A Risk-Based Tool That Accounts for Uncertainty in Water Quality Studies

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1. Abstract

Fundamental Intermittent Standards (FIS) is one definition of ecological harm used in the UK. In-situ river multiparameter water quality instruments have manufacturers' accuracy bandwidths. These bandwidths can be sensibly represented by a probability function of a normal distribution. To consider uncertainty, the users risk appetite for environmental harm must be considered. Parameter threshold ratio (PTR) is a term created to indicate how close a parameter sits to any regulatory limit. Plotting PTR against FIS can provide understanding into a location's sensitivity to levels of uncertainty. Understanding a location's sensitivity to uncertainty has multiple economic implications such as the choice of sensor required, or the need to carry out further monitoring.

2. Introduction

In the UK, implementation of the *Environment Act 2021* (s.82) calls for continuous water quality monitoring both upstream and downstream of an overflow. Therefore, it is likely that over the next decade the number of in-situ river water quality monitoring stations will increase, which could come at considerable cost. This work looks at the effect the monitoring uncertainty has on the data to be used in regulatory assessment, and whether this changes between locations. The Urban Pollution Management Manual (FWR, 2019) specifies water quality standards as Fundamental Intermittent Standards (FIS). FIS are the regulation for wet-weather pollution and consist of concentration-duration-frequency based criteria for Dissolved Oxygen (DO) and unionized Ammonia (UA) in receiving waters.

3. Methodology

At 19 locations across four catchments in the North of England data was collected between September 2019 and September 2020. For each location, the water quality parameters measured were dissolved oxygen (DO), total ammonia (TA), pH and temperature. The measurements were made using multi-parameter sensors, sampling at a frequency of five minutes for twelve months. The manufacturer reported accuracy bands of ± 0.2 mg/L, ± 2.0 mg/L, ± 0.2 and ± 0.15 °C respectively for DO, TA, pH, and temperature. Eighteen of the locations had a known CSO located upstream which was prone to intermittently discharging into the river. Where the sensor had failed to record a value, the data was extrapolated by recording the middle value from the last and next data point. The unionised ammonia (UA) values are calculated based on using the equation 1:

$$\mathrm{UA}\ (\mathrm{mg/L}) = \mathrm{NH4}\ (\mathrm{mg/L})/(1+10^{\ (10.055-(0.0324*\mathrm{Temperature}(^{\circ}\mathrm{C}))-\mathrm{pH})}) \qquad \text{Equation 1}$$

A probability function of a normal distribution was applied to the measured data, with the mean of the distribution as the value of the parameter as recorded by the sensor, and the upper and lower bands of the accuracy range as quoted by the manufacturer. This normal distribution was applied to every timestep in the timeseries. To perform FIS analysis a risk appetite must be considered. Environmental risk is defined as the 'true' DO in the river being below the value chosen to represent the DO at that current timestep and the ‘true’ UA in the river being higher than the value chosen to represent the UA at that current timestep. Therefore, a more risk averse individual will choose a more conservative value to represent the parameter.

Parameter Threshold Ratio (PTR) is a term created to indicate how close a parameter’s value is to the regulatory limit, as illustrated by Figure 1. It is calculated by averaging the parameter’s measured points and dividing it by the averaged parameter regulatory threshold. Locations where the parameter sits closer to the regulatory limit will require a smaller deviation after an environmental input (e.g. intermittent spill) to interact with the threshold. To investigate the relative proximity of the parameter and threshold, over 100 hypothetical thresholds for DO and UA were investigated when carrying out FIS analysis at the 19 monitoring locations.

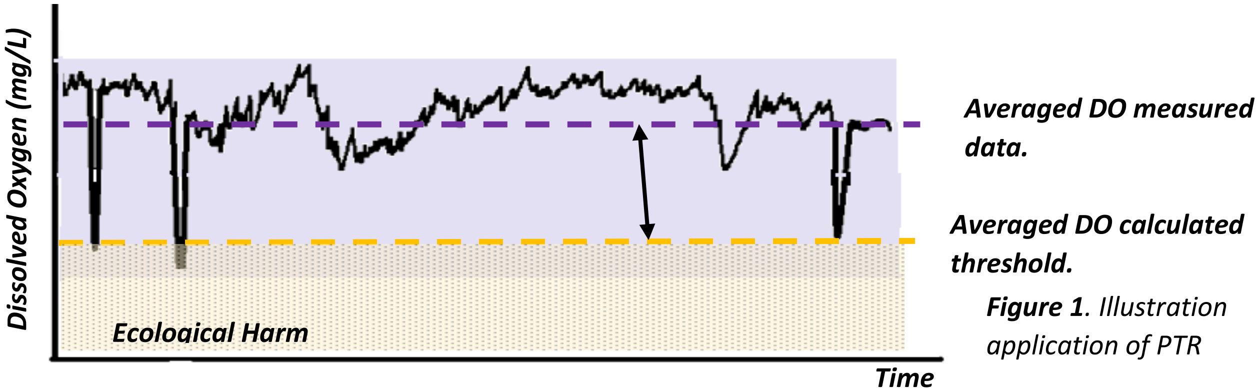

Figure 1. *Illustration application of PTR*

4. Results and Discussion

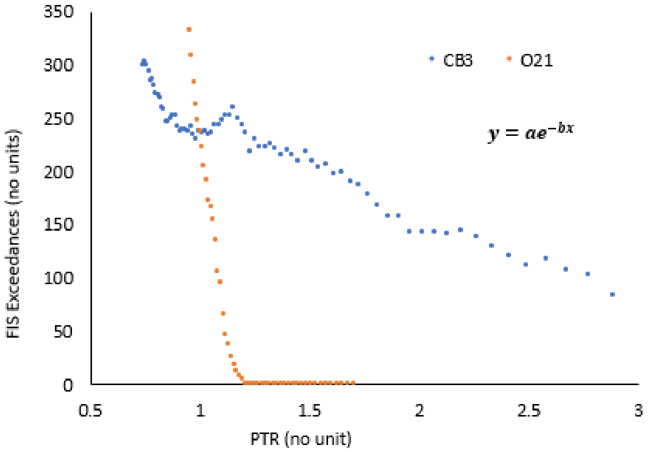

Figure 2; Parameter Threshold Ratio graph based on collected data from two locations.

Table 1; *Table shows FIS exceedance count recorded at different PTR.*

PTR	CB3	
	± 0.13 mg/L	± 0.40 mg/L
1.0	235	239
2.	140	145

Table 2; *Table shows FIS exceedance count recorded at different PTR.*

PTR	O21	
	± 0.13 mg/L	± 0.40 mg/L
1.13	43	86
1.23	1	3

Figure 2 shows that plotting FIS exceedances against PTR for DO, produces an exponential decay curve. The shape of these curves was found to be location specific. Table 1 & 2 compares two different quality sensors (left column as shown in Fig 2, right column a less accurate sensor), and shows that for a location with a shallow gradient of an exponential decay curve, the impact of the quality of sensor on estimated FIS exceedances per year is minimal. Hence implying that locations with shallower curve gradient are less sensitive to uncertainty in FIS exceedance numbers. However, these locations are more likely to be the catchments that will fail, as FIS exceedance numbers are still relatively large at the greater values of PTR. Table 2 shows that for a location with a steeper gradient of the exponential decay curve that the difference between the quality of sensor can be important. Hence implying that steeper gradient of the exponential decay curves are more sensitive to uncertainty. This can affect economic decisions in four ways; choice of sensor, maintenance regime, or if a location is put forward for solution and required size of solution designed using the collected data.

Experience of plotting PTR against number of FIS exceedances for DO and UA, for all 19 field locations, has produced general schematics as illustrated in Figure 3. Both diagrams are segregated into three zones, which links the three different states the river could be in. Zone 1 represents the river being in a continuous state of harm, where the parameter always exceeds the threshold. Zone 2 represents the river entering periods of ecological harm, but it is not continuous. The parameter interacts with the threshold. Zone 3 represents the river not entering the state of ecological harm, the measured parameter doesn't interact with the threshold.

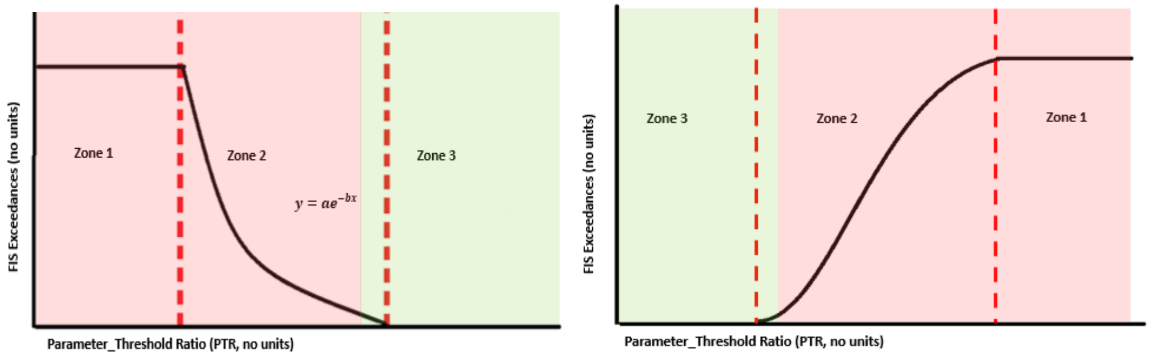

***Figure 3**. Diagram of the effect of PTR will have on reported number of DO and UA FIS exceedance.*

5. Conclusion

Multiparameter sondes have a fixed manufacturer's accuracy bandwidth if the instrument is used as intended. To consider uncertainty when assessing environmental harm, the assessor's risk acceptance must be known. This paper introduced the concept of quantifying the uncertainty in determining FIS failure. A parameter 'PTR' was introduced, that indicates the divergence of the typical water quality in a receiving water from a regulatory threshold. By plotting PTR against FIS exceedances, an understanding of a location's sensitivity to level of instrument-related uncertainty can be gauged. Being able to understand a location's sensitivity to uncertainty has multiple economic implications such as choice of sensor and maintenance regime for in-situ sensors.

6. Acknowledgements

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7. References

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