Results of the trial of a new release regime at Kielder reservoir

Following the flooding that took place around Corbridge as a result of Storm Desmond in early December 2015, NWL were asked to provide additional flood storage capacity at Kielder Reservoir. At the same time the Environment Agency were keen to pursue the idea of variable releases to the river and the hydropower operator (innogy) wished to review operations in order to maximise generation ahead of plans to refurbish the main turbine in 2017.

Kielder reservoir has many important roles including river regulation for water supply, hydropower generation and as a tourist attraction. As such any amendments to the operation of the reservoir should not impact on Kielder's ability to support these activities. The three stakeholders (NWL, innogy and the Environment Agency) worked together to build a **new operating regime** for the hydroelectric plant at Kielder with the following key aims:

- to maintain the security of water supply to the North East;
- to better reflect natural changes in river flows which should protect the ecology of the river;
- to provide increased flood storage in Kielder reservoir;
- to increase the generation of clean, renewable energy; and
- to take into account the requirements of river and reservoir users.

The trial of this new regime began on 1st November 2016 and ended on 31st October 2017, although monitoring will continue for many years to come. This short report examines the results of the trial and assesses the new regime against the following success criteria:

- The reservoir level is kept within zones B to H;
- There is a variation in the amount of water released;
- Fish passage at Riding Mill is not impacted and the broodstock collection is successfully completed;
- The revised release regime does not adversely impact fish populations, as indicated by, for example, electrofishing survey and angler catch data;
- The magnitude of spill is reduced;
- Flood releases are required infrequently; and
- The estimates made for the proposed week release schedule turn out to be correct more often than they are wrong.

Hydrological context

The release of water from Kielder reservoir is dependent on two things: the control rules which determine how much water is released at different times of the year and at different reservoir levels; and the amount of water flowing into the reservoir. This means that before we consider the impact of the new release regime on flows it is important to understand how the weather since 1st November 2016 affected the amount of water available for release.

All of the statistics below use the Met Office NCIC (National Climate Information Centre) dataset which began in 1910 and provides areal rainfall for individual hydrometric areas and Environment Agency areas.

The final third of 2016 was unusually dry in the Tyne catchment with the 6th driest 4 months ending in January 2017, totalling only 73% of the long term average. For the North East area as a whole it was the

3rd driest December/January with just over half of the long term average (LTA) rainfall recorded. However, February and March 2017 were relatively wet, with 140% of the LTA in the Tyne catchment. The dry weather returned in April and May with the total rainfall for the two months (53.3mm) ranking as the 3rd driest for April and May in the NCIC record. There then followed the wettest month of the year, both in terms of the amount of rainfall and % LTA, when over twice the long term average rainfall fell in June. July was also wet, pushing the two month total to 5th position in the wettest rankings.

Table 1: Analysis of Tyne rainfall totals from Nov 2016 to Nov 2017

Month	Total rainfall (mm)	% of long term average	Notable rankings *
Nov	102.4	109	
Dec	64.3	71	
Jan	43.8	47	5th driest since 1910
Feb	90.9	140	
Mar	109.6	140	12th wettest since 1910
Apr	22.7	39	9th driest since 1910
May	30.6	48	11th driest since 1910
June	130	204	8th wettest since 1910
July	104.7	146	
August	65.7	74	
Sept	96.4	117	
Oct	95.7	112	
Nov	85.2	91	

* in the Met Office NCIC record which starts in 1910

Temperatures showed a similar variation with early November 2016 being very cold and frosty but December being relatively mild. 2017 was, overall, a mild year as although half the months were below average (including July and August) they were only marginally so. The warmth of 2017 was because five of the months that were above normal, were so by more than 1ºC. These were February, May, June and October, with March achieving the largest margin and being more like a typical April.

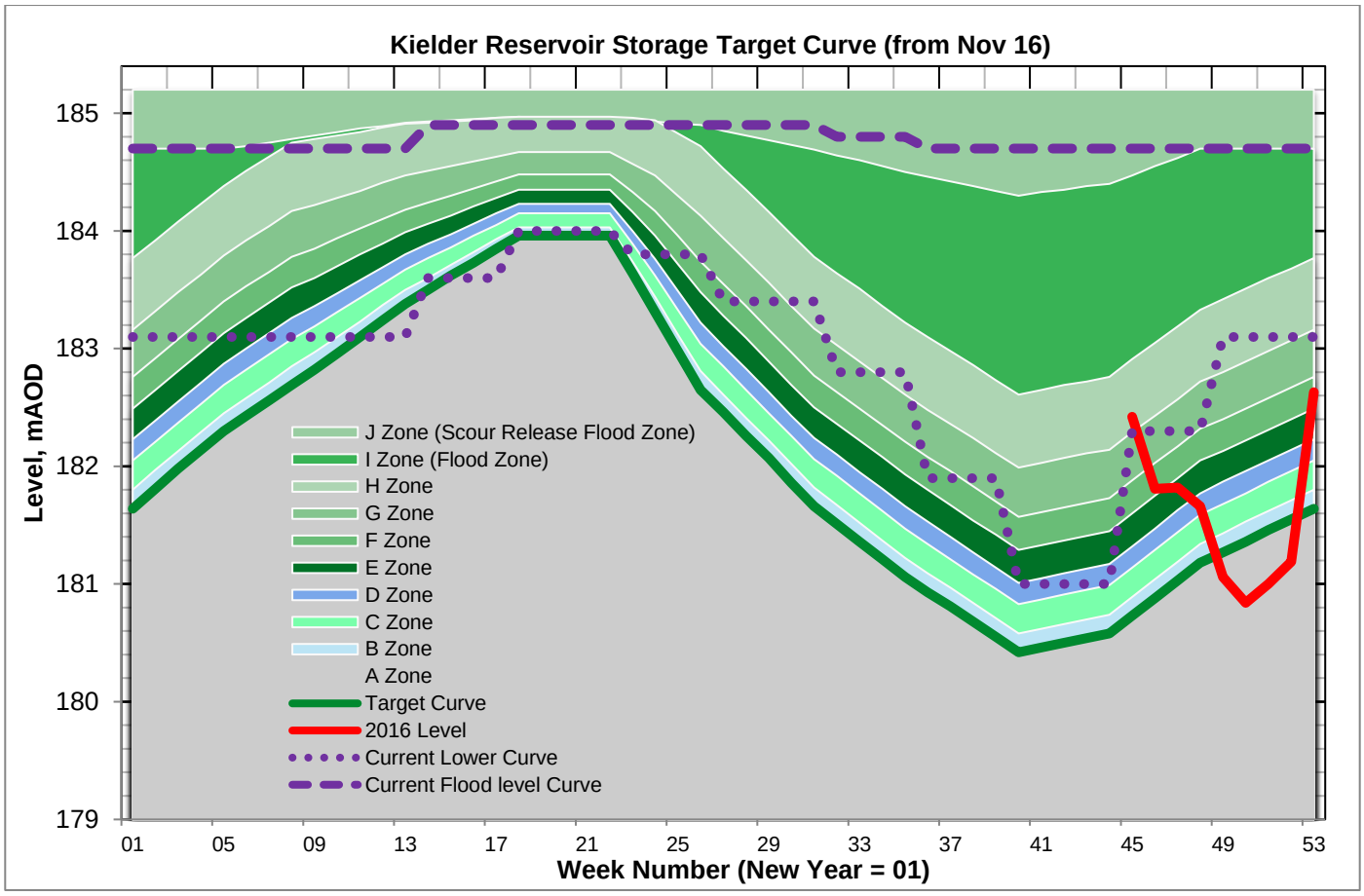
These natural variations in rainfall and temperature have to some degree masked the impact of any changes in the releases and have made it difficult to identify any direct cause and effect.

Success criteria

The following section will look at each of the success criteria in turn and consider whether the trial has achieved the aims of the new regime.

The reservoir level is kept within zones B to H

When the trial began the reservoir was over 1.5 metres above the target curve. A combination of low rainfall and large releases meant that the target curve was reached in only 4 weeks. A period of dry weather then resulted in the reservoir level falling below the target line.



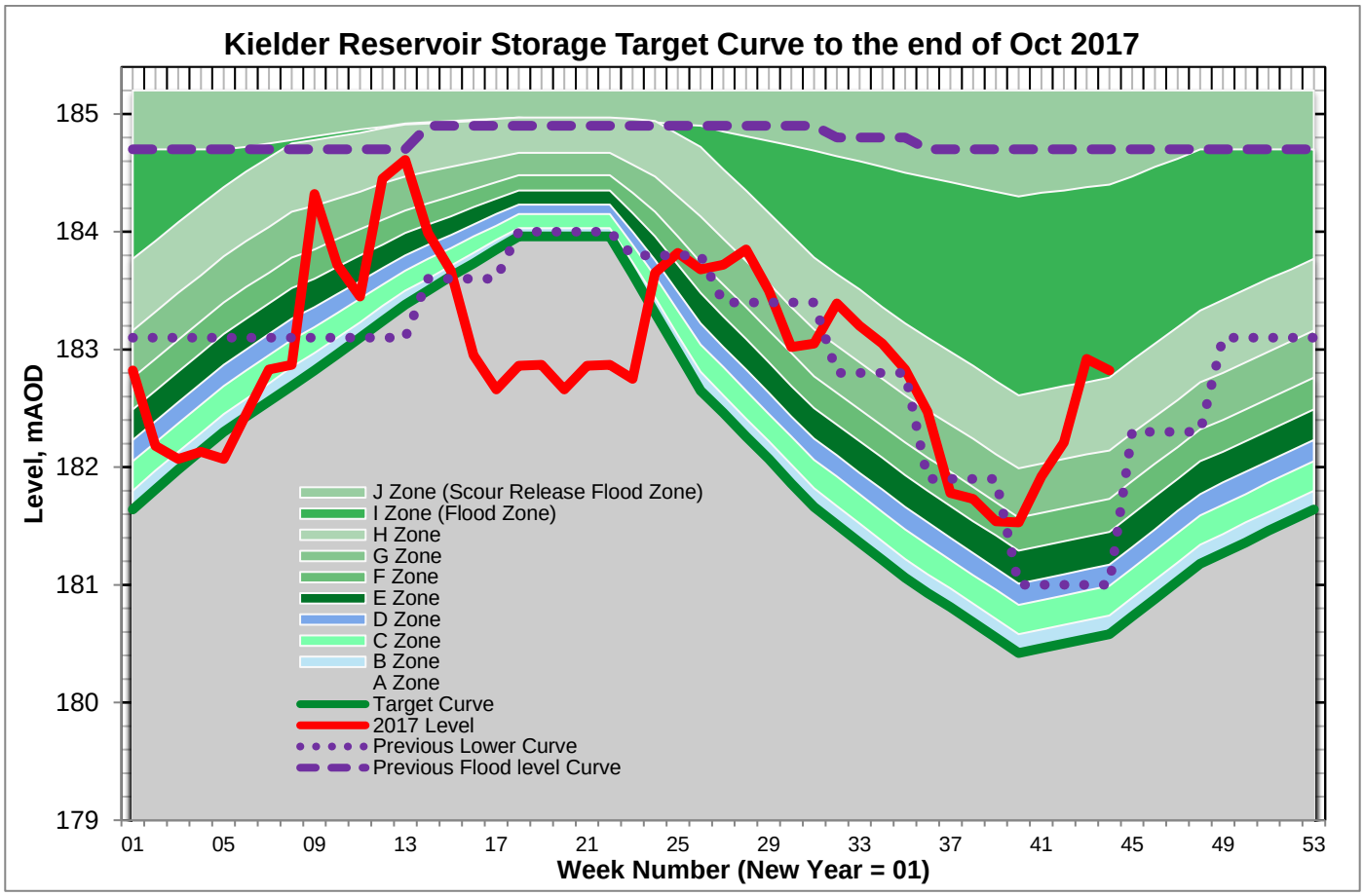


Fig 1 and 1b: Kielder reservoir storage since the start of the trial, compared to the target curve

At the start of 2017 the reservoir level was kept within a planned range of Zones B-H, until the large inflow at the end of February caused by Storm Doris. Extra releases were made which resulted in the reservoir level falling fairly quickly back towards the target curve, before another period of wet weather at the end of March. There then followed a prolonged period of dry weather when river regulation releases were required to increase river flows downstream and support abstractions, causing the reservoir level to drop below the target curve. The reservoir level rose in response to a wet June and July before falling once again during August and September. The reservoir level entered the first flood alleviation zone on October 23rd but, although large releases were attempted, full flood releases were not possible as the main turbine had been taken out of operation earlier in the year.

During the course of the 12 month trial it was generally found that the releases could be adjusted sufficiently quickly to keep the reservoir level in zones B-H.

This objective has been achieved.

There is a variation in the amount of water released

The graph below shows how the releases from Kielder reservoir have varied since the beginning of November 2016 to the end of October 2107. The new regime is designed to release a higher flow at the start of each week's release, followed by slightly lower flows to mimic a natural hydrograph.

In addition to compensation water and river regulation releases, since the start of the trial there have been releases at 8, 10, 12 and 15 cumecs.

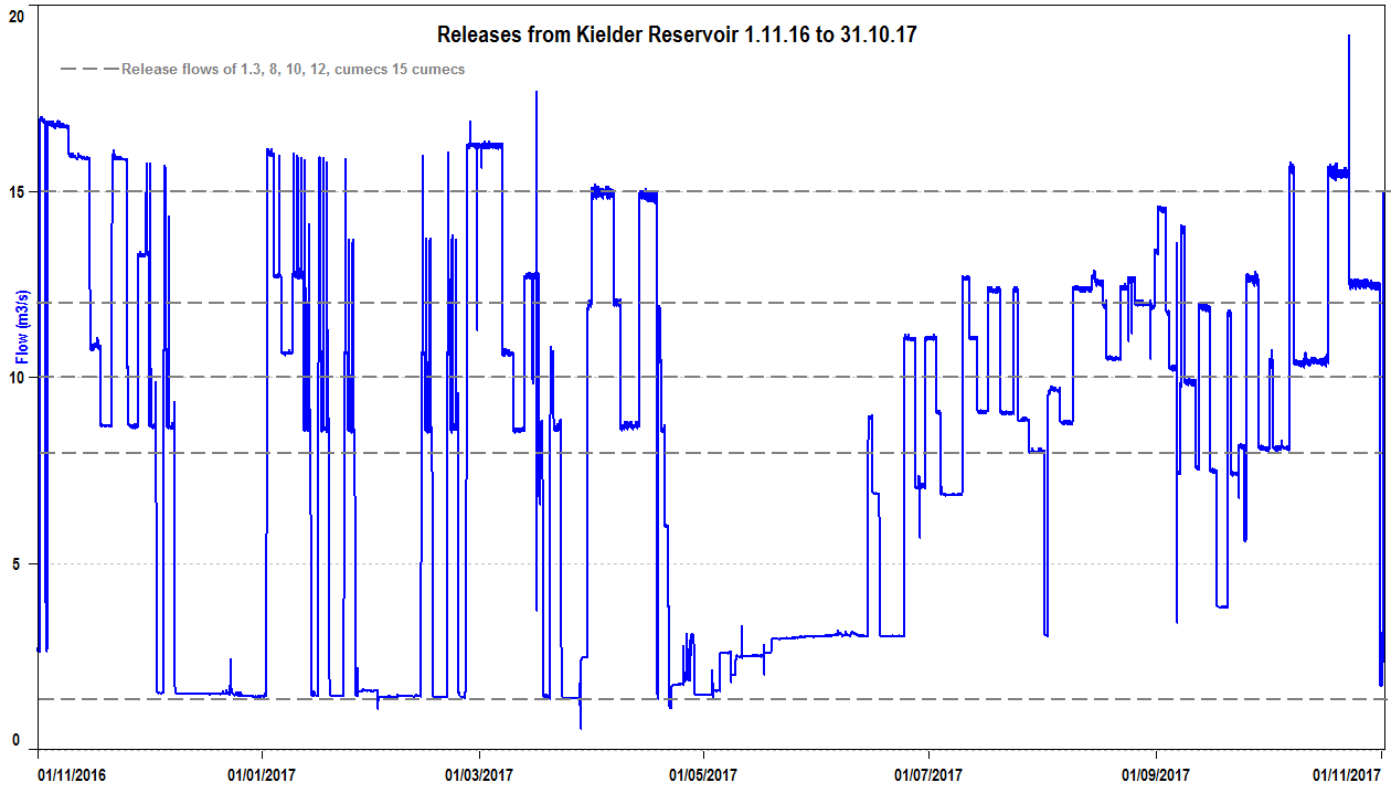


Fig 2: releases from Kielder reservoir during the trial

This variation in flows across the year can be compared to the pattern of releases before the trial in 2014, as shown in figure 3 below. It is evident that, although there was some variation in 2014, the releases were more 'blocky' with periods of several days at the same flow. Releases of 10 cumecs seemed to predominate with few 8 or 12 cumec releases.

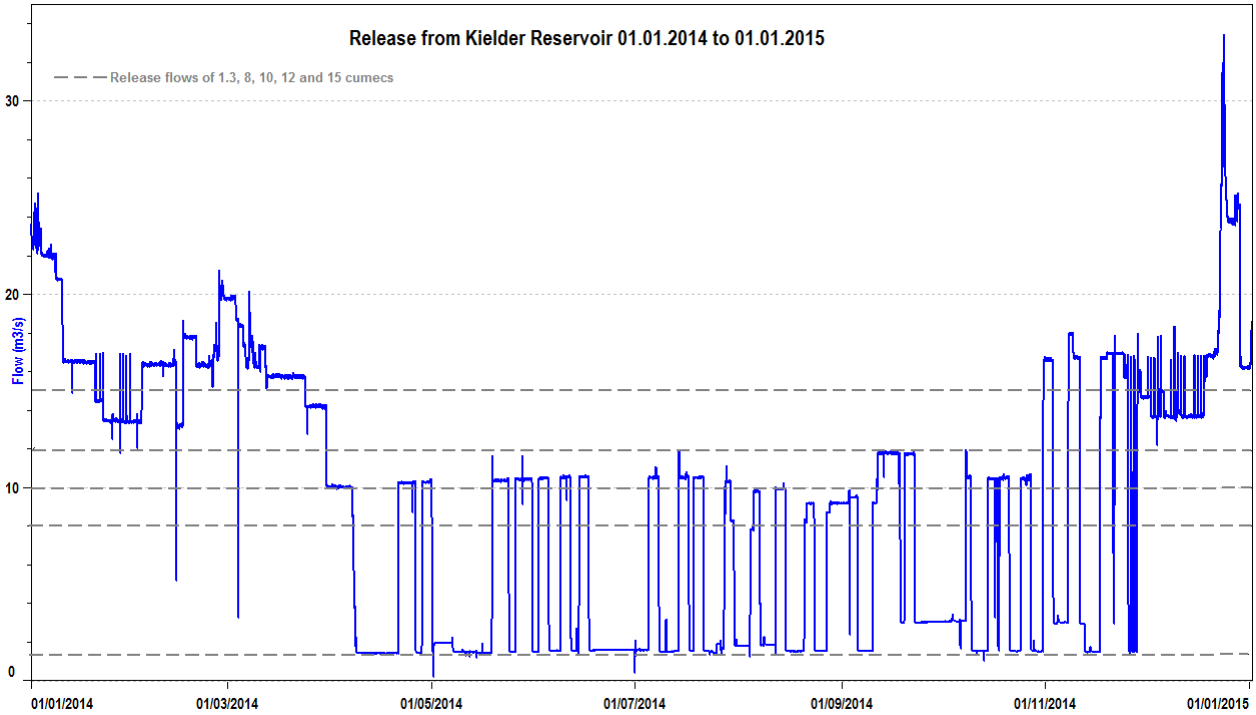


Fig 3: releases from Kielder reservoir before the trial

Despite this increase in flow variation it is evident that, when compared to inflows during the same period, the current restriction on the rate at which water can be released (i.e. no releases between 1.3 and 8 cumecs) means that outflows are still very different to inflows. This is illustrated on figure 4 below.

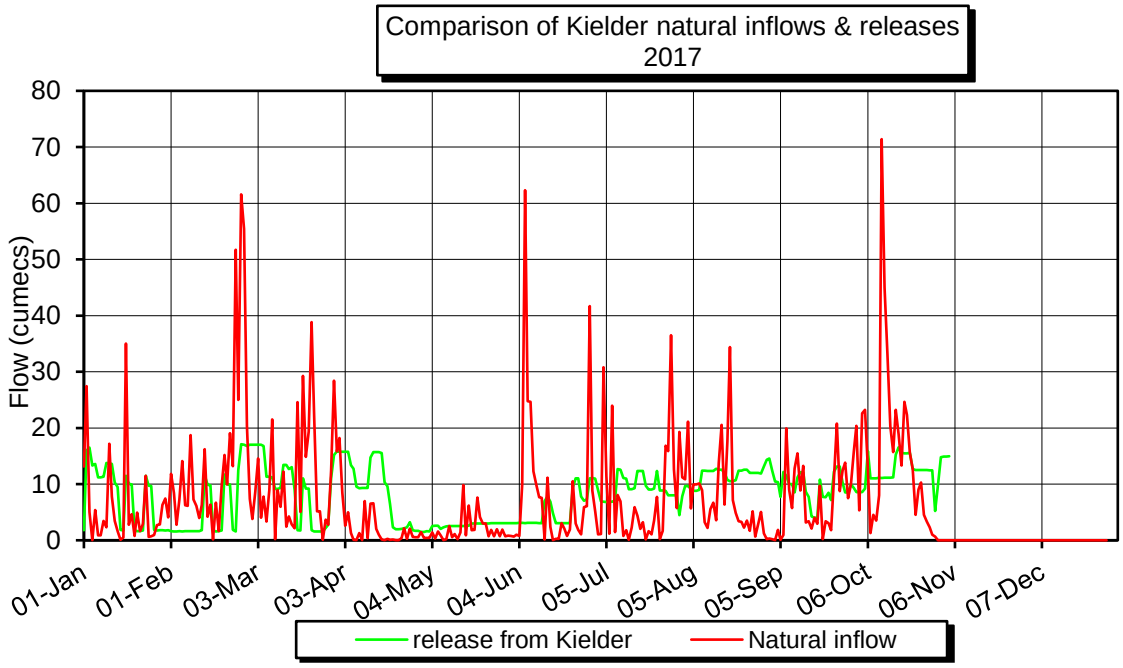


Fig 4: comparison of natural inflows into Kielder and releases from Kielder during the trial

One tool which can used to compare different time series of flow measurements is the flow duration curve (fdc). This shows the percentage of time that a given flow is likely to be exceeded eg Q90 is the flow that is exceeded 90% of the time and is therefore a measure of low flow.

On Figure 5 below it is evident that whereas the pre-impoundment flow duration curve is a smooth line, both post impoundment curves show how releases at around 1.5cumecs (compensation flow) and 3 cumecs (river regulation flow) dominate the release pattern.

The shape of both post impoundment curves is broadly similar but, whereas flows in the range of 4-10cumecs only occurred for 6% of the time under the historic regime (Q56-Q50), they occurred for 24% of the time (Q64-Q40) under the trialled regime, which is closer to the 26% of time (Q42-Q16) in the pre impoundment record.

The pre impoundment record of natural flows illustrates how flows used to be far more extreme with a Q95-Q1 range of 66cumecs (66.7-0.7), compared to a range of just 15.4cumecs (16.8-1.42) in the post impoundment record.

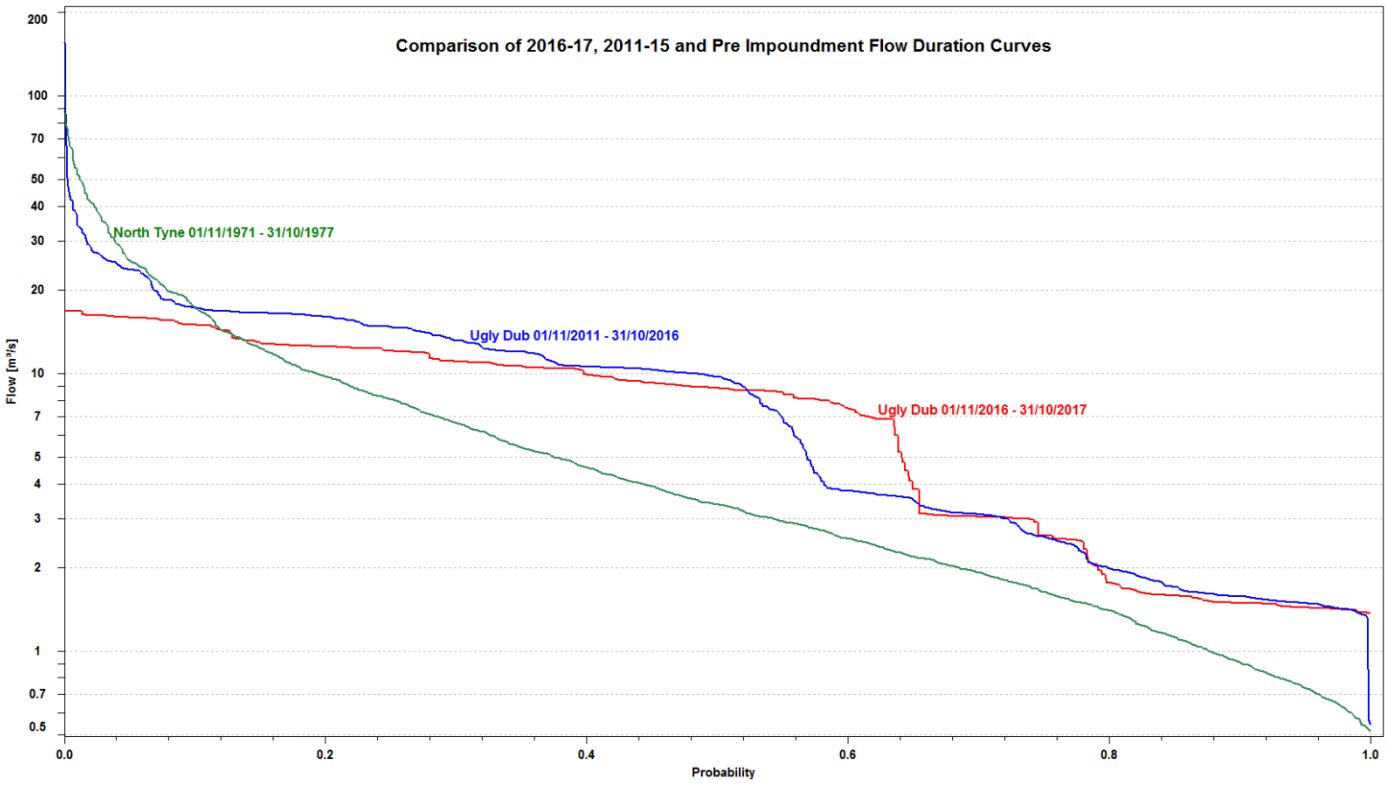


Fig 5: comparison of 2016-17, 2011-15 and pre impoundment flow duration curves

Whilst the very nature of large regulating reservoirs such as Kielder means that low flows will always be higher than natural and high flows will be lower, there is some scope to alter the frequency of mid-range flows to make them more natural. The constraint at Kielder is that the large turbine was only designed to release a minimum of 8 cumecs and can only release a maximum of 15.4cumecs. The main turbine was refurbished during 2017 and was re installed in December 2017 allowing this constraint to be overcome. It is now possible to make releases at any flow from 3.5 to 16.8 cumecs which should allow outflows to more closely reflect the natural range of inflows.

To account for this increased flexibility the release profile was modified in December 2017 to ensure that, whilst the same volume of water is released in each week in each zone, there are now additional releases

at 3.5, 5 and 7 cumecs. The success of these changes will be monitored over the next few years to see if the shape of the fdc changes to become smoother and closer to the pre impoundment fdc.

RELEASE PROFILE FROM DECEMBER 2017

- Each coloured band above triggers the release of different amounts of water
- The bands range from A to K and the volume and duration of each release is shown below
- Higher flows are released at the start of each week to mimic a natural hydrograph
- 1.32 cumecs is the compensation flow from Kielder; the minimum amount that has to be released
- cumec is a measure of flow and stands for "one cubic metre per second"

	1.32 cumecs	3.5 cumecs	5 cumecs	7 cumecs	9 cumecs	11 cumecs	13 cumecs	15.4 cumecs	16.8 cumecs	21/25 cumecs	50.3 cumecs
A	7 days										
B	3 days	2 days	1 day	1 day							
C	2 days		3 days	2 days							
D	2 days			2 days	2 days	1 day					
E	1 day		2 days		2 days		2 days				
F				2 days	2 days	2 days		1 day			
G					2 days	3 days			2 days		
H							2 days	1 day	4 days		
I										7 days	
J										5 days	2 days
K											As long as necessary to reduce level to below 185mAOD

Table 2: new release profiles with refurbished turbine

The hydrograph in figure 6 below illustrates how releases of 3.5, 5.5, 11, 13 and up to 18.7cumecs have been made since the refurbished turbine was reinstalled in mid-December. It is hoped that this wider variation in outflow will have a positive impact on both the ecology and geomorphology of the North Tyne below Kielder reservoir.

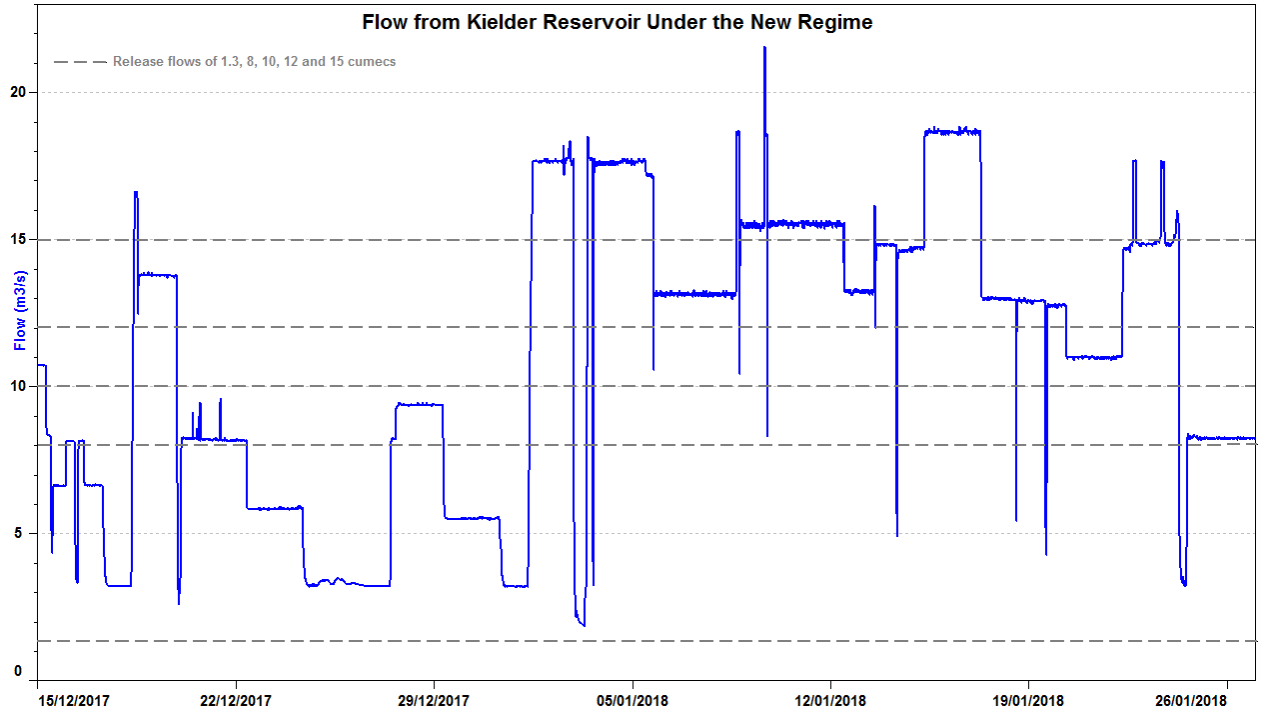


Fig 6: releases from Kielder following the installation of the refurbished turbine in Dec 2017 (note that this includes a period of testing)

This objective has been achieved.

Fish passage at Riding Mill is not impacted and the broodstock collection is successfully completed

Fish passing through the weir at Riding Mill are recorded at our fish counter at the gauging station. Factors influencing the numbers counted include the depth (and therefore velocity) of the water, water temperature and the availability of fish willing to move upstream. Due to natural variation in flow and temperature it is difficult to identify if the changes to the release regime have had an impact on migration and further monitoring will be required before any firm conclusions can be drawn.

Figure 7 below shows the square root of upstream count and the stage heights for Ugly Dub, Haydon Bridge, and Riding Mill for the period 1st November 2016 to 31st October 2017. The square root was taken to reduce the inter-period variability for display purposes. As in 2016 the majority of the upstream counts were recorded during June and July in 2017.

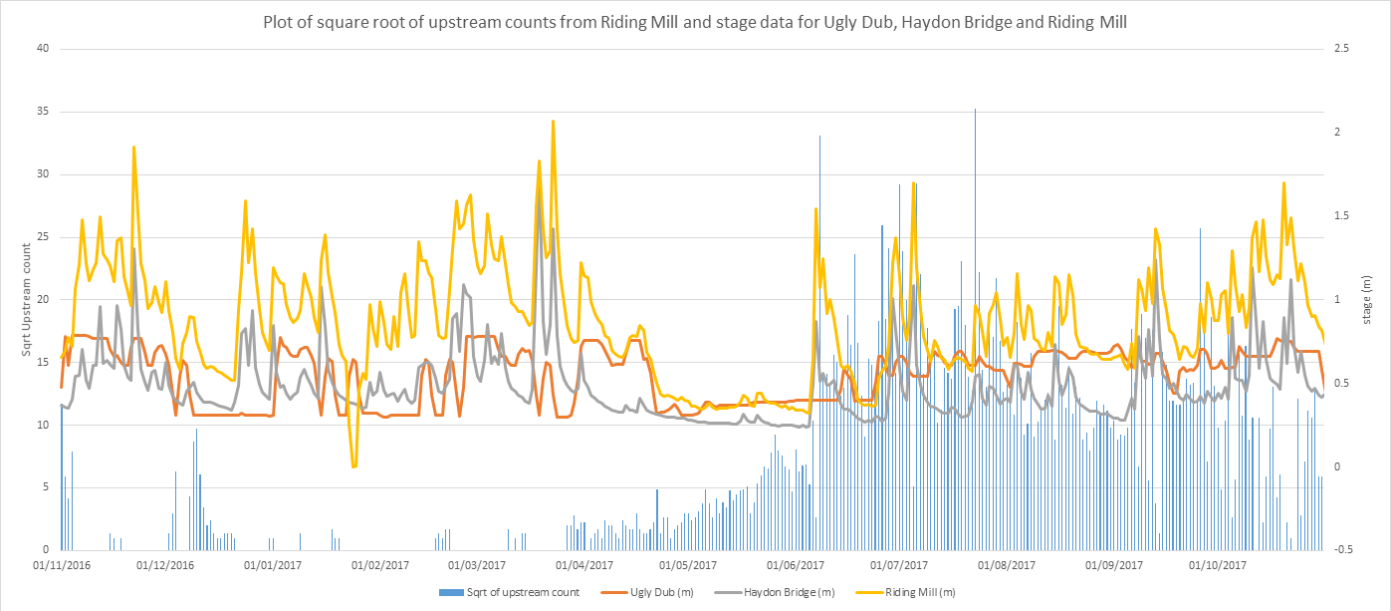


Fig 7: river levels and numbers of fish passing through Riding Mill from Nov 2016 to Oct 2017

Over the past three years May has been very dry and it is felt that some of the counts recorded during June may be recorded during May if conditions were suitable. The late season counts (October and November) have been falling for a number of years but recently counts for August and September have started to diminish. These trends in declining numbers of fish towards the back end of the fishing season are also being observed on other multi-stock rivers such as the River Tweed, and so it is unlikely that this can be solely attributed to the changes in the release regime at Kielder.

As in previous years, there is a slight increase in activity across the counter on rising water with a much larger increase occurring after the peak. If levels exceed 1.4m counter activity almost ceases and stops altogether when levels exceed 1.6m. Reductions to the releases during November will continue to be made if it is felt that this might improve fish passage at this critical time of year. Compensation releases will be made for a day a week if flows on the South Tyne are low enough to result in a beneficial drop in level at Riding Mill.

Temperature proves to be a critical factor in counter activity, especially during the cooler months. When the water temperature falls to below 10°C the height at which counter activity ceases also drops with peak activity. Under 6°C the level drops even further so that when levels at Riding Mill exceed 0.9m activity is negligible.

The brood stock collection was successfully completed in just a few days at the start of November 2016 and 2017.

The revised release regime does not adversely impact fish populations, as indicated by, for example, electrofishing survey and angler catch data

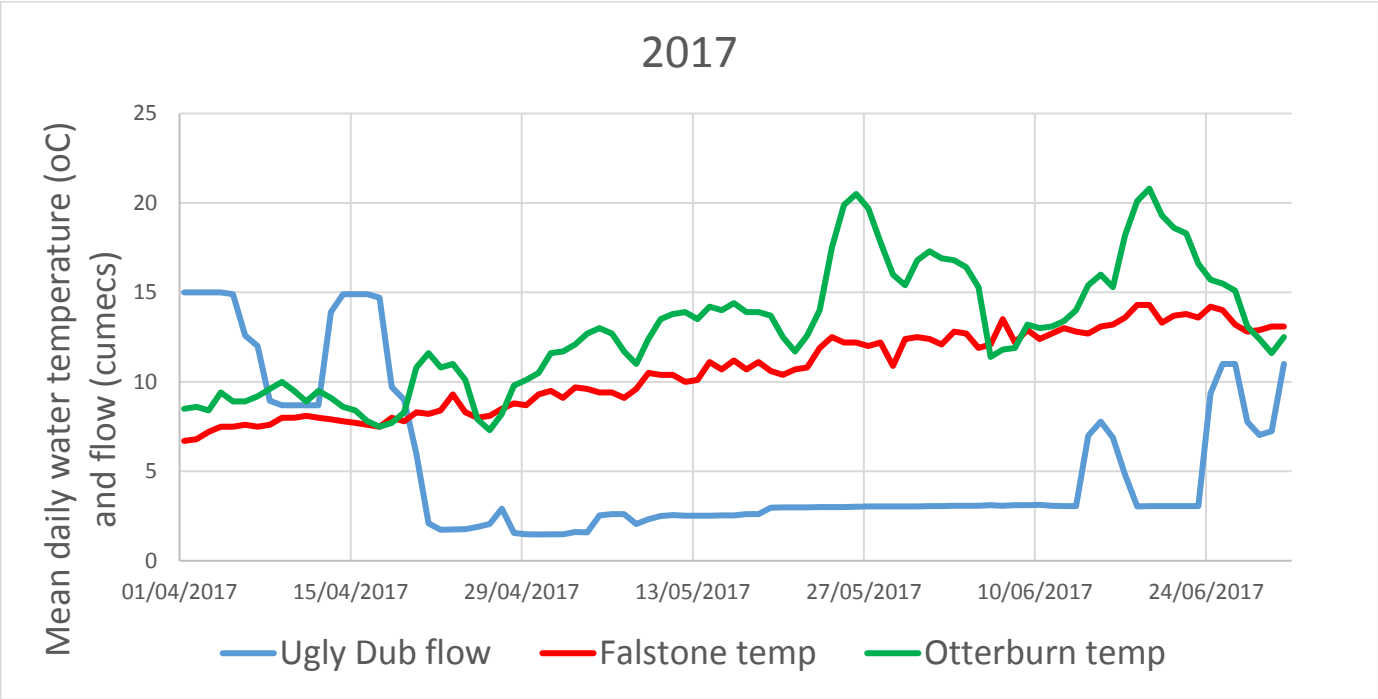
As yet there is insufficient evidence to determine whether or not fish populations have been affected by the changes to the releases. A coarse fish survey was carried out at a dozen locations on the North Tyne at the beginning of August to update and enhance existing information on dace populations. Dace were found to be present throughout the river system and in areas where they have not been recorded for many years, including just downstream of Kielder. The intention is to repeat the survey over next few years to build up a more detailed picture.

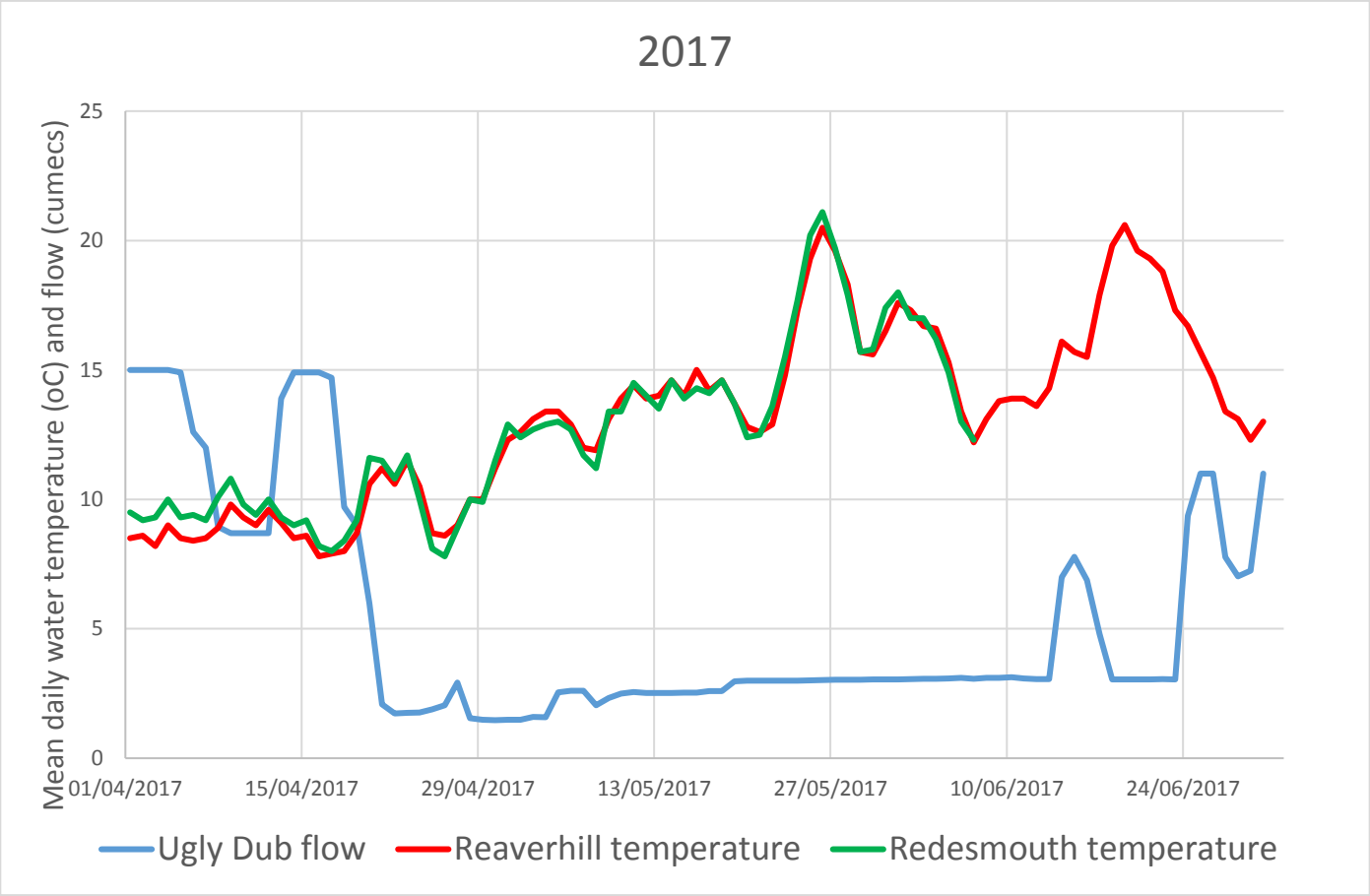
One of the concerns raised at the public drop-in in October 2016 was the possible impact of the revised release regime on water temperature. Because of the higher thermal capacity of impounded water, the rate of change of water temperature in the reservoir is slower than that in the natural stream – the large volume of water takes longer to heat and cool down and is less easily influenced by variations in solar radiation and air temperature. This means that water released downstream tends to exhibit less temperature variability when measured on both sub-daily and seasonal timescales.

Previous studies at Kielder (by Haile, James and Sear (1989)) reported that winter temperatures in the River North Tyne downstream were significantly warmer than ambient conditions, for example, during a winter week 1.5oC above the dam at Butteryhaugh, compared with 4.5oC immediately below the dam at Yarrow and 2.5oC at Chollerford 35 km downstream of the reservoir.

Given the inherent impact of large bodies of impounded water on water temperature, it is important that any changes made to the release regime do not exacerbate this effect. One way in which the impact of cooler temperatures has been reduced is by ensuring that the 21 cumec flood alleviation releases required in zone I are only made from the main draw off levels between April to October, not the scour. Scour valve releases would only be required in the summer if the reservoir level was in Zone J or K when a total of 50 cumecs would be released. It is anticipated that if these releases were required then natural flows would be high which would reduce the impact of any cooler water.

Water temperature is critical between April and June for the successful spawning and hatching of dace. Figures 8a and 8b below compare the water temperature in the Tyne catchment from April to June in 2017 at locations affected by releases from Kielder (Falstone and Reaverhill) and those unaffected (Otterburn and Redesmouth).





Figs 8a and 8b: water temperature at key locations in the Tyne catchment from April to June 2017

Figure 8a shows that, as expected, the impact on water temperature is greatest just downstream of the dam at Falstone. The temperature at the 'control' site at Otterburn is far more responsive, even when only a relatively small amount of flow is being discharged from Kielder. However, by the time the water has reached Reaverhill the pattern of temperature variation is far closer to the control site, this time at Redesmouth. It is noticeable that the temperature at Reaverhill is around 1oC cooler than that at Redesmouth during the larger Kielder release at the start of April which is why the release profile is adjusted to reduce the likelihood of releases at this time of year.

Another way to consider the impact of the trialled regime on water temperature is to compare the November 2016-October 2017 readings with the long term temperature recorded at Ugly Dub. Figure 9 below shows that the water released from Kielder has been generally warmer than average throughout the trial.

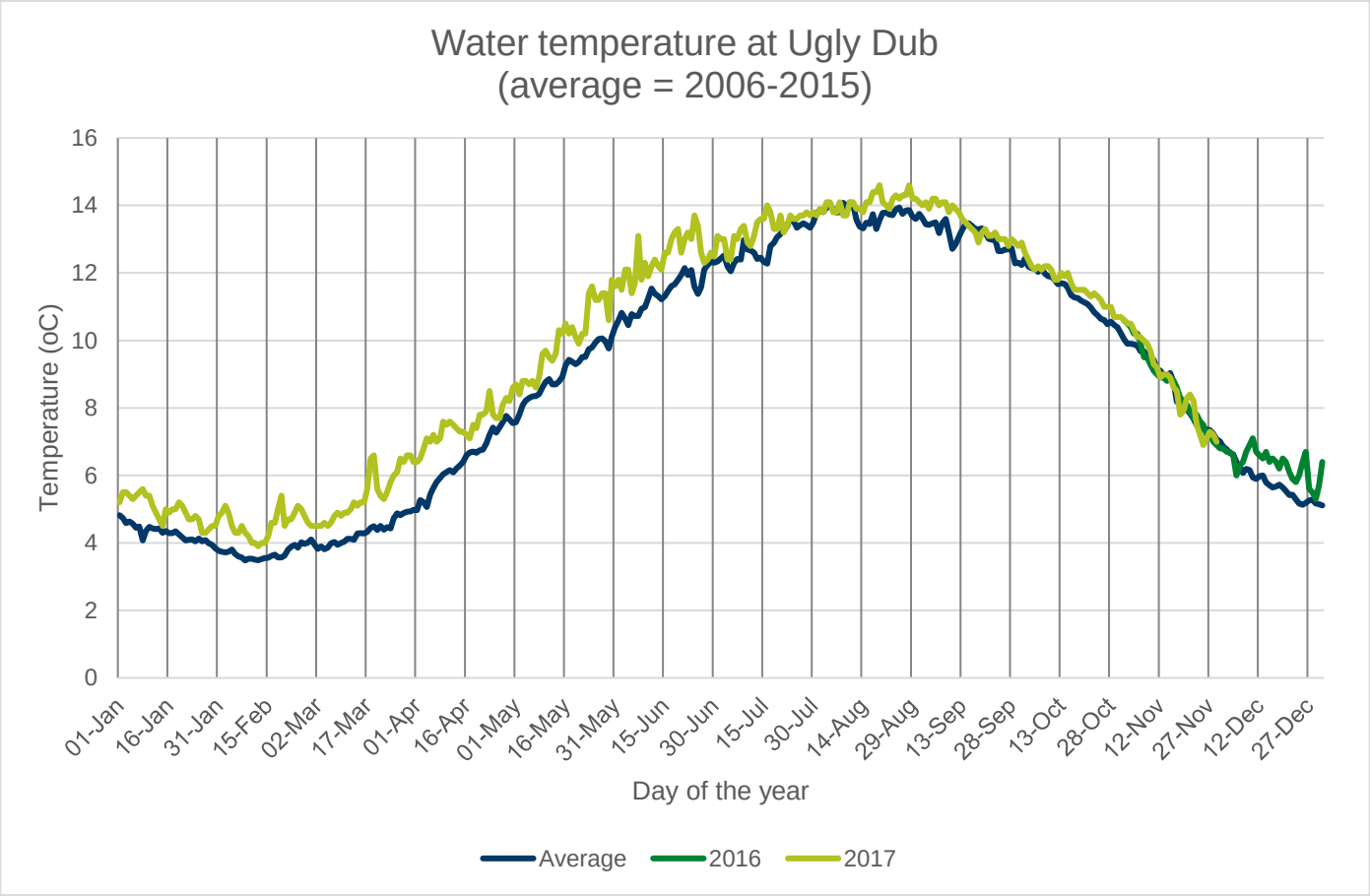


Fig 9: mean daily water temperature recorded at Ugly Dub during the trial, compared to the long term average

In addition to monitoring water temperature, electro fishing surveys are routinely carried out in the North Tyne each year. Table 3 below summarises the density data (number of fish per 100m sq.) for the electro fishing surveys carried out on the main stem North Tyne and tributaries during 2017. The results suggest that neither adult migration or spawning/survival was affected by the changed release programme; the observed density of both salmon and trout in 2017 being higher, on average, than recorded during surveys historically.

Species	Site	2017	Average	Min	Max	St. Dev	N	% of average
Salmon	North Tyne at Newton	**63.8**	**32.7**	14.3	79.0	24.3	7	**195**
Salmon	Chirdon Burn (CHGD)	**15.5**	**16.3**	5.8	50.2	12.4	13	**95**
Salmon	Warks Burn upstream	**19.3**	**12.1**	0.7	30.9	8.9	14	**159**

	of bridge (WKAA)							
							Average	**150**
Trout	North Tyne at Newton	0.8	1.4	0.1	4.0	2.3	7	**60**
Trout	Hareshaw Burn	79.9	83.7	42.0	155.1	64.8	3	**95**
Trout	Chirdon Burn (CHGD)	6.7	10.8	0.8	21.1	5.5	13	**62**
Trout	Warks Burn upstream of bridge (WKAA)	57.3	21.7	2.0	77.8	20.5	14	**265**
							Average	**121**

Table 3: numbers of fish caught during electro fishing surveys on the North Tyne in 2017

Data for the site on the main stem North Tyne at Newton also suggests no marked change in the relative proportions of 0+ and >0+ salmon and trout, as follows:

		0+	>0+	Total
2007	salmon	208	20	228
2008	salmon	230	16	246
2009	salmon	182	10	192
2010	salmon	446	28	474
2014	salmon	398	38	436
2016	salmon	82	45	127
2017	salmon	605	7	612
	2007-2016 mean	**258**	**26**	**284**
2007	trout	7	2	9
2008	trout	3	0	3
2009	trout	1	0	1
2010	trout	1	4	5
2014	trout	21	11	32
2016	trout	13	8	21

2017	trout	7	1	8
	2007-2016 mean	**8**	**4**	**12**

Table 4: age of salmon and sea trout caught during electro fishing surveys on the North Tyne in 2017

It is not possible to conclude if this objective has been achieved or not.

The magnitude of spill is reduced

There were no periods of spill during the trial and the highest reservoir content was just over 97% on 02.04.17. This was in part due to the fact that April and May were dry and there were no prolonged periods of high inflows. The amount of spill from the reservoir will be closely monitored over the coming years as it is important that some spill is achieved for ecological, geomorphological and reservoir safety reasons.

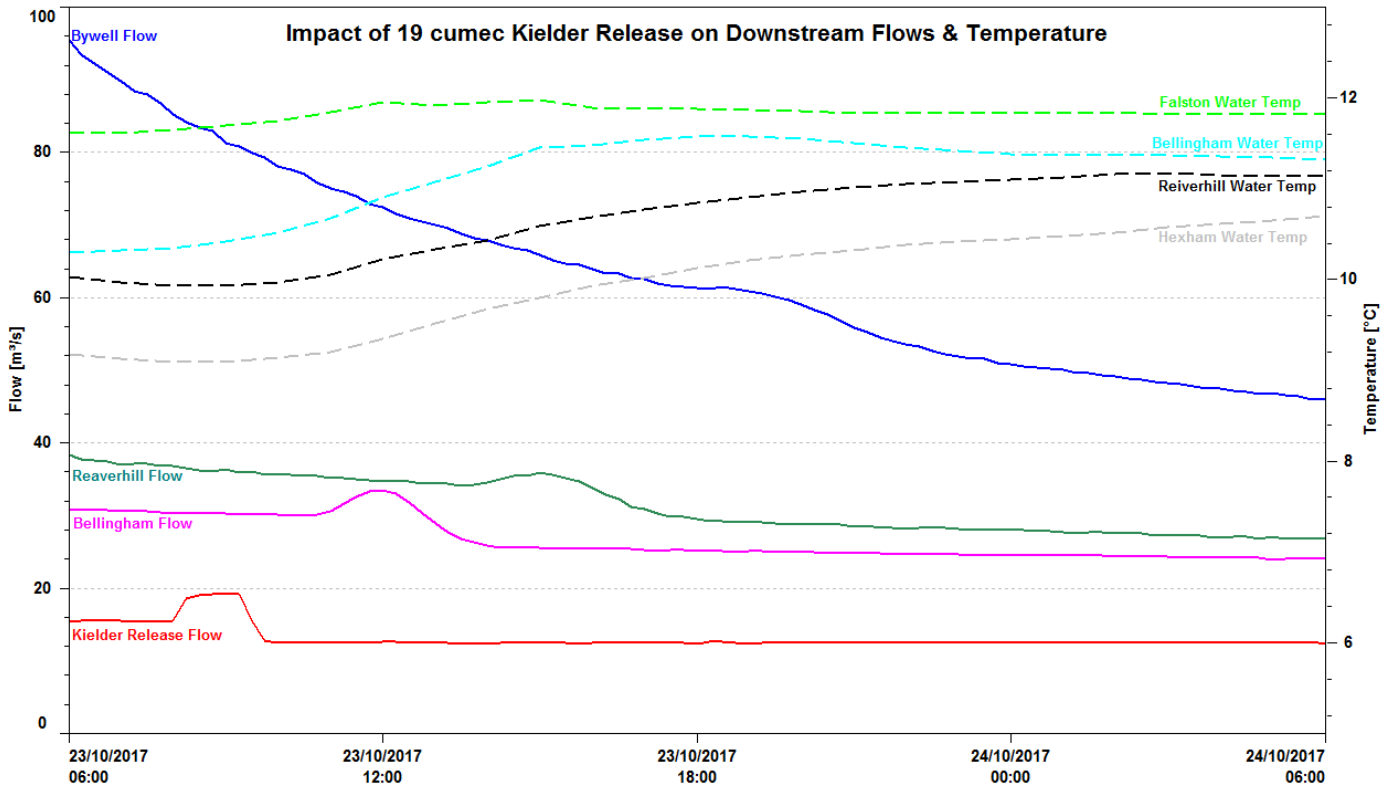
This objective has been achieved.

Flood releases are required infrequently

Flood releases (in excess of 15 cumecs) were only triggered once during the trial, on the 23rd October. However, the main turbine had been removed in April to be refurbished which meant that it was not possible to safely release the full 25cumecs and the release had to be aborted when it reached 19cumecs. NW and innogy are still confident that now the main turbine is reinstalled, 25cumec and 50cumec releases will be able to be made from the reservoir, using a combination of hydro releases, draw off levels and outflows.

It remains one of the main shortcomings of the trial that it has not been possible to monitor in detail any impact on temperature or rate of rise that these large releases may have.

Figure 10 below shows how the 19 cumec release from Kielder travelled downstream and how it was barely noticeable at the Tyne at Bywell. The temperature of the release wave was also monitored (shown as dashed lines) and there was no discernible impact on water temperature.



Figs 10: Impact of 19 cumec Kielder release on river flows and temperatures downstream

This objective has been achieved.

The estimates made for the proposed week turn out to be correct more often than they are wrong

Due to differences in the way the releases for the coming week are calculated there was some uncertainty at the start of the trial about how accurate the releases in the 'proposed' week would be. At the drop-in event in October 2016 several river users expressed a preference for keeping the 'proposed' week and so, although these releases have not been communicated via the innogy webpage, they have been calculated. However, the results have shown that the proposed week is rarely correct due to the wide variation in inflows.

This objective has not been achieved and views will be sought from external stakeholders about whether or not to publish the proposed releases, given how often the releases then need to be changed.

Summary of the success criteria

The reservoir level is kept within zones B to H	The revised regime was designed to keep the reservoir contents within the release zones B-H and avoid large releases or spill. This has been largely achieved.
Variation in the amount of water released	Some improvement in flow variation but still does not reflect natural inflows. It is hoped that this will improve with the revised regime of releases made by the refurbished turbine.
Fish passage at Riding Mill is not impacted and the broodstock collection is successfully completed	No evidence to suggest fish passage has been impacted; broodstock collection was completed successfully in 2016 and 2017.
Not adversely impact fish populations	Little evidence either way, but no major reduction in fish numbers or change in population age.
The magnitude of spill is reduced	No spill.
Flood releases are required infrequently	Flood releases only triggered once.
Estimates made for the proposed week turn out to be correct more often than they are wrong	The proposed week was rarely correct.

Shortcomings of the trial and further work

It is difficult to draw too many conclusions about the impact of the annual trial of the new regime on river flows, given the short dataset and the unusually dry, then wet, weather conditions. The main shortcoming of the trial is that no releases in excess of the maximum hydropower generation were successfully made. Furthermore, it was not possible to arrange monitoring of the TRIAD releases (these are short duration increases in hydropower generation to capture periods of peak energy demand during week day evenings).

Given that no adverse impact of the new regime has been detected during the annual trial, it will be adopted for use, subject to the results of continuous monitoring. If any impacts are detected at any stage in the future, then further changes will be made to mitigate their impact.

One of the key changes for 2018 is the introduction of a new range of flows which can be made from the refurbished turbine. Historically only releases at 8, 10, 12 and 15.4cumecs could be made from the main turbine. The turbine was removed in April and reinstalled at the start of December 2017 and has been taken through a range of tests, releasing flows from 3.5cumecs to 16.8cumecs. A new suite of release regimes (B-H) has been developed in partnership between innogy, NW and the Environment Agency which will see flows of 3.5, 5, 7, 9, 11, 13 and 18cumecs being released to the North Tyne for the first time since 1982.

Further monitoring is planned, some of which is aimed at trying to increase the understanding of freshwater pearl mussels and how they may react to the releases.

The additional monitoring includes:

- rate of rise, velocity, wetted area and turbidity measurements during 25 and 50 cumec releases;

- time lapse, rate of rise, velocity and turbidity readings during TRIAD releases when natural flows are low, ramping from 8 cumecs to 16.4 cumecs;
- a trial of a 3.5cumec release to assess if it would be safe for broodstock collection. This is the new minimum flow rate through the refurbished turbine;
- a repeat of the annual coarse angling survey for the next 4-5 years;
- continued monitoring of temperatures and flows during the summer months when there is the potential for the effects of the releases to be more noticeable.

Comments and more information

This document presents the key conclusions of the trial. A wealth of information and data exists covering river levels, flows, water temperature, water quality and ecology; all of which is freely available from the Environment Agency using the contact details below:

GHCL team

Environment Agency

Tyneside House

Skinnerburn Road

Newcastle upon Tyne

NE7 4AR

Email: Kielder.reservoir@environment-agency.gov.uk

Similarly we are keen to hear the views of any reservoir or river users about how the trial has gone so that we can use your experience to shape the future release regime from Kielder reservoir.