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Assessing the impact of measurement frequency on accuracy and uncertainty of water quality data

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Physico-chemical water quality is a major objective for the evaluation of the ecological state of a river water body. Physical and chemical water properties are measured to assess the river state, identify prevalent pressures and develop mitigating measures. Regularly water quality is assessed based on weekly to quarterly grab samples. The increasing availability of online-sensor data measured at a high frequency allows for an enhanced understanding of emission and transport dynamics, as well as the identification of typical and critical states.
In this study we present a systematic approach to assess the impact of measurement frequency on the accuracy and uncertainty of derived aggregate indicators of environmental quality. High frequency measured (10 min^{-1} and 15 min^{-1}) data on water temperature, pH, turbidity, electric conductivity and concentrations of dissolved oxygen nitrate, ammonia and phosphate are assessed in resampling experiments. The data is collected at 14 sites in eastern and northern Germany representing catchments between 40 km^2 and 140 000 km^2 of varying properties. Resampling is performed to create series of hourly to quarterly frequency, including special restrictions like sampling at working hours or discharge compensation. Statistical properties and their confidence intervals are determined in a bootstrapping procedure and evaluated along a gradient of sampling frequency.
For all variables the range of the aggregate indicators increases largely in the bootstrapping realizations with decreasing sampling frequency. Mean values of electric conductivity, pH and water temperature obtained with monthly frequency differ in average less than five percent from the original data. Mean dissolved oxygen, nitrate and phosphate had in most stations less than 15 % bias. Ammonia and turbidity are most sensitive to the increase of sampling frequency with up to 30 % in average and 250 % maximum bias at monthly sampling frequency. A systematic bias is recognized in oxygen and temperature with sampling at working hours. Turbidity has a systematic negative bias with decreased sampling frequency. Most matter constituents show a site specific bias that increases with decreasing sampling frequency. Discharge compensation largely decreases uncertainty and bias of the results for almost all constituents and stations. For upper quantiles and maximum concentration the described tendencies in bias are almost always more pronounced. Small and steep catchments are most sensitive to bias of the aggregate indicators with frequency decrease.
The expanding use of high frequency sensors for water quality monitoring enables an enhanced understanding of water quality dynamics. Turbidity and ammonia as particle related variables are especially sensitive to low measurement frequency. The observation that especially small catchments require a high monitoring frequency poses a challenge for future research and the development of monitoring schemes.