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Supplementary material

Effect of climate variability on water quality trends in New Zealand rivers

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The analysis in the main document were based on flow adjusted water quality observations. This supplementary material provides additional information describing the flow adjustments that were made and results for the same analyses that are described in the main document, but which were carried out using 'raw' (i.e. non-flow adjusted water quality observations).

Flow adjustment

Flow adjustment of the observations for each variable at each site, apart from FLOW, was performed by fitting a ordinary least-squares regression with log (base 10) transformed values for both the water quality variable observations and flow observations pertaining to the entire timeseries. If this model was statistically significant ($\alpha = 0.05$), the flow adjusted observations were derived as the residuals of this model. Table S1 summarises the proportion of sites for which flow adjustments were made (i.e. for which the regression model was statistically significant). Table S1 also indicates, the proportion of the significant regression models for which the fitted regression coefficients were positive (indicating that the observations values tended to increase with increasing flow).

Table S1. Summary of the proportion of sites for which flow adjustements were made and, when significant, the proportion of fitted regression coefficients that were positive

Water quality variable	Proportion of sites flow adjusted (%)	Proportion of sites with positive regression coefficients (%)
TEMP	100	100
TURB	98	100
COND	100	100
CDOM	96	100
DRP	91	100
NH4N	89	100
NNN	86	96
TN	100	100
TP	95	100

Analyses performed using raw (non-flow adjusted) water quality observations

The figures and tables in this supplementary material document are mostly the results of the same analyses that are reported in the main document. The exception is Fig. 1 in this document, which provides a comparison between trends calculated using raw and flow adjusted water quality observations for selected time windows and durations. This comparison indicates that flow adjustment can result in appreciable differences in trend

strength and direction for individual site and variable combinations (indicated by Kendall's τ) compared to analyses performed on the raw data. However, the comparison shown in Fig. 1 also indicates that the overall pattern of trend strength and direction across sites (indicated by τ_w) is not very sensitive to flow adjustment and that the sensitivity to flow adjustment decreases with increasing trend window duration.

The results reported in Fig. S1–S5 and Table S2 in this document are very similar to the corresponding results reported in the main document. This indicates that the study's findings are not very sensitive to whether raw or flow adjusted data are used in the analysis. Flow adjustment removes the influence of instantaneous flow on water quality observations. Therefore, the similarity in the results between analyses performed on raw and flow adjusted data indicates that the influence of climate variation on water quality trends is more than the influence of climate on instantaneous flow.

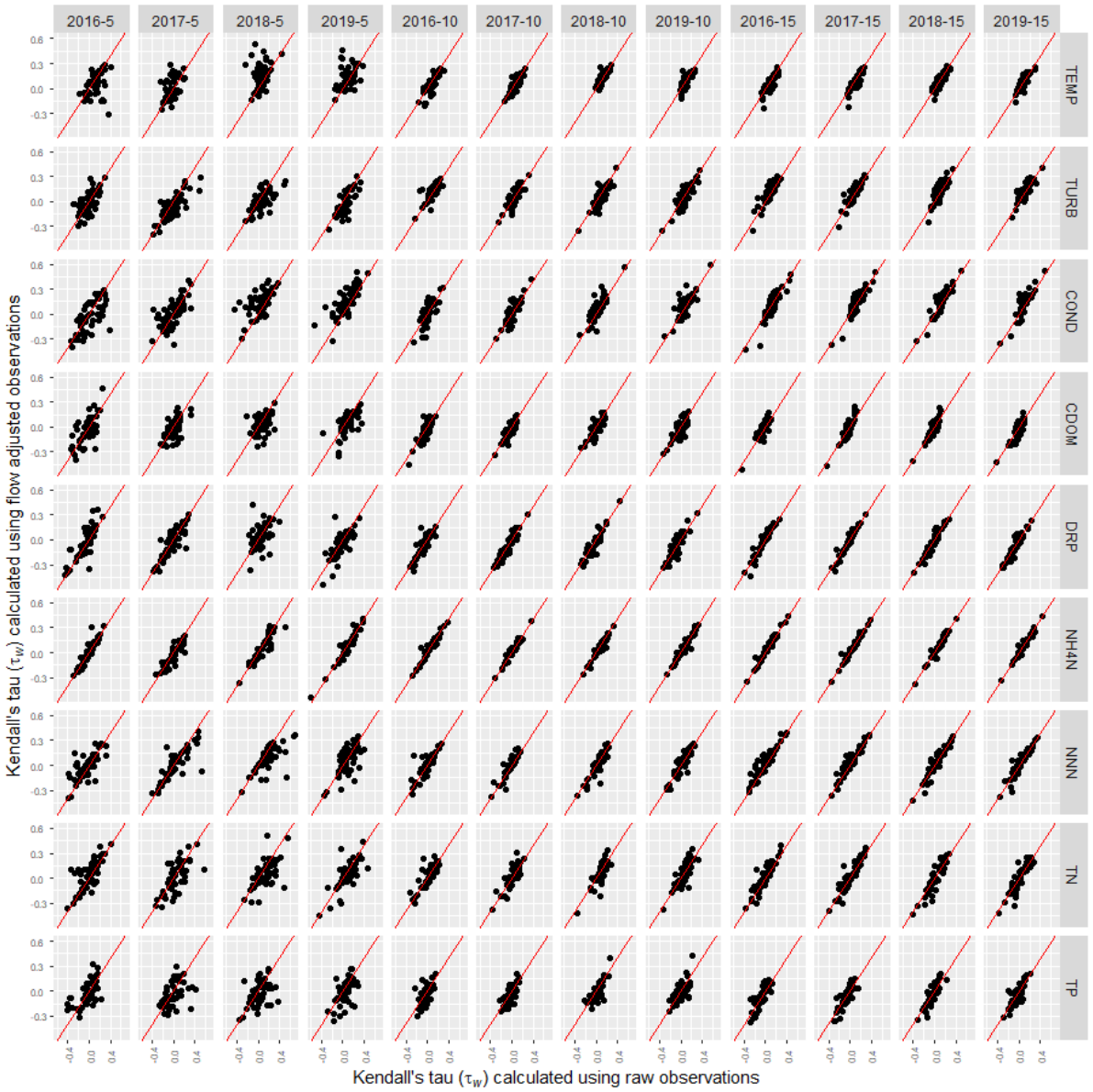

Fig. S1. Comparison of trends calculated using raw and flow adjusted water quality observations for selected time windows ending 2016, 2017, 2018 and 2019 and three durations (5, 10 and 15 years). The labels at the top of the columns indicate the time window end year and duration (Year-Duration) and the labels on the right-hand side of the rows indicate the water quality variable.

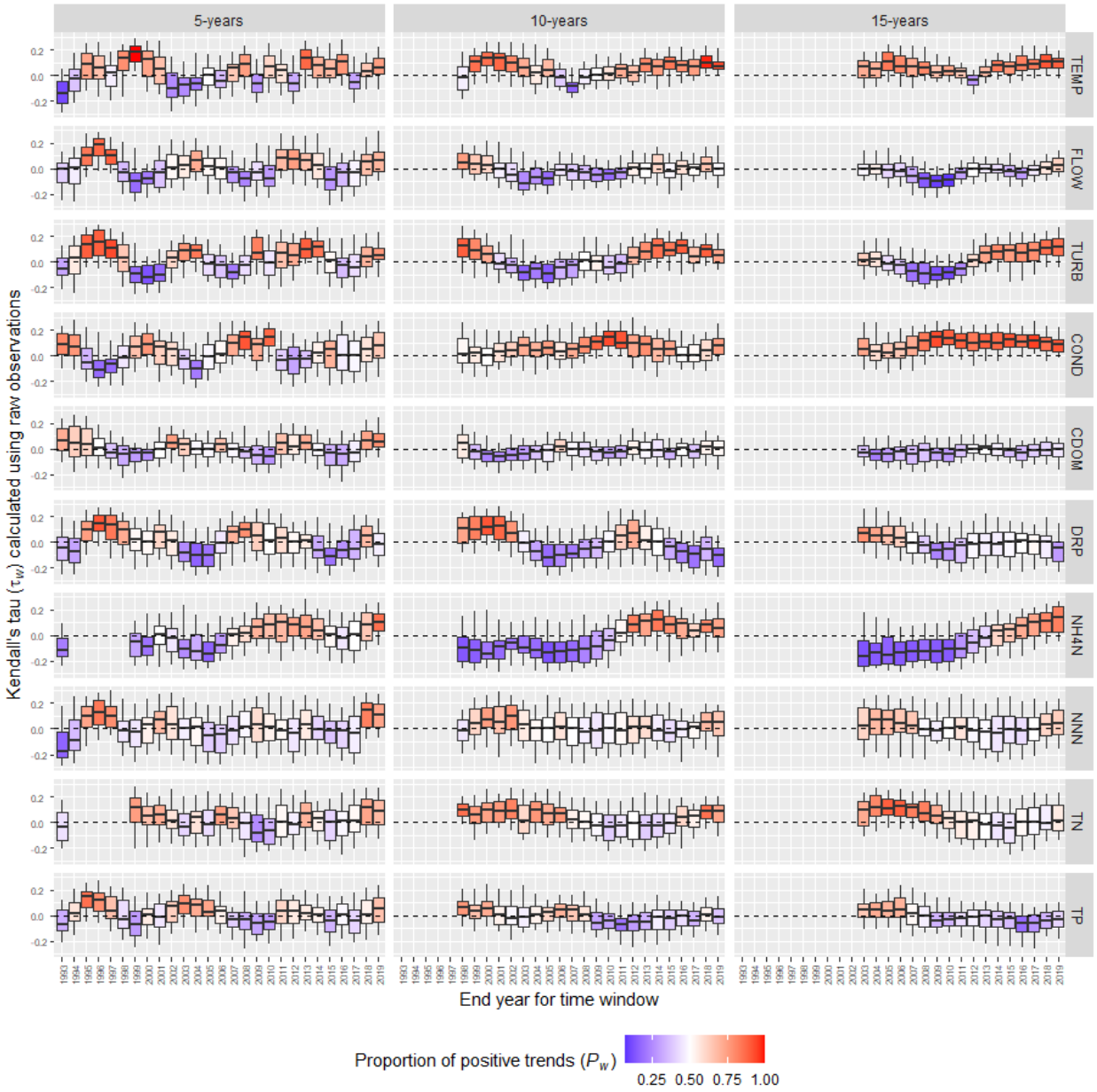

Fig. S2. Distributions of the Kendall tau (τ_w) values for all sites, for each water-quality variable and assessment window for the 5-, 10- and 15-year durations and the proportion of positive trends (P_w) calculated using raw observations. The central bar indicates the median τ_w value, the box indicates the interquartile range and the whiskers extend to the 5th and 95th percentile values. The horizontal dotted line indicates a tau value of zero. Each panel corresponds to a water quality variable (rows) and a time window duration (columns). This figure was derived from raw water quality observations (not flow adjusted) and corresponds with Fig. 4 in the main document.

Table S2. Distributional characteristics of site r_o values for each water quality variable calculated using raw observations

This table corresponds with Table 2 in the main document

Water quality variable	Median and range of r_o	Proportion of absolute r_o values greater than 0.1, 0.2 and 0.3
TEMP	0.2 (–0.1, 0.45)	77, 50, 23
FLOW	0.03 (–0.37, 0.5)	70, 34, 16
TURB	–0.03 (–0.43, 0.38)	57, 29, 9
COND	–0.08 (–0.63, 0.48)	70, 38, 16
CDOM	–0.03 (–0.45, 0.56)	68, 38, 12
DRP	0.21 (–0.28, 0.68)	75, 55, 30
NH4N	–0.08 (–0.38, 0.36)	64, 39, 9
NNN	0.17 (–0.13, 0.69)	70, 45, 21
TN	0.02 (–0.44, 0.49)	55, 29, 12
TP	–0.02 (–0.34, 0.34)	55, 27, 4

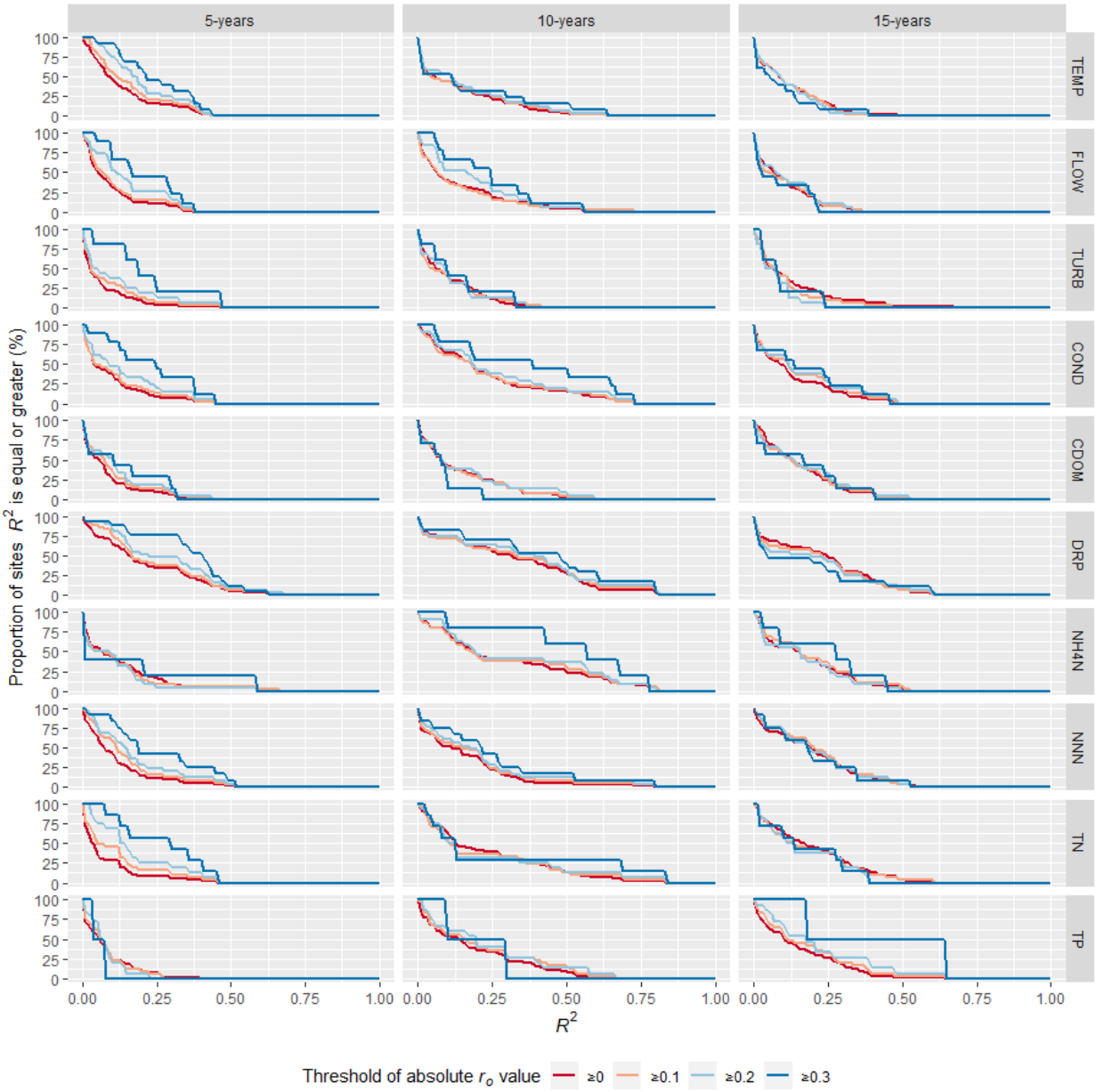

Fig. S3. Cumulative frequency distribution of R^2 values measuring the strength of the association between τ_w and δSOI_w (Eqn 1). The distributions are shown for four categories defined by the absolute value of r_o (≥0, i.e. all sites, ≥0.1, ≥0.2, ≥0.3). Each panel corresponds to a water quality variable (rows) and a time window duration (columns). This figure was derived from raw water quality observations (not flow adjusted) and corresponds with Fig. 7 in the main document.

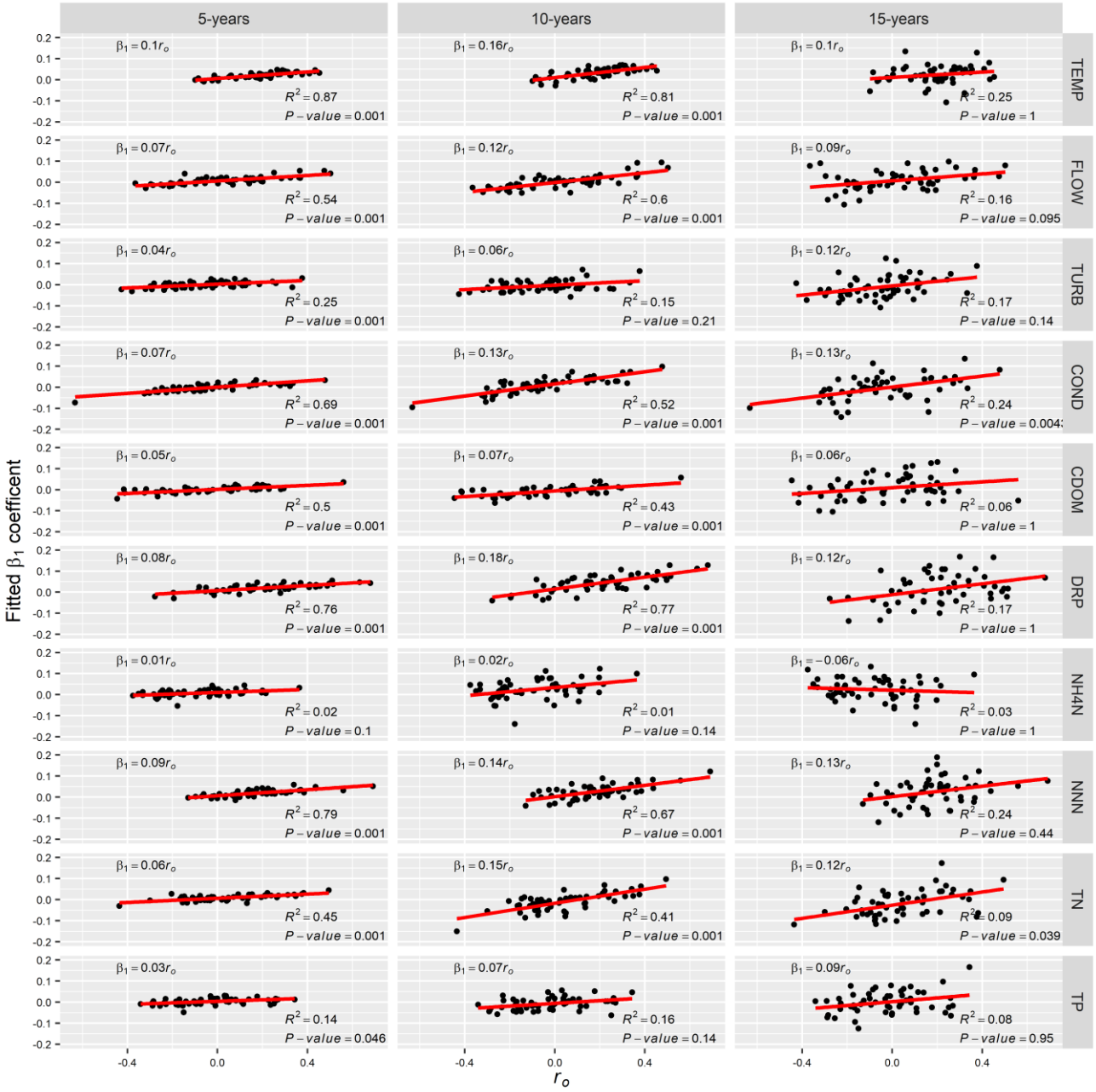

Fig. S4. Fitted β_1 coefficients for Eqn 1 indicating the relationship between τ_w and δSOI_w for each site compared to r_o values (Eqn 2). Each panel corresponds to a water quality variable (rows) and a time window duration (columns). The red line indicates a regression fitted to these data and the annotations on each panel indicate the regression equation (i.e. Eqn 2), R^2 and adjusted P-values. This figure was derived from raw water quality observations (not flow adjusted) and corresponds with Fig. 8 in the main document.

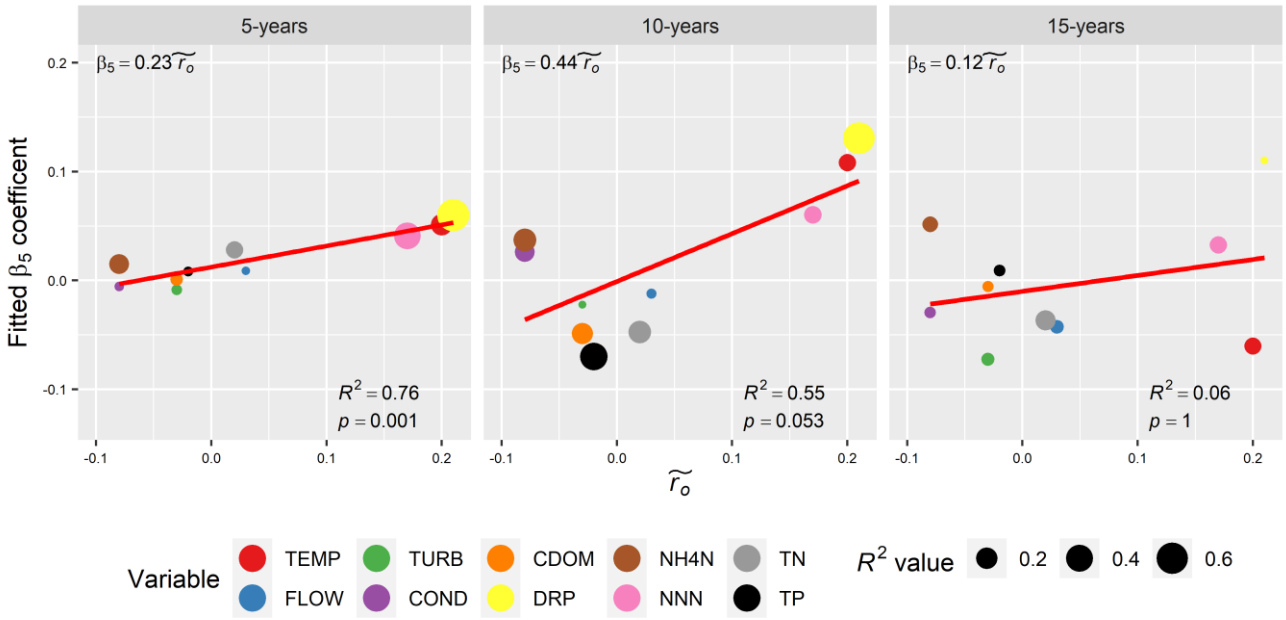

Fig. S5. Fitted β_3 coefficients for Eqn 3 indicating the relationship between P_w and δSOI_w for each variable compared to $\tilde{r}_o$ values (Eqn 4). Each panel corresponds to a duration. The red line indicates a regression fitted to these data and the annotations on each panel indicate the regression equation (i.e. Eqn 4), R^2 and adjusted P-values. Points are scaled according to each model's R^2 values for the models represented by Equation 3 This figure was derived from raw water quality observations (not flow adjusted) and corresponds with Fig. 9 in the main document.