweswater) for the 4-month period to the end of June 1984 (last complete month prior to point of application) was 135mm or about 33% of the long-term average.

- Comparing this to a ranked data series of annual 4-month rainfall totals from March to June, for the 87-year period from 1932–2018, the 4-month period to June 1984 was the driest on record.

Results



Timings (Days)	Minimum Days Required	Simulated Days Haweswater	Simulated Days Dee
Level 1	12	30	-
Level 2	35	-	-
Level 3	27	-	-

Figure 2 – Haweswater simulated storage, also showing new drought levels, salient drought and operational actions and timing between levels (inset table)

Discussion

As shown in Figure 2, this scenario helps to demonstrate the huge improvements in our supply system since 1984. Our modelling indicates that a repeat of 1984 climatic conditions would lead to a minimum storage of 24% in Haweswater. The level triggering applications for Low Environmental Impact Drought Permits would have just been reached by August but is followed by a recovery in storage a month later. The benefits of Windermere and Ullswater are limited in this type of event because it develops so quickly that the hands-off flow conditions come into effect early in the draw down period. However, they are integral to recovery when the conditions are met. The Dee drought level 1 is crossed in August and remains within level 1 for 45 days however never reaches drought level 2.

3.1.2 1995-96 Historical Event (Two Season)

Rationale

Whilst 1984 is the most severe event in overall RZ terms, the 1995-96 event is most severe for many individual sources in the RZ, i.e. if they were disconnected from the conjunctive supply system this event would define their yield. Most of the Pennine reservoirs fall into this category. The interconnected nature of the RZ means that it is better able to deal with an event that is extended over two years.

Event Description

This drought scenario is based on a repeat of the climatic and hydrological conditions experienced in our region during 1995-96, and has the following characteristics:

- A two season drought covering the period 1995-96

- Impacts the whole of our region
- Historically, drought permits and orders were applied for from early August onwards and implemented between early September 1995 and December 1995. A number of drought permits and orders were extended into 1996 and others were applied for from the beginning of the 1996 and implemented between late January and July.
- Rainfall at Holden Wood rain gauge (a representative for the Pennines region) for the 6-month period to the end of September 1995 (last complete month prior to application) was 306mm or ~ 49% of the long-term average for the 6-month period from April to end of September inclusive.
- Comparing this to a ranked data series of annual 6-month rainfall totals from April to September for the 106-year period from 1910 – 2018, the 6 -month period to the end of September 1995 was the driest on record.
- Regional rainfall (average of 10 gauges) for the 15-month period to the end of June 1996 (last full month prior to application) was 906 mm or ~ 53% of the long-term average for the 15-month period from April 1995 to end of June 1996.
- Comparing this to a ranked data series of annual 15-month rainfall totals from the previous April to July for the 108-year period from 1911 – 2018, the 15-month period to the end of June 1996 was the driest on record.

Results

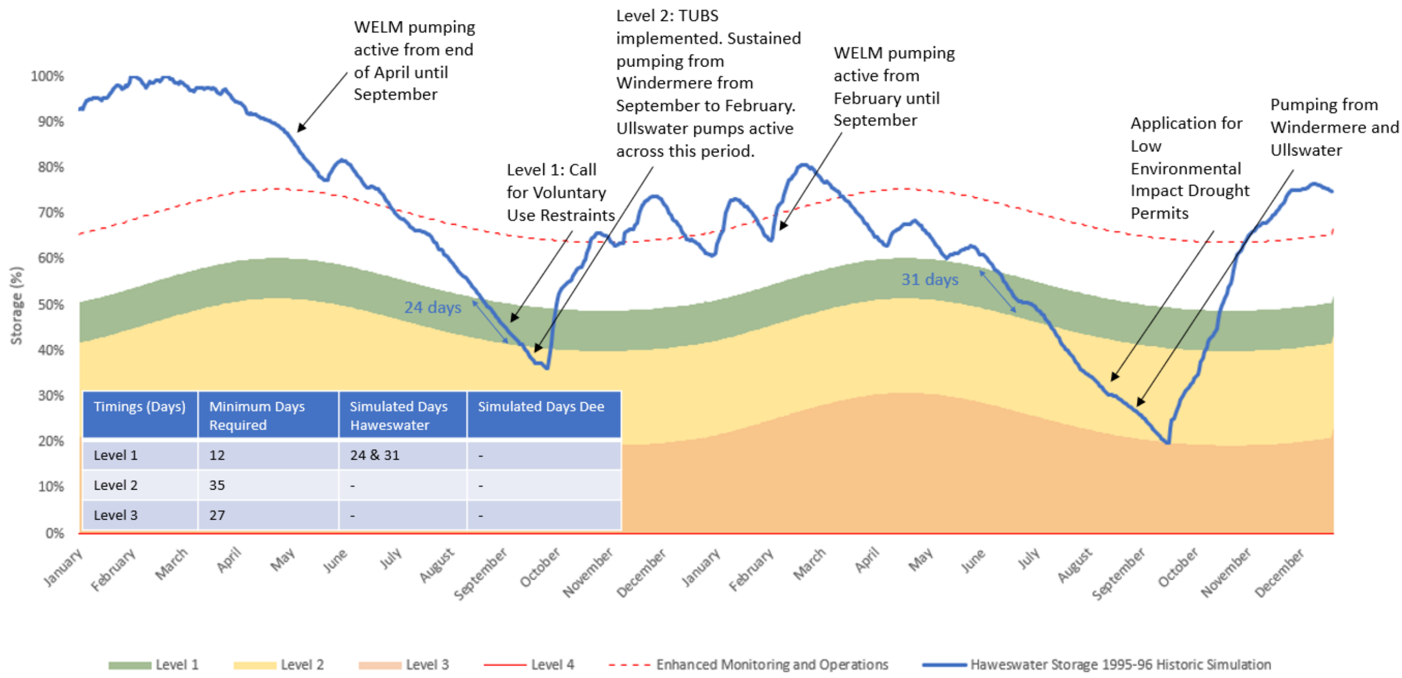


Figure 3 – Haweswater simulated storage, also showing new drought levels, salient drought and operational actions and timing between levels (inset table)

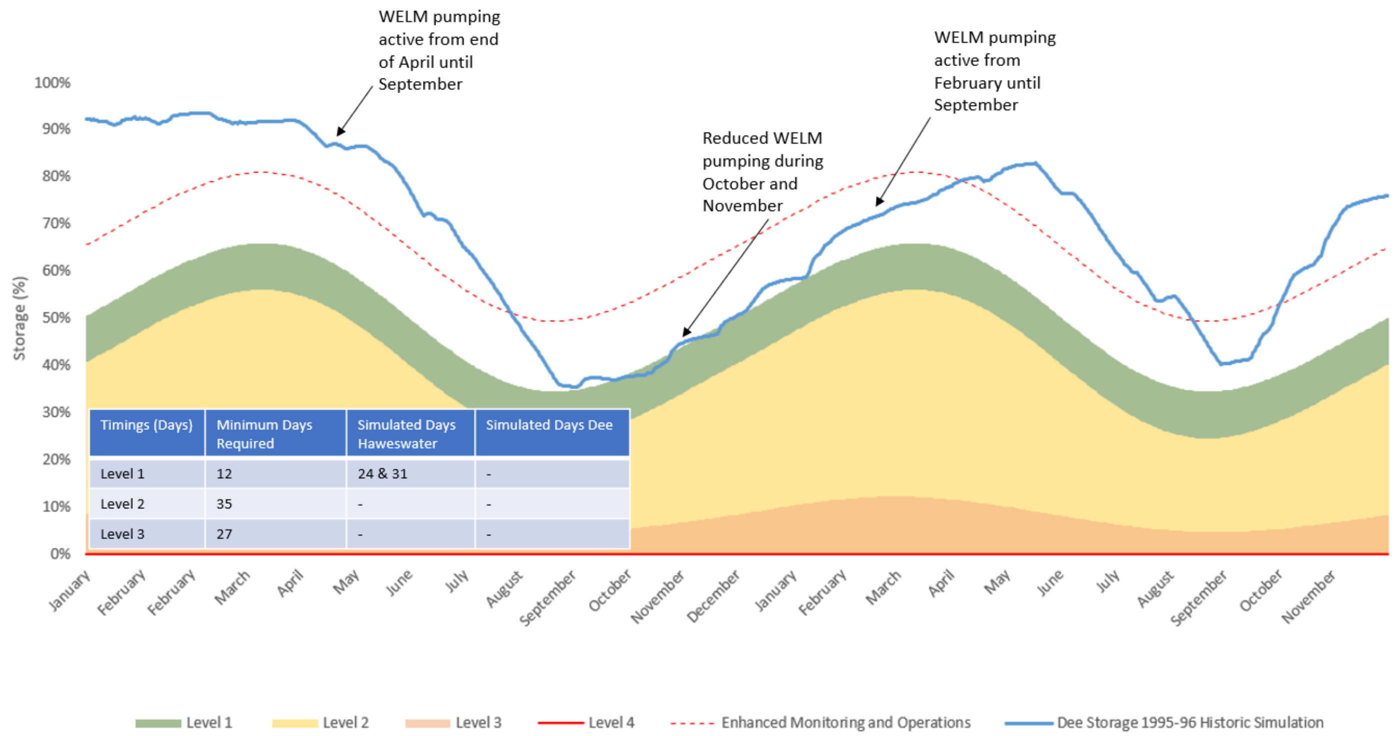


Figure 4 – Dee simulated storage, also showing new drought levels, salient drought and operational actions and timing between levels (inset table)

Discussion

Historically, Haweswater reached its minimum position on 1 October 1995. However, similar to 1984, our models indicate that during a repeat of 1995 climatic conditions Haweswater would reach a minimum total storage of 36%, avoiding application of drought permits in the first year of the event (Figure 3). Storage in the Dee drops below Level 1 for just 33 days at the end of October 1995. A large factor in this change is the significant reduction in leakage that has occurred since then, plus the commissioning of WELM (West East Link Main) in 2012.

During the second year of the event Windermere and Ullswater pumping help to mitigate the impacts and levels in 1996 drop to around 20%. The level for triggering drought permits would have been crossed in the second year of the event though the implementation of NEUBS is avoided. Storage in the Dee remains above Level 1 throughout 1996. Windermere and Ullswater pumping also form a key component of the recovery in the 1996-1997 winter.

3.1.3 1 in 500 Year Stochastic Event (One Season)

Rationale

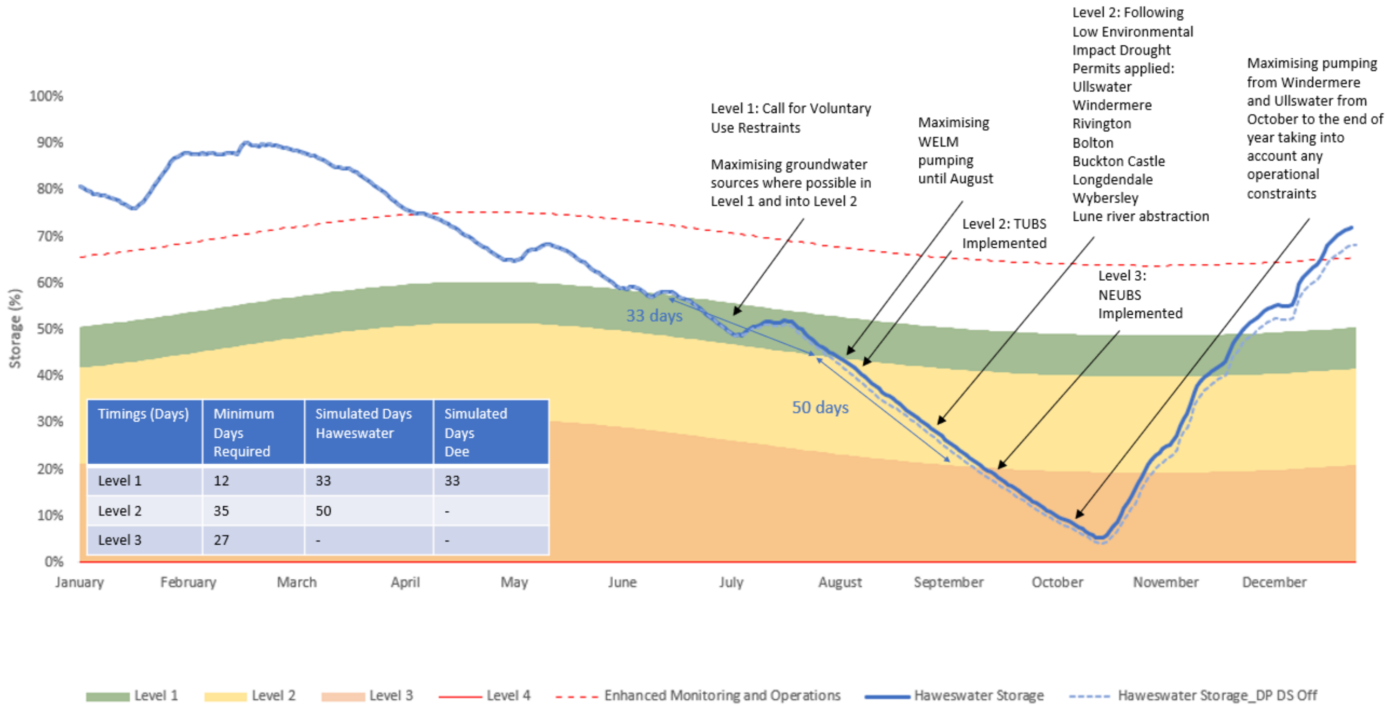
We are most vulnerable to single season events, where storage drops rapidly from springtime. This event resembles the 1984 event but with a much higher degree of severity (1 in 500 year return period).

Note that we are not currently resilient to all 1 in 500 year drought events, in all future conditions. In this specific event the simulation shows that we would not need to implement EDO. However, in other 1 in 500 year droughts, or with different future conditions, for example higher climate change emissions, we might need to implement EDO. As noted in Section 2 of the drought plan, our current minimum level of service for EDO is 1 in 200 years. From 2039, following significant planned leakage reduction and demand management, we will improve our minimum level of service for EDO to 1 in 500 years.

Event Description

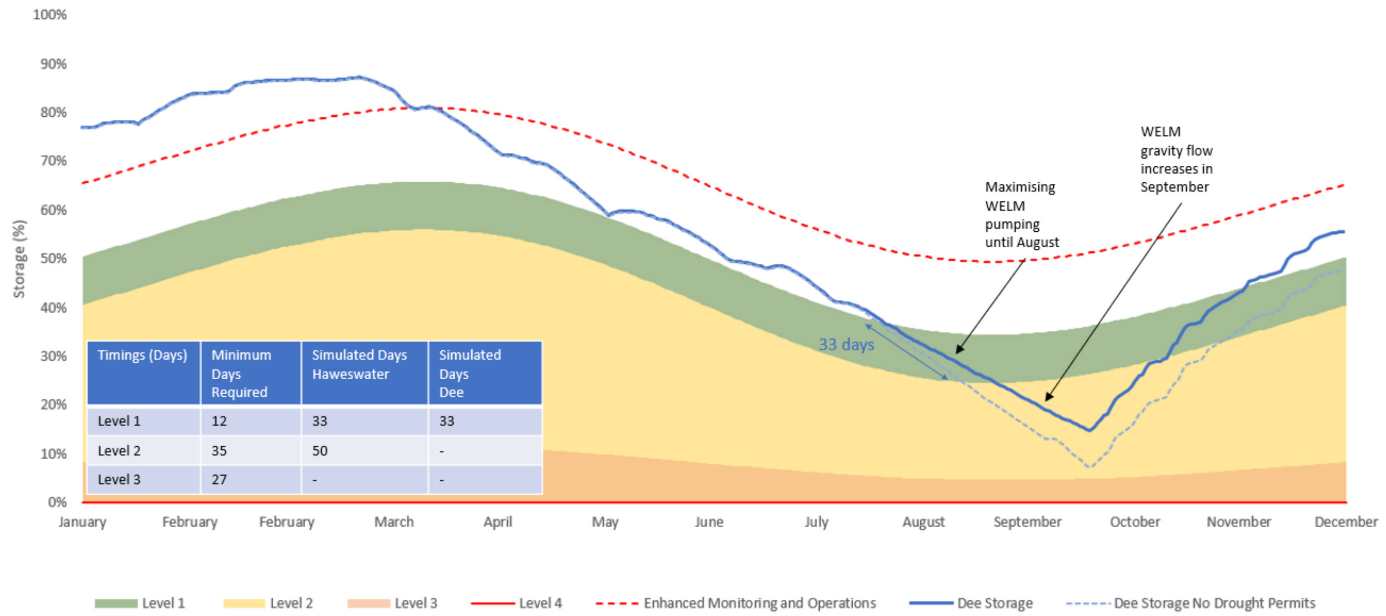
- This drought scenario is a stochastic single season 1 in 500 year event based on the system response across our Strategic RZ. The minimum storage at Haweswater reached 5.28% and crossed Level 3 triggering NEUBs in September.
- For five out of the eight months prior to reaching NEUBs, cumulative rainfall across the system remained below 50% of the monthly average (February, March, April, August and September).
- All reservoir sources began to drawdown rapidly at the start of March, triggering Level 2 TUBs at Haweswater on 7 August. At this time the total three-month cumulative rainfall at gauges relevant to the implementation of drought measures, was equal to or less than 75% of the stochastic long term average (S-LTA).
- All reservoir sources continued to drawdown and a Level 3 NEUBs event was triggered on 16 September. The three month cumulative rainfall totals prior to this remained at less than 45% of the S-LTA.

Results



Timings (Days)	Minimum Days Required	Simulated Days Haweswater	Simulated Days Dee
Level 1	12	33	33
Level 2	35	50	-
Level 3	27	-	-

Figure 5 – Haweswater simulated storage, also showing new drought levels, salient drought and operational actions and timing between levels (inset table)



Timings (Days)	Minimum Days Required	Simulated Days Haweswater	Simulated Days Dee
Level 1	12	33	33
Level 2	35	50	-
Level 3	27	-	-

Figure 6 – Dee simulated storage, also showing new drought levels, salient drought and operational actions and timing between levels (inset table)

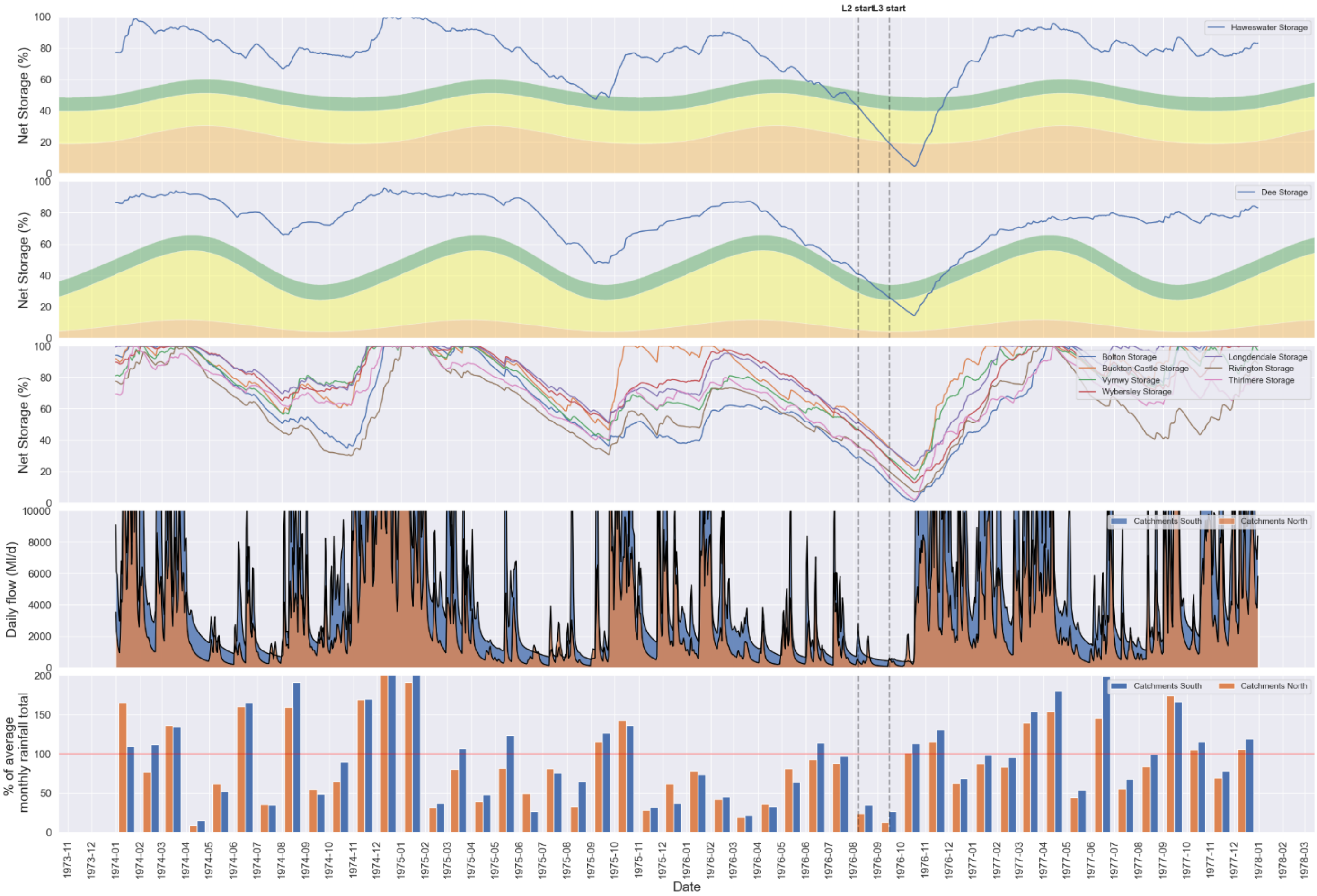


Figure 7 – Breakdown of the stochastic event 4154 from the drought characterisation exercise (Appendix J) showing storage across a range of reservoirs as well as rainfall and flow aggregated into north and south catchments.

Discussion

Figure 7, which was created for all Strategic RZ stochastic events as part of the drought characterisation exercise, provides a breakdown of the event (including preceding years) showing simulated storage across a selection of our other reservoirs, as well as rainfall and flow (split into north and south catchments). As noted above, based on storage levels reached in the Strategic RZ this event has a return period of 1 in 500 years. As explained in Appendix J this does not mean that we expect an event this severe to happen only once in a 500 year period but that each year there is a 1 in 500 or 0.2% chance of occurrence. The chance of an event this severe happening at least once during the 5 year window of this drought plan is only 1% but we need to ensure that our plan is robust. 1 in 500 years also corresponds to the government's new drought resilience standard and therefore aligns with the scenarios we use in our Water Resources Management Plan. As noted above, our current level of service for EDO however is 1 in 200 years, and this will be improved to 1 in 500 years from 2039.

Our simulations show that we would be resilient to this event, although we would likely need to implement NEUBs. Operationally, Windermere and Ullswater are again limited by their hands-off flow conditions but the WELM is very effective in balancing reserves between the north and south of the RZ[4]. The vast majority of modelling we undertook, including most of the scenarios shown below, indicated that drought permits were extremely beneficial in helping to prevent the need for more severe customer restrictions. Interestingly in this scenario, as indicated by the blue dashed lines in Figure 5, the benefits of drought permits are apparent, but less pronounced at Haweswater than in other events. Figure 6 does however still show a notable benefit in the Dee. This highlights that droughts are complex events and, as outlined in Appendix J, we can only be confident that our drought plan is robust by testing it against a wide range of different plausible droughts patterns.

[4] WELM is a bidirectional link that can operate through pumping or gravity

Even though this is a severe single season event, as shown in the timing tables inset in the figures our new drought levels provide time to enact the actions and afford us the flexibility we need to make the correct decisions according to the conditions at the time.

3.1.4 1 in 500 Year Stochastic Event (Two Season)

Rationale

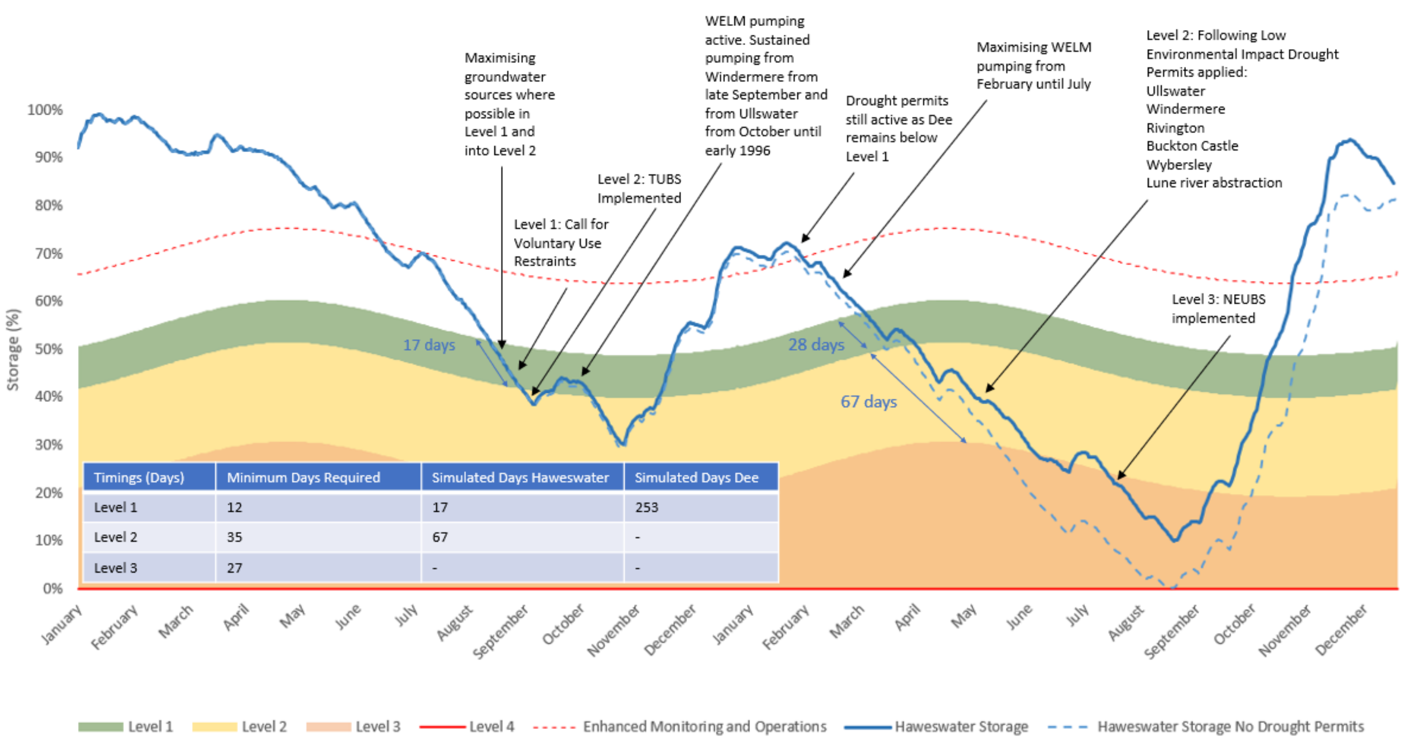
Our modelling assessments and previous experience, for example from the 1995-96 event, have shown that we are also vulnerable to two season events. In terms of the maximum point of stress, i.e. the minimum reservoir storage levels reached and the most severe actions implemented, this event is very similar to the previous one with a return period of 1 in 500 years. However, the progression of the event to get to this point is very different and it represents another key scenario for testing the drought plan.

As per the single year event presented in Section 3.1.3, the simulation shows that we would not need to implement EDO in this specific event. However, as we are only fully resilient to 1 in 200 year droughts there could be other 1 in 500 year two season stochastic events that lead to the implementation of EDO.

Event Description

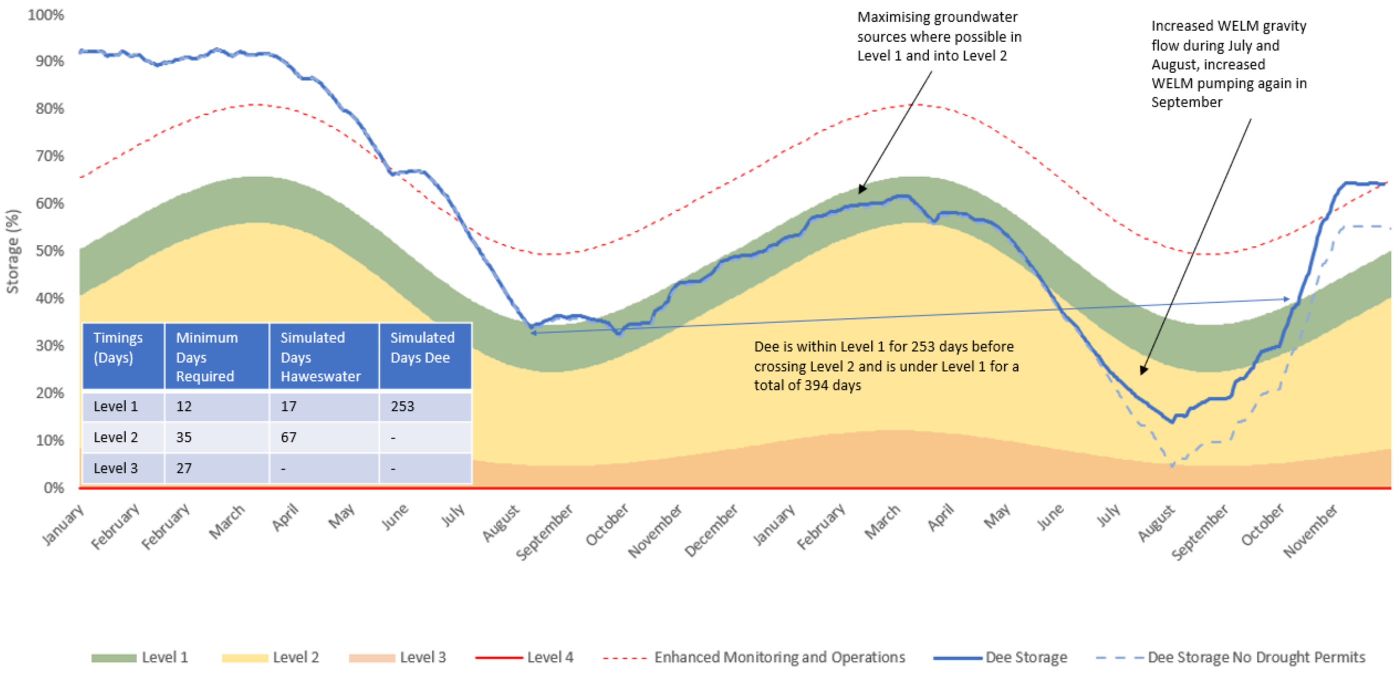
- This stochastic drought scenario is a two season 1 in 500 year event based on the system response of our Strategic RZ. The minimum storage at Haweswater reached 10% and crossed Level 3 triggering NEUBs in June of the second year.
- The first year of the event is characterised by a relatively rapid drawdown of sources at the beginning of May with a minimum storage of 30% at Haweswater by the end of October. Storage in the Dee remains within Level 1 across the winter.
- In all but one of the winter months between October-March, cumulative rainfall was less than 70% of the monthly average and no strategic sources are greater than 75% full by the start of the second year's drawdown period. A lower winter storage results in the more severe minimum at Haweswater in the second year and the triggering of a NEUBs event.
- However, there is a reduced rate of drawdown in the second year due to drought measures being implemented. Drought Permits are triggered in May of the second year at Haweswater as rainfall remains below the monthly average until this point and into June. Rainfall increases slightly in July but then drops to around 50% of the monthly average in August. Without the application of Drought Permits at this time, the simulation has shown that storage in Haweswater would have just reached dead water in the second year of the event.

Results



Timings (Days)	Minimum Days Required	Simulated Days Haweswater	Simulated Days Dee
Level 1	12	17	253
Level 2	35	67	-
Level 3	27	-	-

Figure 8 – Haweswater simulated storage, also showing new drought levels, salient drought and operational actions and timing between levels (inset table)



Timings (Days)	Minimum Days Required	Simulated Days Haweswater	Simulated Days Dee
Level 1	12	17	253
Level 2	35	67	-
Level 3	27	-	-

Figure 9 – Dee simulated storage, also showing new drought levels, salient drought and operational actions and timing between levels (inset table)

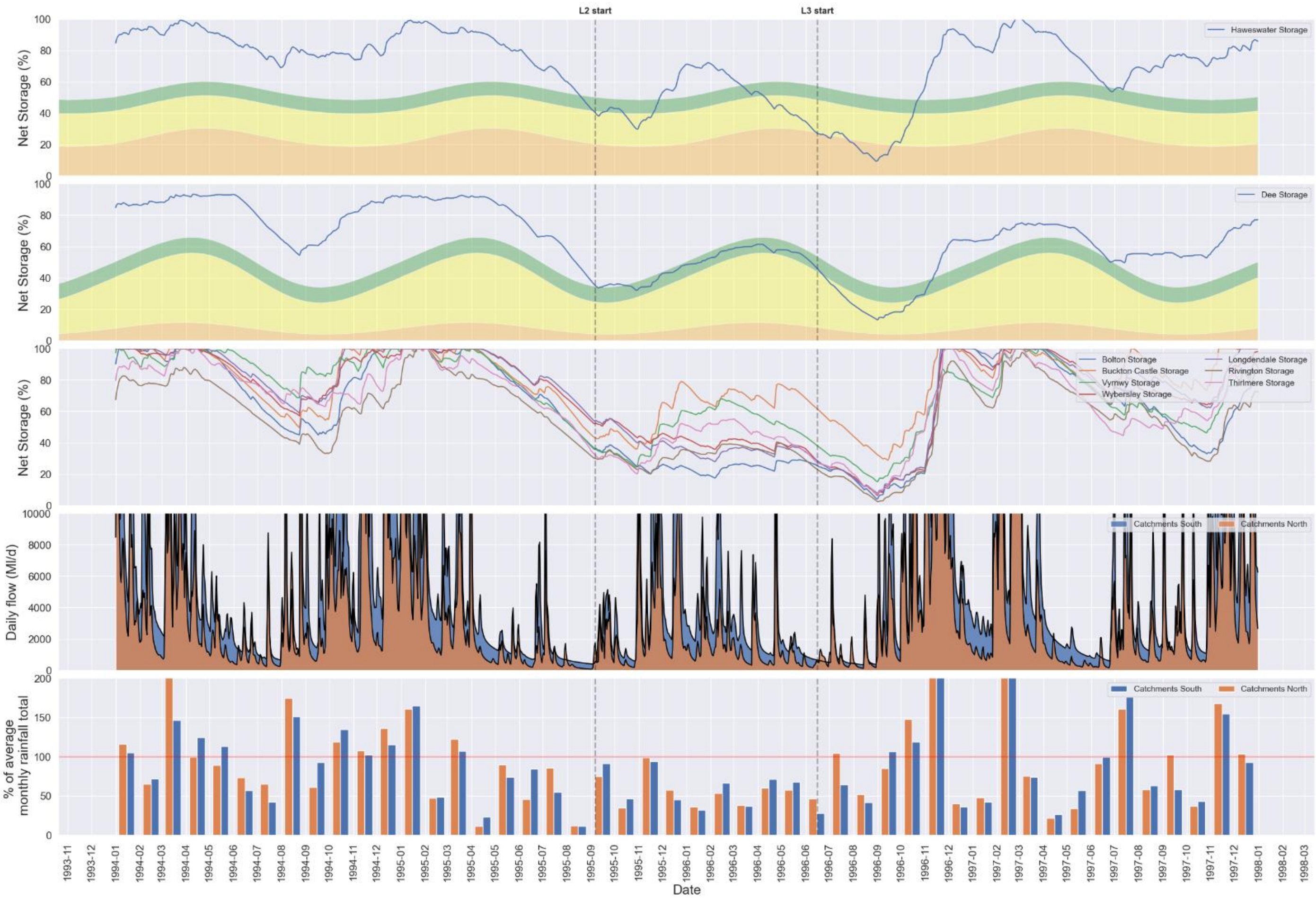


Figure 10 – Breakdown of the stochastic event 4270 from the drought characterisation exercise (Appendix J) showing storage (gross) across a range of reservoirs as well as rainfall and flow aggregated into north and south catchments.

Discussion

As noted above the end point of this 1 in 500 year two year drought scenario, i.e. the implementation of non-essential use bans, is very similar to the previous 1 in 500 year one year scenario. However, the path to this point is very different due to conditions in the preceding year, including poor winter refill. The benefits of drought permits in this scenario are profound and prevent entry into drought level 4, accompanied by the implementation of emergency drought orders such as stand pipes. Again, despite the severity of the event the new drought levels provide ample timing for the implementation of drought actions in this case.

The simulated drawdown in the Dee based on the latest system model and stochastic dataset is less severe during July and August of the first year, than simulated in the previous version of the Drought Plan. Storage remains within Level 1 for 253 days before crossing Level 2 and then remains below either Level 1 for a further 394 days. The previous modelling simulated a faster drawdown crossing from Level 1 to Level 2 within 27 days, however then remained under Level 1 for a further 453 days with a similar pattern to this latest simulation.

3.1.5 Longest Duration Stochastic Event

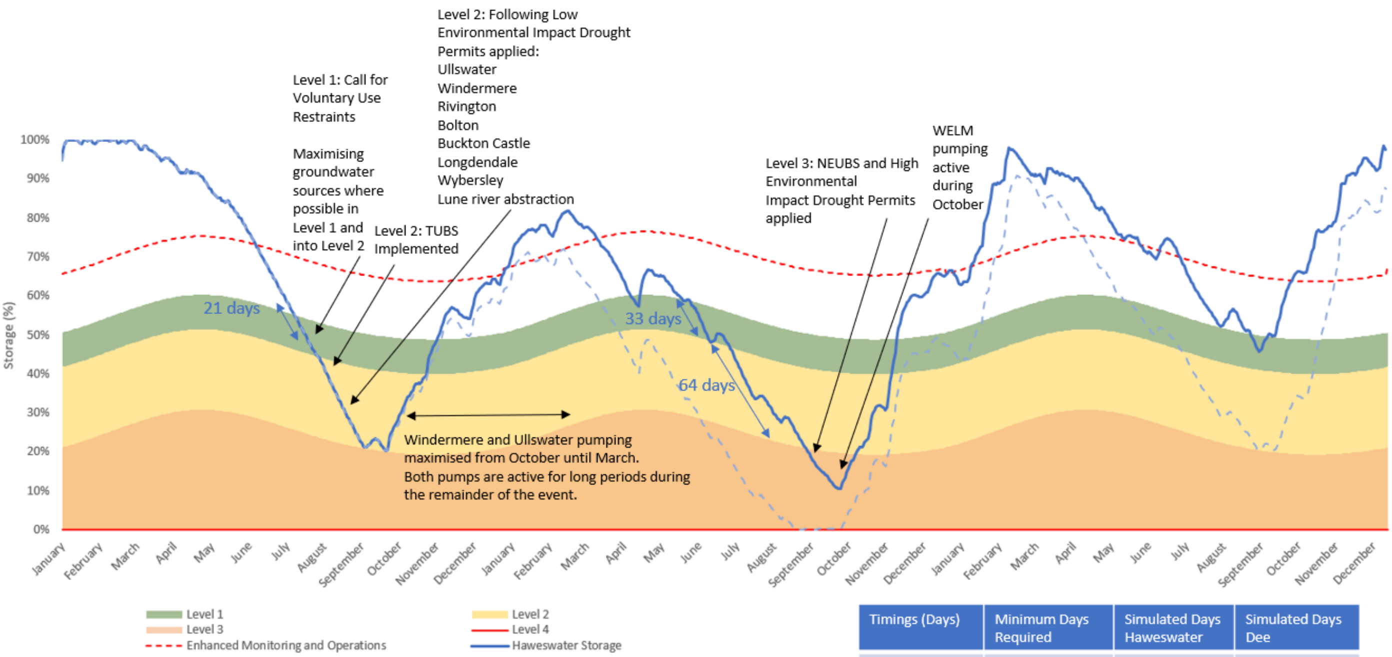
Rationale

An event which stays below drought level 1 for one of the longest periods in the stochastic dataset and hence would require the most extensive management in terms of duration of activities.

Event Description

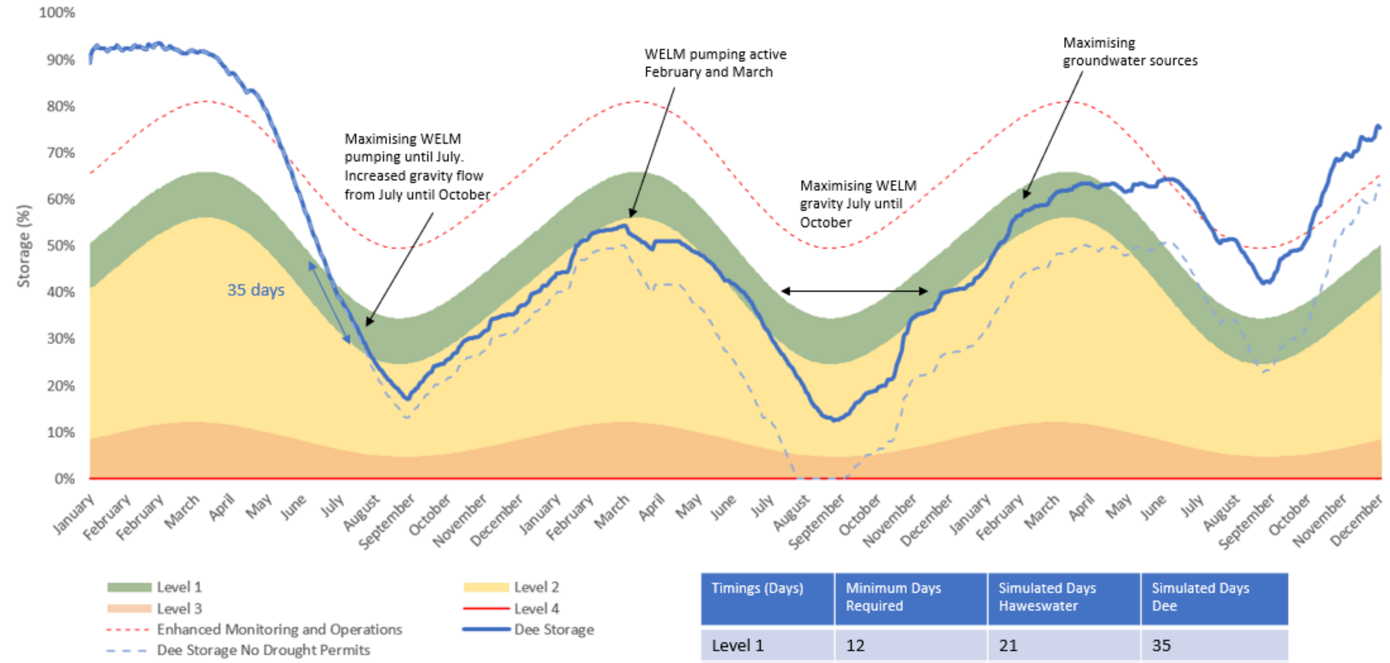
- This stochastic drought scenario reflects a long duration event based on the period Level 1 restrictions were in place. This event remained below Level 1 for 665 days from 15 July to 10 May in the third calendar year of the event.
- Drawdown began in late May, reaching Level 2 in Haweswater on 4 August. The winter rainfall totals that followed the dry summer were also low, sufficient only to maintain storage rather than to significantly refill reservoir sources.
- During the second year rainfall totals were lower than the monthly average from May to September and the Dee remained within Level 2 until December of this second year, and smaller sources such as Longdendale had reached dead water by October of the second year.

Results



Timings (Days)	Minimum Days Required	Simulated Days Haweswater	Simulated Days Dee
Level 1	12	21	35
Level 2	35	64	-
Level 3	27	-	-

Figure 11 – Haweswater simulated storage, also showing new drought levels, salient drought and operational actions and timing between levels (inset table)



Timings (Days)	Minimum Days Required	Simulated Days Haweswater	Simulated Days Dee
Level 1	12	21	35
Level 2	35	64	-
Level 3	27	-	-

Figure 12 – Dee simulated storage, also showing new drought levels, salient drought and operational actions and timing between levels (inset table).

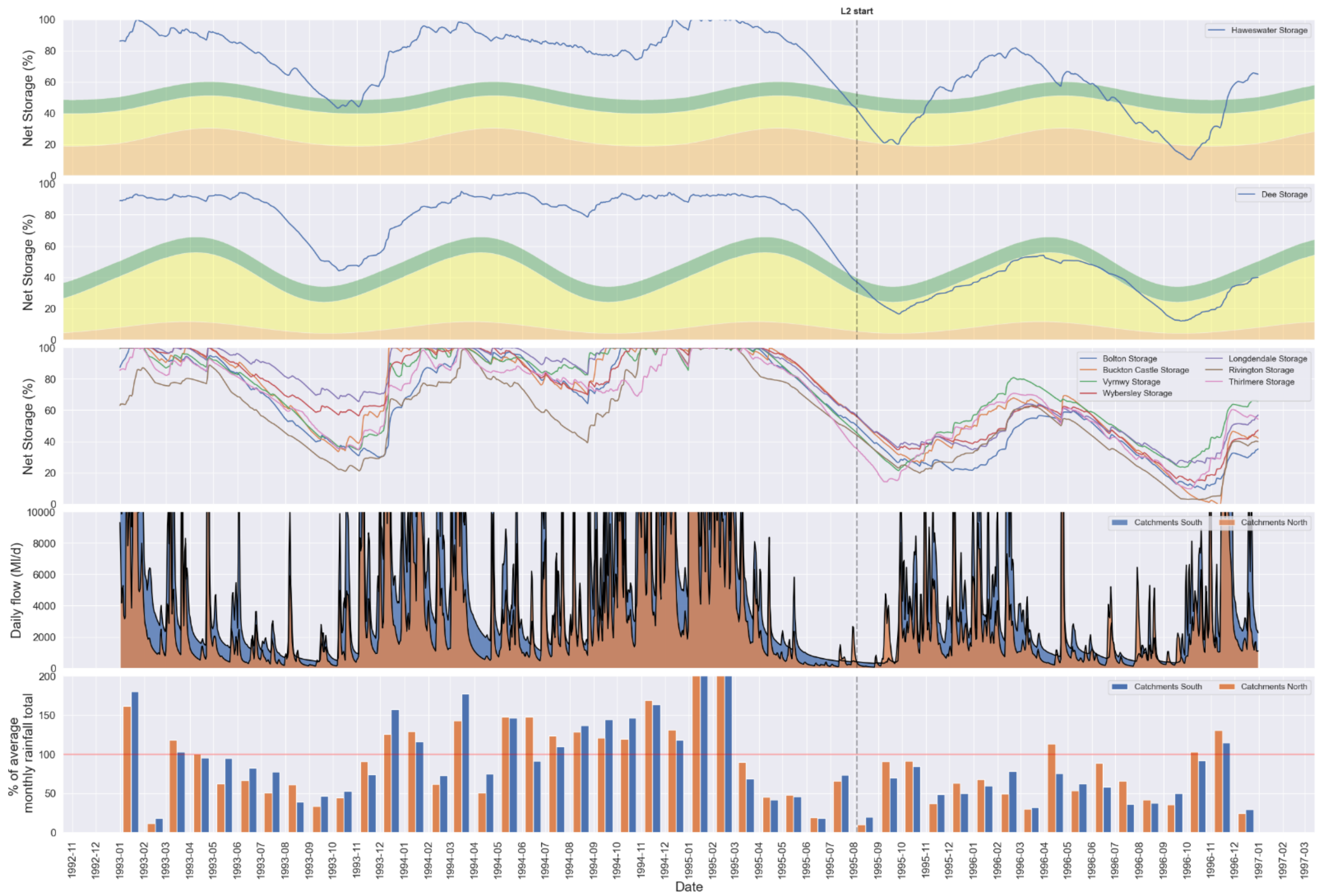


Figure 13 – Breakdown of the stochastic event 9885 from the drought characterisation exercise (Appendix J) showing storage (gross) across a range of reservoirs as well as rainfall and flow aggregated into north and south catchments.

Discussion

As noted above this is one of the longest events in the stochastic dataset; there are no events that extend into three drought years. The event has a return period of 1 in 100 years and is less severe than others presented based on minimum reservoir storage in the Strategic RZ, however it is an unusual event due to the prolonged period of lower than average monthly rainfall. Again, this scenario highlights the benefits of the drought permits, here having a profound effect on drawdown and preventing dead water at both Haweswater and the Dee.

3.2 Carlisle Resource Zone

3.2.1 1976 Historical Event (One Season)

Rationale

The most severe historical event on record based on the minimum storage level reached in Castle Carrock Reservoir.

Event Description

This drought scenario is based on a repeat of the climatic and hydrological conditions experienced in our region in 1976, and has the following characteristics:

- A single season drought.
- Historically, no drought orders and permits were applied for during 1976 in the Carlisle Resource Zone.
- Rainfall at Burnbanks rain gauge (Haweswater) for the 3 month period to August 1976 was 126mm or about 43% of the long-term average for the 3 month period from June to August inclusive.
- Comparing this to a ranked data series of annual 3 month rainfall totals from June to August, for the 86-year period from 1932 – 2018, the 3 month period to August 1976 was the third driest on record.

Results

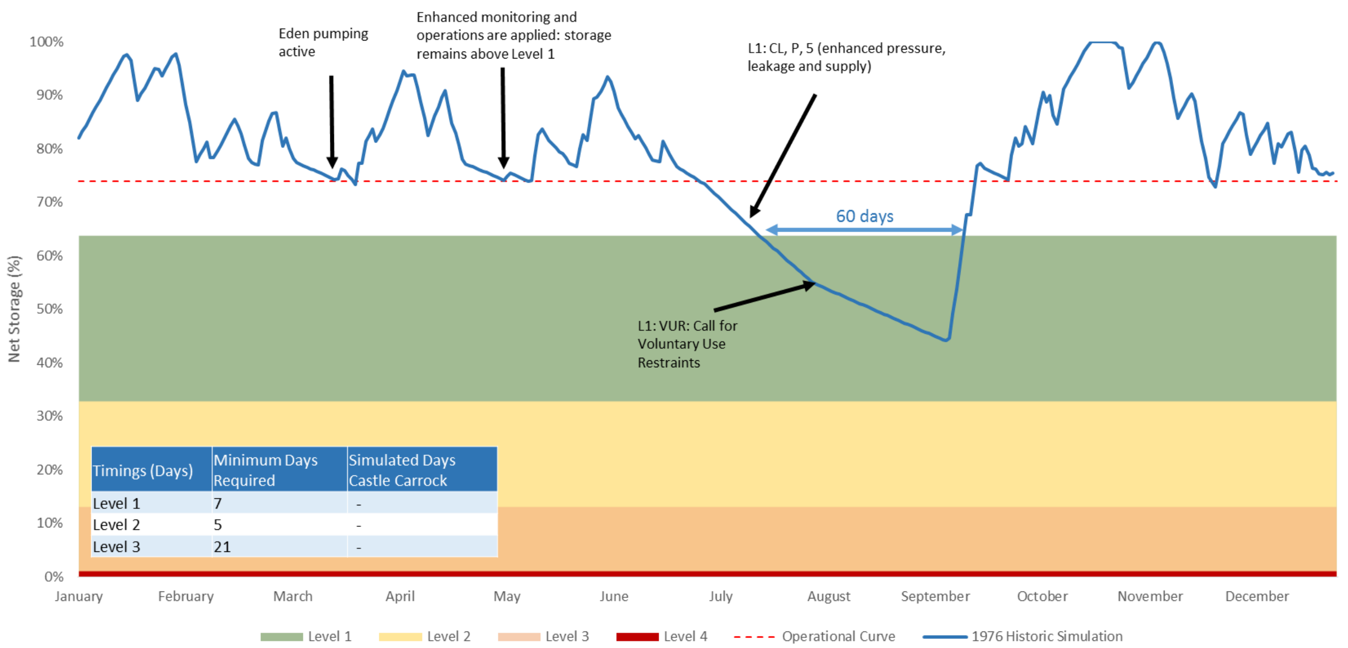


Figure 14 – Castle Carrock simulated storage, also showing new drought levels, salient drought and operational actions and timing between levels (inset table)

Discussion

Our modelling indicates that a repeat of 1976 climatic conditions would lead to a minimum storage of around 55% in Castle Carrock. The main simulated drawdown occurs when Castle Carrock storage drops below 95% on 12/06/1976 and recovers to full approximately 4 months later on 20/10/1976. Castle Carrock reservoir volume spends 60 days in Level 1 but does not reach Level 2.

3.2.2 1 in 500 Year Stochastic Event (Single Season)

Rationale

Extensive analysis of the Carlisle RZ, for example in the Drought Vulnerability Framework (DVF) assessment (Appendix J), has shown that it is very resilient to drought. In the rare event that a drought event could affect the RZ our analysis showed that this would likely be a short duration event of around three to six months. Therefore, this scenario considers a stochastic event with a severity of 1 in 500 years (based on minimum storage levels reached) and a drawdown duration of about four and a half months. Unlike the Strategic RZ, the stochastic dataset does not contain drought events in this RZ which extend into a second year.

Event Description

- This stochastic drought scenario is a single season 1 in 500 year event based on minimum storage in Castle Carrock Reservoir
- A minimum storage level close to 50% is modelled in Castle Carrock.
- Castle Carrock reservoir volume spends 101 days in Level 1 but does not reach Level 2.

Results

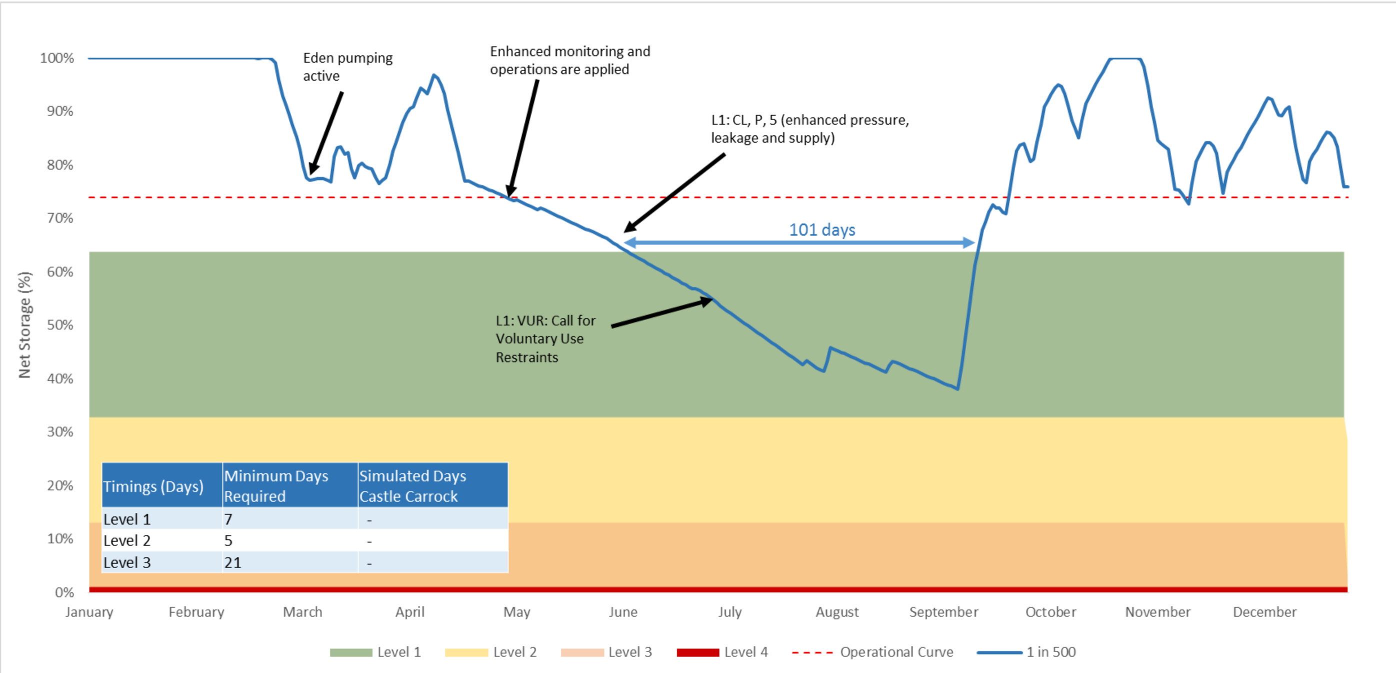


Figure 15 – Castle Carrock simulated storage, also showing new drought levels, salient drought and operational actions and timing between levels (inset table)

Discussion

This scenario helps further demonstrate that the Carlisle RZ has a high level of drought resilience.

3.3 Timing for drought actions

As outlined in Appendix A, we optimised our new drought levels to help provide flexibility in decision making for implementing drought actions. The time available to take actions during each level is largely dependent on the speed of reservoir drawdown, which itself depends mainly on hydrological conditions and customer demand for water. Therefore, this timing can vary quite widely from event to event. We ensured there is sufficient time to deal with a wide range of different conditions in three ways:

1. We calculated the minimum time required to undertake the actions in each level and applied a constraint in the optimiser to ensure this was met across a very wide range of drought events. The optimisation used around 100 years of historical hydrological data and 2,500 years of synthetic data (our new stochastic hydrological dataset is introduced in Appendix A).
2. We set an objective in the optimiser to maximise the timing between levels. This was then balanced against other objectives such as minimising the likelihood of customer restrictions.
3. We tested the results by simulating the new levels in a range of drought events, for example as shown in the scenario figures included in the previous section.

In previous drought plans we set drought triggers based on timing from the simulation of historical drought events. The ability to simulate hundreds of plausible stochastic drought events, with many different weather patterns and higher levels of severity, means we can have much more confidence in the robustness of our drought levels. Table 3 provides summary information on simulated drawdown times for the Strategic RZ. As shown in the previous section, even in the simulation of a 1 in 500 year drought event the Carlisle RZ did not pass all the way through Level 1.

Table 3 – Simulated timing for drought levels across a range of historical and stochastic drought events in the Strategic RZ

<table>
<tr><th rowspan="2">Scenario</th><th colspan="3">Simulated timing</th></tr>
<tr><th>Level 1</th><th>Level 2</th><th>Level 3</th></tr>
<tr><td>Minimum time required</td><td>12 days</td><td>35 days</td><td>27 days</td></tr>
<tr><td>Worst historical (1984)</td><td>30 days</td><td rowspan="2">Did not pass completely through this level</td><td rowspan="2">Did not pass into this level</td></tr>
<tr><td>Second worst historical (1995-96)</td><td>24 days</td></tr>
<tr><td>Single-season 1 in 500 year event</td><td>33 days</td><td>50 days</td><td rowspan="2">Did not pass completely through this level</td></tr>
<tr><td>Two-season 1 in 500 year event</td><td>17 days</td><td>67 days</td></tr>
</table>

4 Conclusions

We tested the drought plan to a wide range of challenging drought events taken from our historical record and stochastic dataset of plausible synthetic events. The historical events we selected are the most severe events on record. For the stochastic events we focussed on selecting different patterns of event, but with a return period of 1 in 500 years. This level of severity links with the new 1 in 500 year drought resilience standard used in the Water Resource Management Plan and at the same time provides a very robust test of our plan. As noted above the risk of experiencing a 1 in 500 year event in any one year is 0.2%. This extends beyond our current 1 in 200 year level of service, and until 2039 there may be some 1 in 500 year events in which we would need to implement EDO.

In our wider modelling we tested hundreds of synthetic droughts, including some with a much higher severity and that led to the simulated implementation of emergency drought orders (one such event is presented in Figure 4 of Appendix J). Consistently the results have shown that the drought plan is robust and will maintain our agreed levels of service for customer restrictions and drought permits. The main difference in the selected scenarios presented here is that drought permits were applied in a more realistic, event-specific manner. Overall the approach has been to test as many droughts as possible using a more generic setup and then focus in on a selection of these for specific scenario modelling.

In all forms of modelling undertaken, including these scenarios, we needed to make several assumptions about the conditions that may occur over the lifespan of the drought plan, for example the level of demand we could experience. However, we introduced a new stress-testing stage to help mitigate this. It showed us that our key future risks are related to demand and climate change, but also that extreme projections would be required to materially increase the risk of customer restrictions or drought permits above that already factored into the new drought levels.

When taken along with the work presented elsewhere in the drought plan, the analysis presented here therefore demonstrates that:

- Our drought plan is robust to many different patterns of droughts with a severity of at least up to 1 in 200 years, and in some specific cases 1 in 500 years.
- The new drought levels will afford us the time and flexibility we require to make the correct decisions in a drought or conditions that could lead to drought.
- Our new drought levels are robust to a range of future uncertainties. The key risks are from customer demand and climate change but only extreme levels result in a material increase in the risk of restrictions or drought permits.