UNDERSTANDING BACKGROUND CONDITIONS AND PATTERNS OF CHANGE

General variability in rainfall and runoff

Seasonal and inter-annual variability

As the occurrence of pollution events is, to a large extent, dependent on rainfall, climatic variability will naturally lead to different types of responses. Therefore, not considering seasonal and inter-annual climatic variability in water quality analysis can risk mistaking the reasons for water quality change. Similarly, climatic variability might hide smaller water quality changes. In this section, continuous flow data were used to identify significant variations in general flow and climatic conditions between monitoring years in view of contributing to further analysis.

- In rivers, rainfall is a key driver in the mobilisation and movement of pollutants, and water quality tends to worsen during rainfall events.
- Rainfall driven differences between river base flows in the summer and in the winter result in seasonal scale variations in water quality data. Although there is some inter-annual variability, on an annual scale, there is often a cyclical pattern, with worse water quality in winter and better water quality in summer.
- Although rapid, short-term changes in water quality are linked to individual rainfall events and flow responses, the behaviour during these events is still influenced by the seasonal differences.
- Because of their size, water quality issues in reservoirs tend to not be rainfall event driven; seasonal algal blooms are the biggest water quality concern in reservoir sources, primarily occurring in the summer.
- Inter-annual variability in climatic conditions and diffuse pollution is likely to cause variability in the timing and extent of the algal blooms.
- Differences between reservoirs in the South West and understanding the extent of the water quality problems across the region allows Upstream Thinking interventions to be focussed in the most appropriate catchments.

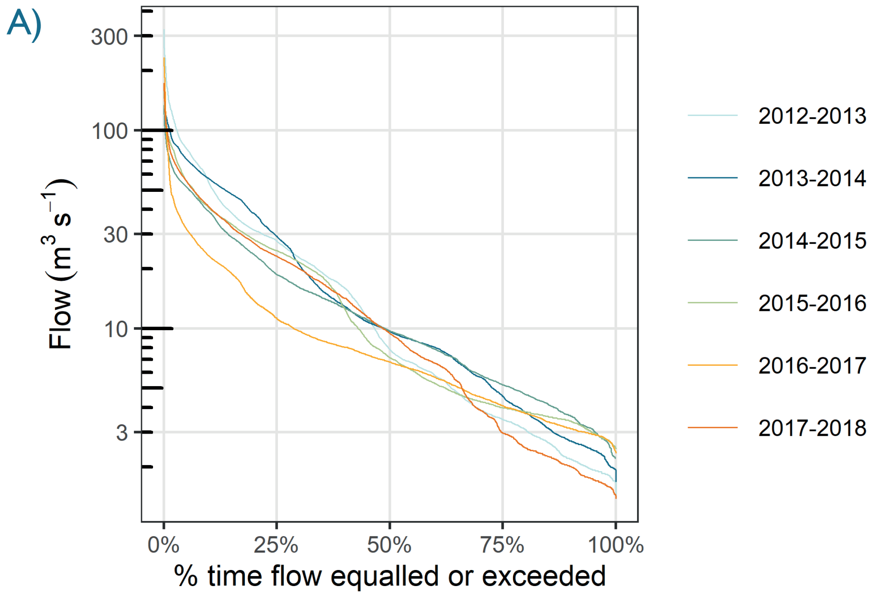
Drift reservoir; photo by Emilie Grand-Clement.

Through the use of flow duration curves (FDC) for each of the monitoring years and per season in the Exe, Figure 1 shows how climatic variability has affected river flows. In particular, this plot highlights a number of abnormal periods:

- The year 2013-2014 was identified as the wettest winter on UK record[1];
- The year 2016-2017 was the driest year during the study[2];
- In addition some years show particular change in one season;
- Particularly high flow during winter 2012-2013 (October to March), and significantly higher than the following years, with FDC curve placed higher on the plot;
- A high spring flow (April to June) in 2013-2014;
- A dry period in winter of 2016-2017: from October to December (Figure 1B) flow measured between 5 and 75% of the time is significantly lower than other years, and closer to observed summer flow range;
- During winter 2017-2018 the UK was affected by a prolonged winter cold period with heavy snowfall on a number of days during February and March 2018. This cannot be seen in the seasonal plot but will be seen in event scale responses;
- A period of particularly low flow during summer 2018, as a result of the warmest and driest year on record in the UK, with cumulative summer rainfall across the UK recorded as only 73% of the long term average[3].

These variations are observed across the whole region, and are particulary shown in data from the Exe (Figure 1). For example, in 2016 -2017, a flow of 10 $m^3 s^{-1}$ is exceeded for only 28.8% of the year; in 2013-2014 flows are greater than 10 $m^3 s^{-1}$ for 48.6% of the year. The flow values exceeded for only 5% time, representing the highest flow rates, are 31.9 $m^3 s^{-1}$ and 71.6 $m^3 s^{-1}$ for 2016-2017 and 2013-2014 respectively. This shows that in 2013-2014 the flow is high for a larger proportion of the year, and that the highest flows are also greater. Looking at the seasonal plots (Fig 1B), this can also be seen as the 2013-2014 curves sits towards the top of the plot for the winter months, and the 2016-2017 curve sits well below the others during early winter (October to December), and slightly below between January and July.

A)



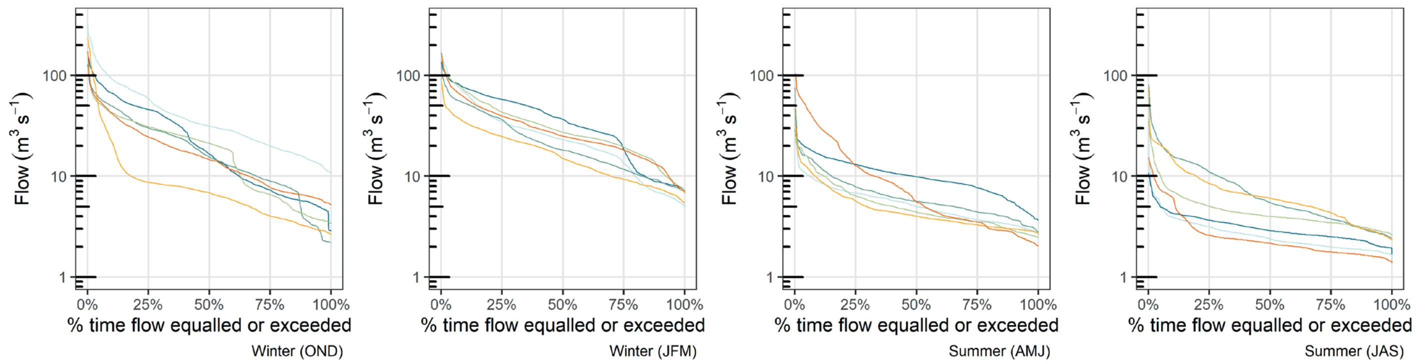


Figure 1 The flow duration curves for the River Exe at Northbridge show some of the differences in flows between years and seasons (A) by hydrological year, and (B) displayed for the seasons over the same period; each line represents the flow for a different hydrological year between 2012-2013 and 2017-2018.

River patterns

River and pollution dynamics

The dynamics in river systems are driven by rainfall events, with runoff over and through the land feeding streams, rivers and other water bodies. As well as directly affecting chemical processes, climatic conditions influence the rainfall and runoff patterns: changes in the frequency and intensity of rainfall events will affect the pathways that water takes to reach streams and rivers, the speed it travels, and in turn, the patterns seen in rivers for different pollutants. Understanding how rivers respond to rainfall, the differences between the normally wet hydrological winter and dry hydrological summer (Figure 2A) and the wider climatic influences, helps untangle how these patterns change over timescales (from minutes to months). When it rains and river flows increase, pollutant concentrations either increase (concentration) as they are washed in from different sources, or decrease (dilution) with the addition of 'cleaner' water. Alternatively, levels of pollutants might stay the same (static); in complex or larger catchments, there might be a mix of behaviours in different sub-catchments and at different times. These behaviours can be broadly grouped by the type of pollutant. Across the river sites and feeder streams in this study, ammonia, colour and turbidity typically increase as flows increase following rainfall events. Some nutrients (e.g. Total Oxidised Nitrogen) and other indicators such as dissolved oxygen (DO), pH and conductivity drop as the flow increases. Both dissolved oxygen and pH display strong daily changes (diurnal cycles) (Figure 2C), these are more pronounced over the summer months.

Year on year variability

One of the benefits and challenges of monitoring over multiple years is that it enables the observation of year by year variation due to different climatic and flow conditions. Being able to see this variation helps identify patterns in the behaviour of different contaminants in the rivers and in feeder streams to reservoirs, pointing to both key risks to rivers (e.g. heavy rainfall in the middle of drought conditions) but also provides insight into how a changing climate could affect these in the long term.

For example, over the monitoring period, the first couple of winters (2012-2013 and 2013-2014) were wetter (Figure 1B) with higher base flows in rivers across the South West. Across all the sites, and in the number and magnitude of peaks in colour and turbidity. Conversely, the dry winter of 2016-2017 resulted in much lower base flow levels, with reduced turbidity peaks and overall values. While the dry summer of 2018 reduced the turbidity and the highest colour peaks associated with rainfall events, there were overall increases in colour recorded for this summer.

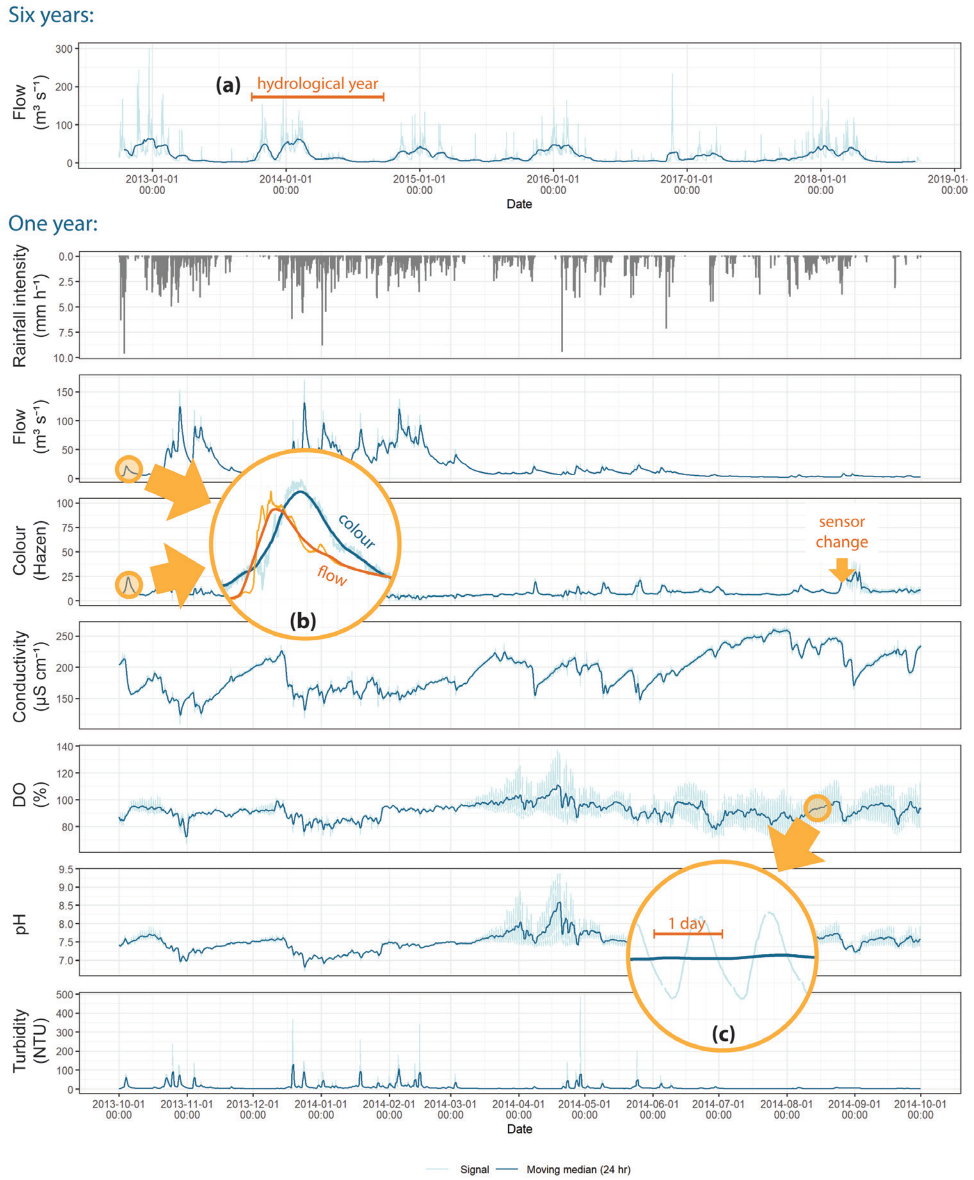


Figure 2 Water quality signal from the river displaying patterns of different scales with (a) inter-annual and seasonal changes across the monitoring period (e.g. increased flow in the hydrological winter); and a breakdown of the year 2013-2014 showing (b) clear rainfall events with either concentration (colour, turbidity) or dilution (conductivity, dissolved oxygen, and pH) effects and (c) diurnal (daily) cycles in the recorded signal.

Figure 3 Rainfall (A), flow (B) and turbidity in the feeder stream to Upper Tamar Lake (C), and turbidity in the reservoir (D) between September and October 2017. Note the difference in scales between locations C and D; orange circle highlights a significant rainfall event that has impact on flow, and turbidity both in the feeder stream and in the reservoir.

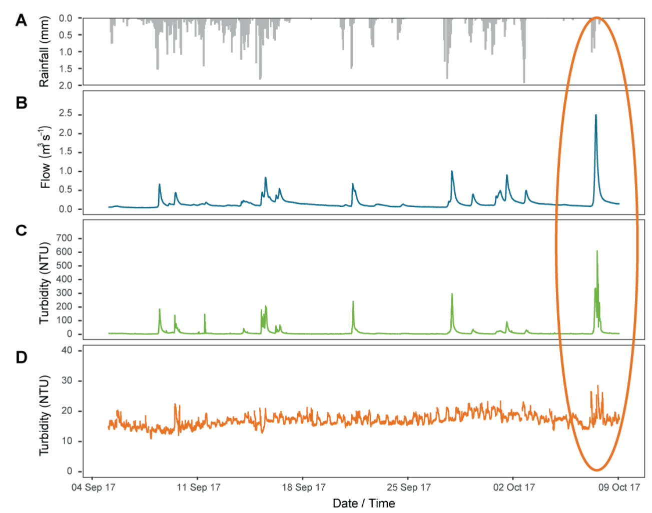
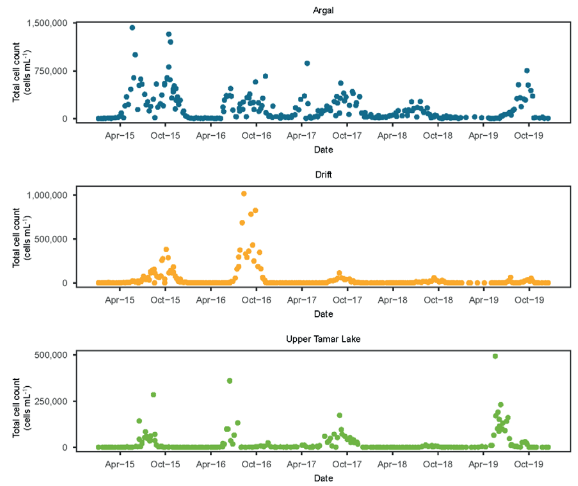


Figure 4 Algal blooms between 2015 and 2015 for Argal Lake (top), Drift reservoir (middle) and Upper Tamar Lake (bottom) measured in total cell count (cells mL⁻¹).



Reservoir sites – what do they have in common?

Reservoir patterns

As explained previously, the majority of pollution delivery in rivers and feeder streams to reservoirs occurs during rainfall events. In continuous datasets, such events have identifiable patterns matching that of flow rise and fall (See p17). For example, Figure 3 B and C shows an example of the turbidity time series (i.e. turbidity data plotted in time order) in the feeder stream to Upper Tamar Lake that clearly increases and decreases following rainfall and flow variations, illustrating the erosion of soil and flow of sediment into the lake. However, reservoirs experience a very different dynamic to that of rivers, which is generally not driven by rainfall events. This is shown by the turbidity signal measured in the reservoir (Figure 3D): on this plot, the turbidity signal does not follow flow variations. Turbidity values in the reservoir also show less change and do not reach such high concentrations as the turbidity in the feeder stream (i.e. remains between ca. 10 and 20 NTU). Instead, the signal experiences smaller variations, some of which may be due to daily variations. However, large rainfall events, such as the one occurring in October 2017, can be noticeable in the turbidity signal.

Seasonality of algal blooms in reservoirs

The occurrence of rainfall events are less of a direct water quality concern for the production of drinking water in reservoir sources than that from river sources. Instead, water quality issues in large bodies of water are affected by reservoir dynamics and tend to occur over longer timescales. In particular, a common water quality issue, especially in the South West region, has been the occurrence of large algal blooms occurring seasonally. Algal blooms are a particular problem for the ecology of the water body as they prevent light penetration into the water. They are also a problem for drinking water production, as they have to be physically removed during the treatment process, and produce harmful toxins.

Although the input of nutrients from diffuse pollution to reservoirs is one of the controls on algal blooms, others factors also include: total nutrient content already present in the reservoir, hydrology (i.e. reservoir level), mixing, general water chemistry (e.g. pH or conductivity), temperature or sunlight.

Figure 4 shows the occurrence of algal blooms in each of the reservoirs within the project. It highlights in particular the occurrence of peaks that tend to occur in the summer to autumn; inter-annual variability in climatic conditions are likely to explain differences in the timing of blooms. For instance, at Argal Lake, 2015 sees a first algal peak in spring, followed by another one in the autumn. Figure 4 also highlights differences between reservoirs: discrepancies in the timing of peaks between reservoirs in the same region is likely to be due to local conditions, and specific in-reservoir dynamics. For example, the double peak of 2015 at Argal Lake is not observed in Drift or Upper Tamar Lake. Finally, the scale of the algal bloom is very different between reservoirs: with a maximum cell count measured between 2015 and 2019 of c.a. 1,500,000 cells mL⁻¹, Argal Lake is the worst affected, compared to Drift (i.e. maximum cell count of c.a. 1,000,000 cells mL⁻¹) and Upper Tamar Lake (maximum cell count of c.a. 500,000 cells mL⁻¹).

Such periodicity highlights the at-risk period for these water sources, but also the need for further understanding of reservoir dynamics that may be able to help to improve water quality in these water sources.

REFERENCES

1. Kendon, M., and McCarthy, M. (2015), The UK's wet and stormy winter of 2013/2014. Weather, 70: 40-47. doi:10.1002/wea.2465
2. Kendon, M., McCarthy, M., Jevrejeva, S., and Legg, T. (2017). State of the UK Climate 2016, Met Office, Exeter, UK.
3. MetOffice. Summer 2018. (Accessed 11th November 2020) https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/uk-past-events/interesting/2018/summer-2018---met-office.pdf