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Uncertainty in the frequency distribution of water quality parameters: comparing three Bayesian approaches

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Observational uncertainties are a notably under-researched area in environmental science, despite their impact on process understanding, model prediction (via the input, calibration and validation stages) and decision making. In this paper I focus on water quality parameters, such as sediment, phosphorus, nitrogen, chloride and oxygen concentrations, which are routinely monitored by environmental regulators to assess the status of surface waters and inform water resources management. This assessment is typically done based on a low temporal monitoring resolution, which in the UK, for example, is fortnightly or monthly so that no more than 12-26 samples per year are typically available. This sampling pattern introduces an unknown bias to the empirical frequency distribution of the parameters, particularly those that are highly variable in time, such as sediment and phosphorus. This bias translates into uncertainty about the statistical moments and percentiles which are ultimately compared to environmental standards or used to drive, calibrate and validate models.

In this paper I estimate this uncertainty probabilistically comparing three Bayesian inference models: (1) estimating the parameters of a theoretical frequency distribution, (2) averaging over multiple hypotheses of the frequency distribution, (3) the Bayesian Bootstrap. Uncertainty estimates are propagated through to percentiles of key water quality parameters for practical cases of rural pollution management in the UK and compared to existing standards to illustrate the impact of observational uncertainty on the assessment of surface waters. I also demonstrate a case of model calibration against these uncertain data. The three inference models compared all have limitations and rely on more or less subjective assumptions about the data not collected which are illustrated and discussed.

As the science here offers multiple solutions, I will argue that the methodological choice is best made together with those making and affected by the decisions based on the uncertain data (the stakeholders) in an analytic-deliberative and adaptive setting of natural resources management. I will conclude with insights from applying these principles in practice.