

Appendix 17. Model Archival Summary for Total Nitrogen Concentration at U.S. Geological Survey Site 06887500, Kansas River at Wamego, Kansas, during June 2014 through September 2019

This model archival summary summarizes the total nitrogen (TN; U.S. Geological Survey [USGS] parameter codes 49570 + 62854) concentration model developed to compute 15-minute TN concentrations from June 2014 onward. This model supersedes all previous models.

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Site and Model Information

Site number: 06887500

Site name: Kansas River at Wamego, Kansas

Location: Lat 39°11'54", long 96°18'19" referenced to North American Datum of 1927, in SW 1/4 NW 1/4 SE 1/4 sec.9, T.10 S., R.10 E., Pottawatomie County, Kans., hydrologic unit 10270102.

Equipment: A YSI 6600 water-quality monitor equipped with sensors for water temperature, specific conductance, dissolved oxygen, pH, and turbidity (TBY) was installed from August 2012 through June 2014. A Xylem YSI EXO2 water-quality monitor equipped with sensors for water temperature, specific conductance, dissolved oxygen, pH, TBY, and chlorophyll (fCHL) and phycocyanin fluorescence was installed during June 2014 through September 2019. The monitor was housed in a 4-inch-diameter galvanized steel pipe. Readings from the water-quality monitor were recorded every 15 minutes and transmitted by way of satellite, hourly.

Date model was created: April 15, 2020

Model calibration data period: June 11, 2014, through September 23, 2019

Model application date: June 11, 2014, onward

Model-Calibration Dataset

All data were collected using USGS protocols (Wagner and others, 2006; U.S. Geological Survey, variously dated) and are stored in the National Water Information System (U.S. Geological Survey, 2020) database and available to the public. Ordinary least squares analysis was used to develop regression models using R programming language (R Core Team, 2020). Potential explanatory variables that were evaluated individually and in combination included streamflow, water temperature, specific conductance, dissolved oxygen, pH, TBY, fCHL, and phycocyanin fluorescence. These potential explanatory variables were interpolated within the 15-minute continuous record based on sample time. The maximum time span between two continuous data points used for interpolation was 2 hours (in order to preserve the sample dataset, field monitor averages obtained during sample collection were used for model development data if no continuous data were available or if gaps larger than 1 hour in the continuous data record resulted in missing interpolated data). Seasonal components (sine and cosine variables) were also evaluated as potential explanatory variables.

The final selected regression model was based on 74 concurrent measurements of TN concentration, sensor-measured TBY, fCHL, and seasonal components (sine and cosine variables) during June 11, 2014, through September 23, 2019. Samples were collected throughout the range of continuously observed hydrologic conditions. Total nitrogen results were calculated by combining total particulate nitrogen (USGS parameter code 49570) and total dissolved nitrogen (USGS parameter code 62854). One total particulate nitrogen sample (USGS parameter code 49570) had a concentration below the laboratory detection limit and was halved to preserve the full dataset. Summary statistics and the complete model-calibration dataset are provided below. Potential outliers were identified using the methods described in Rasmussen and others (2009). Additionally, studentized residuals from the final model were inspected for values greater than three or less than negative three. Values outside of that range were considered potential outliers and were investigated. All potential outliers were not found to have errors associated with collection, processing, or analysis and were therefore considered valid.

This model is specific to the Kansas River at Wamego, Kans., during this study period and cannot be applied to data collected from other sites on the Kansas River or data collected from other waterbodies.

Total Nitrogen Sampling Details

Cross-section samples typically were collected either from the downstream side of the bridge or instream within 100 feet of the bridge. The equal-width-increment collection method was used (although multiple vertical, single vertical, and grab samples were

occasionally collected), and samples typically were composited for analysis (U.S. Geological Survey, variously dated). During July 2012 through June 2017, cross-section samples were collected every 2 weeks during March through October, once a month during November through February, and during selected reservoir release and runoff events. During July 2017 through September 2019, cross-section samples were collected on a monthly to bimonthly basis, depending on flow conditions. A FISP US DH-81, DH-95, D-95, D-96a, or D-96 depth integrating sampler was used. Additional detail on sample collection is available in Foster and Graham (2016) and Graham and others (2018). Samples were analyzed for TN concentration at the USGS National Water Quality Laboratory in Lakewood, Colorado.

Model Development

Ordinary least squares regression analysis was done using R programming language (R Core Team, 2020) to relate discretely collected TN concentration to sensor-measured TBY, fCHL, and seasonal components (sine and cosine variables). The distribution of residuals was examined for normality, and the plots of residuals (the difference between the measured and computed values) were examined for homoscedasticity (departures from zero did not change substantially over the range of computed values). Previously published explanatory variables were also strongly considered for continuity.

TBY, fCHL, and seasonal components (sine and cosine variables) were selected as good surrogates for TN based on residual plots, coefficient of determination (R^2), and model standard percentage error. Values for all the aforementioned statistics were computed and are included below along with all relevant sample data and additional statistical information.

Model Summary

The following is a summary of final regression analysis for TN concentration at USGS site 06887500:

TN concentration-based model:

$$\log TN = 0.281 \times \log TBY - 0.184 \times \log fCHL + 0.0716 \times \sin(2\pi D) + 0.00669 \times \cos(2\pi D) - 0.154$$

where

\log = logarithm base 10;

TN = total nitrogen concentration (USGS parameter codes 49570 + 62854), in milligrams per liter;

TBY = turbidity, in formazin nephelometric units;

$fCHL$ = chlorophyll fluorescence, in relative fluorescence units;

\sin = sine;

D = date, in decimal years; and

\cos = cosine.

TBY and seasonal components (sine and cosine variables) make physical and statistical sense as explanatory variables for TN because increases in TN can be associated with precipitation runoff events which can exhibit a seasonal pattern and cause increases in TBY. fCHL also was used as an explanatory variable in the model previously published by Foster and Graham (2016).

The logarithmically (\log) transformed model may be retransformed to the original units so that TN can be calculated directly. The retransformation introduces a bias in the calculated constituent. This bias may be corrected using Duan's bias correction factor (BCF; Duan, 1983). For this model, the calculated BCF is 1.02. The retransformed model, accounting for BCF is as follows:

$$TN = 1.02 \times (TBY^{0.281} \times fCHL^{-0.184} \times 10^{[0.0716 \times \sin(2\pi D)]} \times 10^{[0.00669 \times \cos(2\pi D)]} \times 10^{-0.154})$$

Previous Models

Start Year	End Year	Model Equation	Reference
2012	2019	$\log TN = 0.314 \log TBY - 0.149 \log fCHL - 0.131$	Foster and Graham (2016)
1999	2003	$\log TN = 0.237 \log TBY - 0.179$	Rasmussen and others (2005)

Model Statistics, Data, and Plots

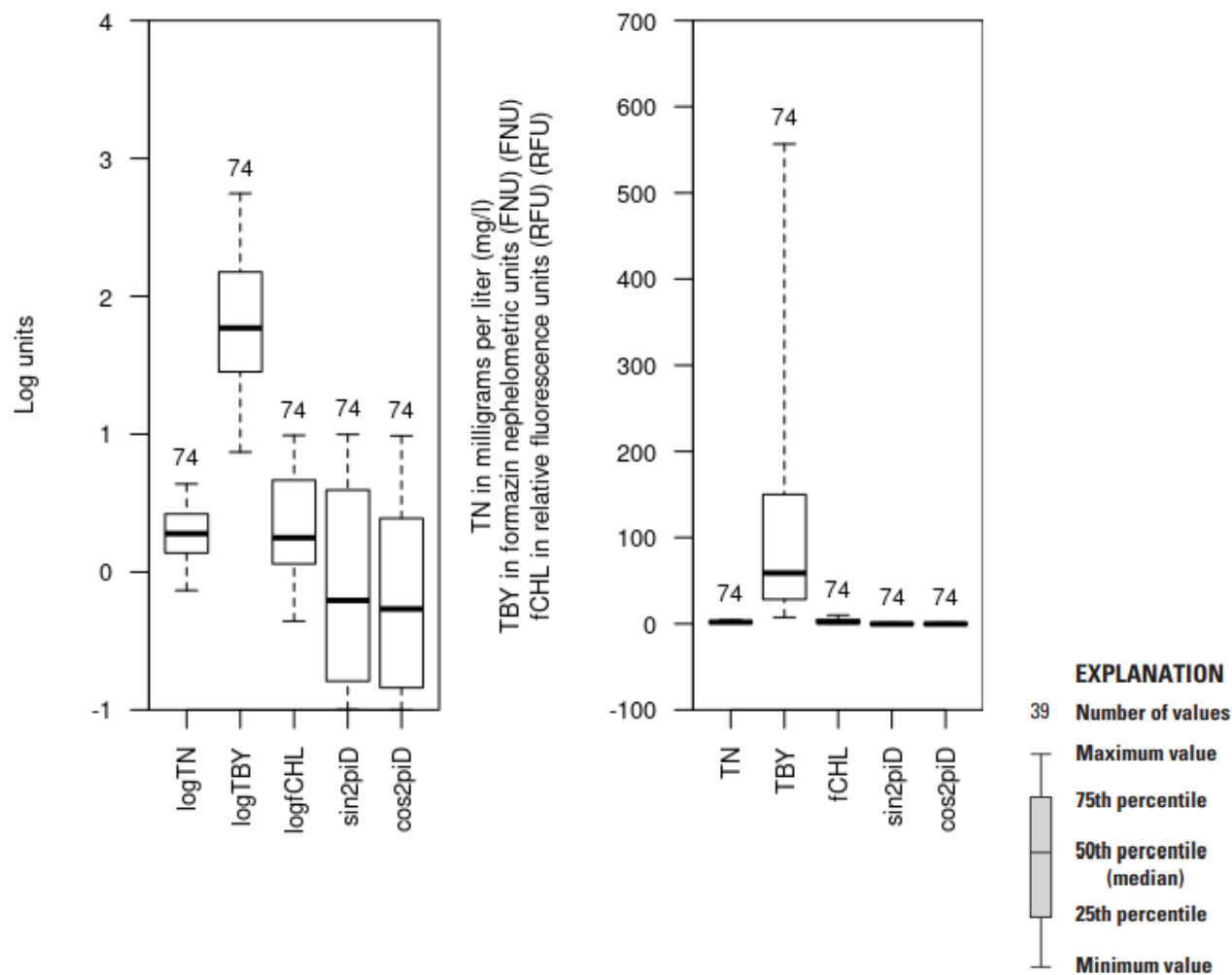
Model

$$\text{logTN} = + 0.281 * \text{logTBY} - 0.184 * \text{logfCHL} + 0.0716 * \text{sin2piD} + 0.00669 * \text{cos2piD} - 0.154$$

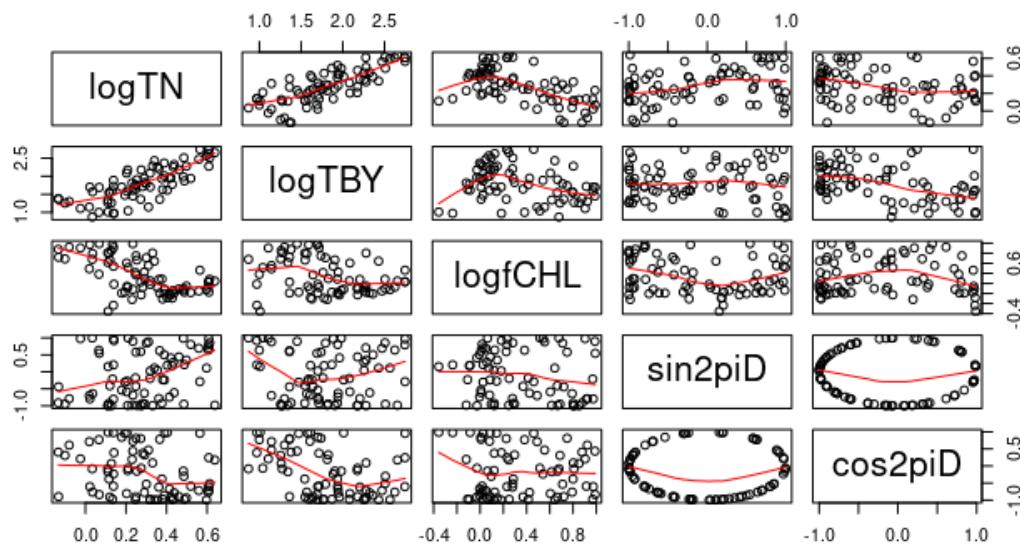
Variable Summary Statistics

	logTN	TN	logTBY	logfCHL	sin2piD	cos2piD	TBY	fCHL
Minimum	-0.134	0.735	0.87	-0.3570	-0.9980	-1.000	7.42	0.44
1st Quartile	0.138	1.370	1.45	0.0594	-0.7910	-0.838	28.30	1.15
Median	0.279	1.900	1.77	0.2490	-0.2050	-0.268	58.80	1.77
Mean	0.282	2.110	1.81	0.3460	-0.0924	-0.185	116.00	3.09
3rd Quartile	0.421	2.640	2.18	0.6670	0.5950	0.390	150.00	4.64
Maximum	0.638	4.350	2.75	0.9910	0.9980	0.988	557.00	9.80

Box Plots



Exploratory Plots



Red line shows the locally weighted scatterplot smoothing (LOWESS).

The x- and y-axis labels for a given bivariate plot are defined by the intersecting row and column labels.

Basic Model Statistics

Number of Observations	74
Standard error (RMSE)	0.0839
Average Model standard percentage error (MSPE)	19.4
Coefficient of determination (R^2)	0.824
Adjusted Coefficient of Determination (Adj. R^2)	0.814
Bias Correction Factor (BCF)	1.02

Variance Inflation Factors (VIF)

logTBY	logfCHL	sin2piD	cos2piD
1.39	1.17	1.03	1.28

Explanatory Variables

	Coefficients	Standard Error	t value	Pr(> t)
(Intercept)	-0.15400	0.0472	-3.250	1.76e-03
logTBY	0.28100	0.0238	11.800	2.99e-18
logfCHL	-0.18400	0.0301	-6.130	4.73e-08
sin2piD	0.07160	0.0141	5.060	3.29e-06
cos2piD	0.00669	0.0162	0.414	6.80e-01

Correlation Matrix

	Intercept	logTBY	logfCHL	sin2piD	cos2piD
Intercept	1.0000	-0.9560	-0.522	-0.0834	-0.4020
logTBY	-0.9560	1.0000	0.352	0.0858	0.4630
logfCHL	-0.5220	0.3520	1.000	0.1730	0.2110
sin2piD	-0.0834	0.0858	0.173	1.0000	0.0822
cos2piD	-0.4020	0.4630	0.211	0.0822	1.0000

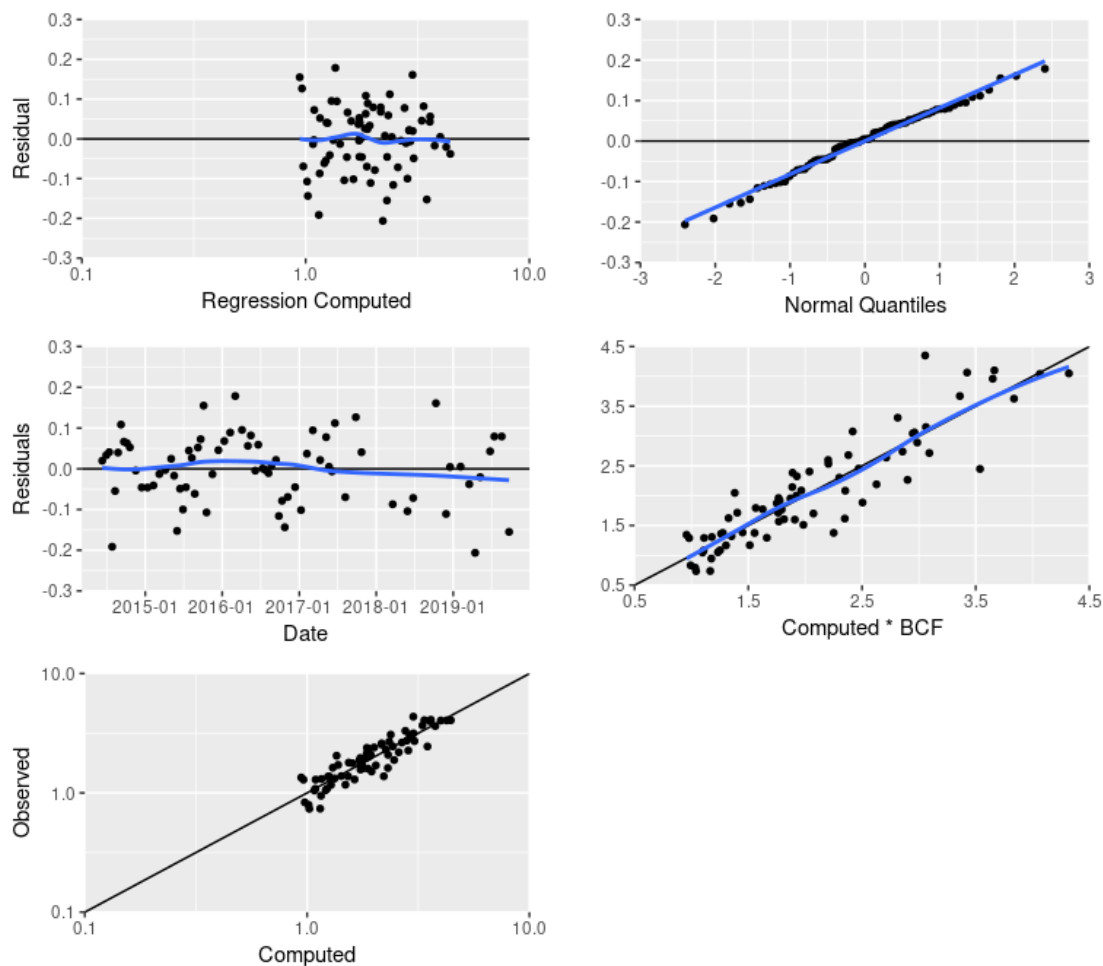
Outlier Test Criteria

Leverage	Cook's D	DFFITS
0.203	0.363	0.520

Flagged Observations

	logTN	Estimate	Residual	Standard Residual	Studentized Residual	Leverage	Cook's D	DFFITS
201407281000	-0.133	0.0589	-0.191	-2.36	-2.44	0.0658	0.0786	-0.649
201603030930	0.311	0.1330	0.178	2.21	2.27	0.0717	0.0753	0.632
201701091010	0.112	0.2130	-0.101	-1.31	-1.32	0.1460	0.0585	-0.544
201810110940	0.638	0.4780	0.161	2.02	2.07	0.1020	0.0934	0.699
201904150950	0.139	0.3450	-0.206	-2.53	-2.64	0.0566	0.0769	-0.646

Statistical Plots

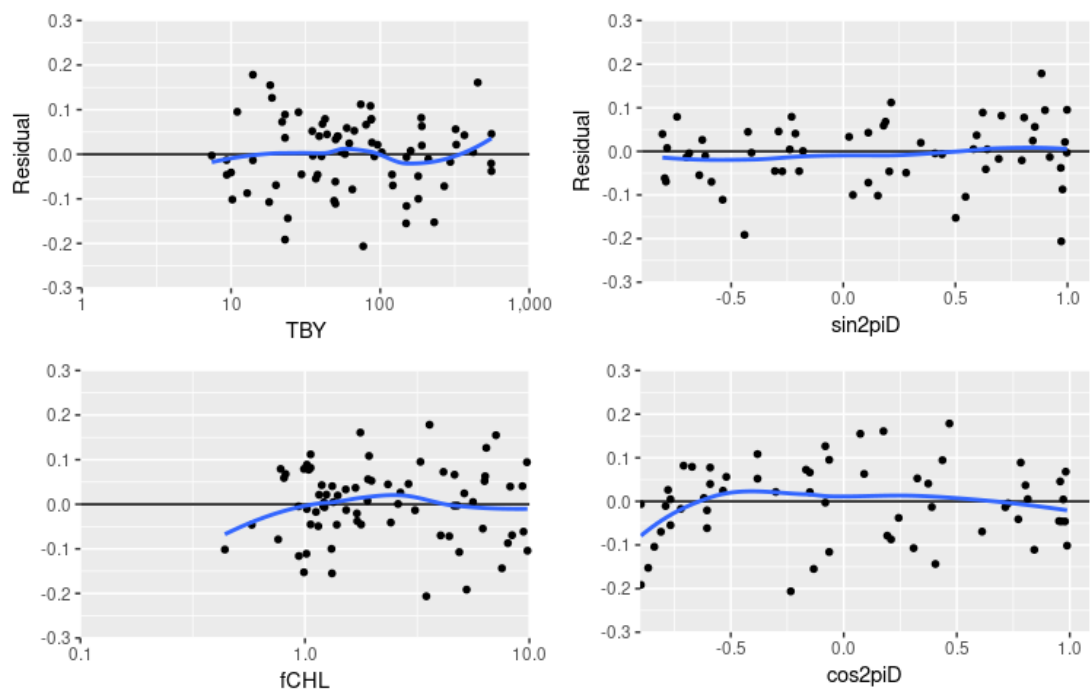


First row (left): Residual TN related to regression computed TN with local polynomial regression fitting, or locally estimated scatterplot smoothing (LOESS), indicated by the blue line.

First row (right): Residual TN related to the corresponding normal quantile of the residual with simple linear regression, indicated by the blue line.

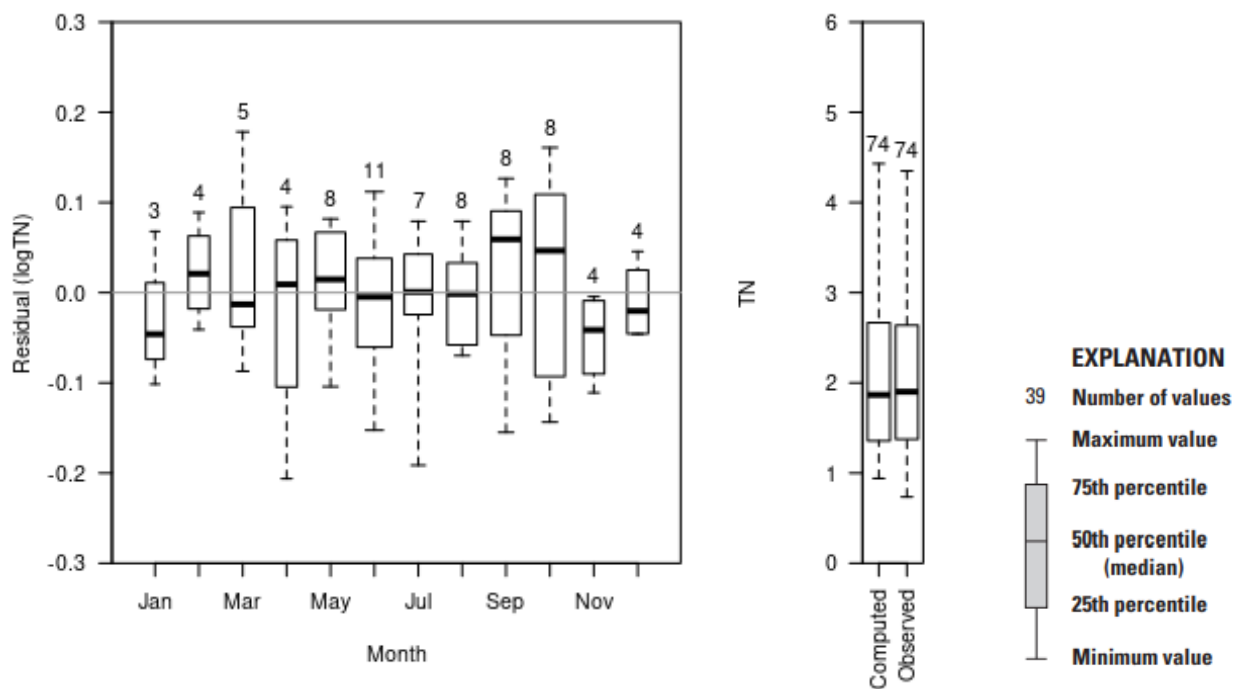
Second row: Residual TN related to date (left) and regression computed TN multiplied by the BCF (right) with LOESS, indicated by the blue line.

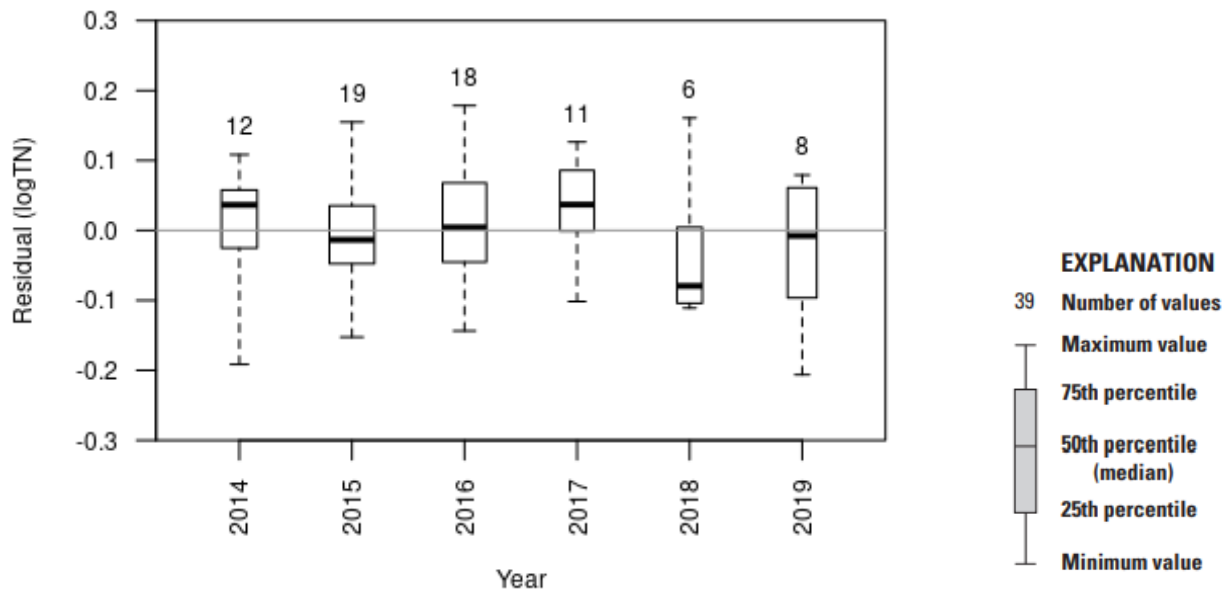
Third row: Observed TN related to regression computed TN.



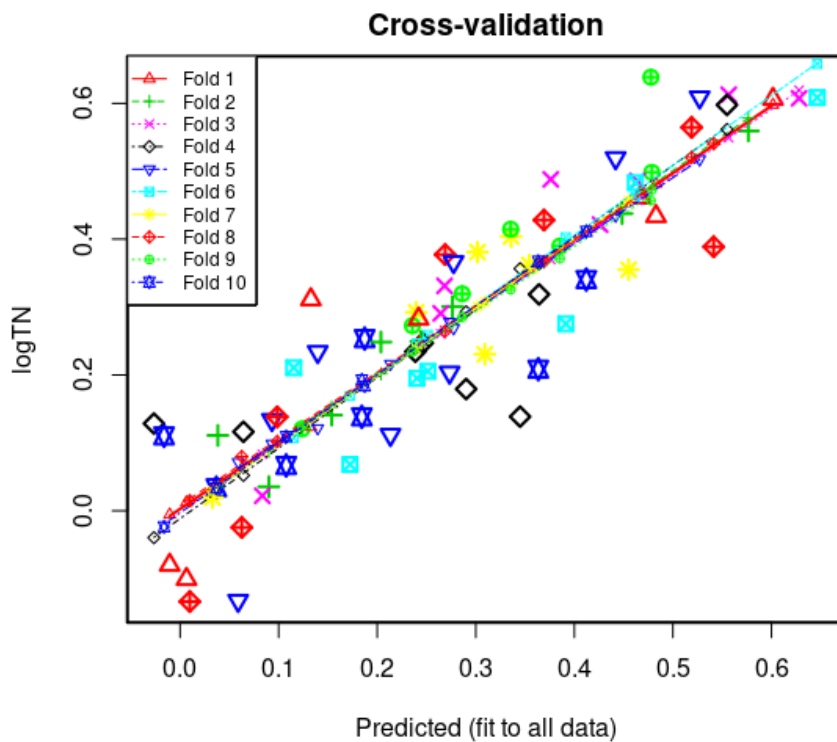
First row: Residual TN related to TBX (left) and sin2piD (right) with LOESS, indicated by the blue line.

Second row: Residual TN related to fCHL (left) and cos2piD (right) with LOESS, indicated by the blue line.





Cross-Validation



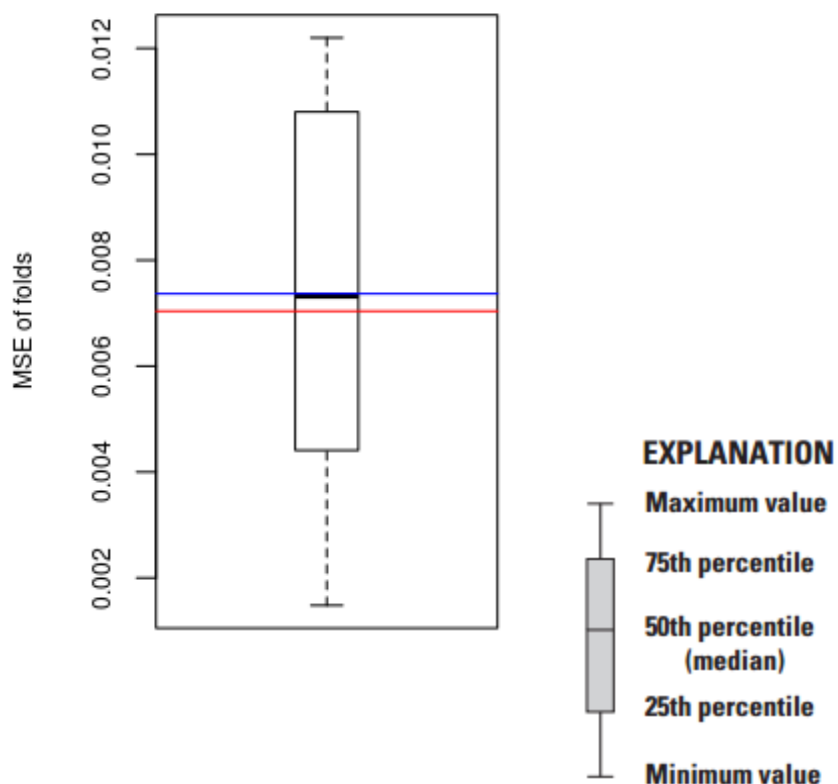
Fold - equal partition of the data (10 percent of the data).

Large symbols - observed value of a data point removed in a fold.

Small symbols - recomputed value of a data point removed in a fold.

Recomputed regression lines - adjusted regression line with one fold removed.

Minimum MSE of folds: 0.00148
Mean MSE of folds: 0.00737
Median MSE of folds: 0.00733
Maximum MSE of folds: 0.01220
(Mean MSE of folds) / (Model MSE): 1.05000



Red line - Model MSE

Blue line - Mean MSE of folds

Model-Calibration Dataset

0	Date	logTN	logTBY	logfCHL	sin2piD	cos2piD	TN	TBY	fCHL	Computed logTN	Computed TN	Residual	Normal Quantiles	Censored Values
1	2014-06-11	0.498	2.28	0.146	0.346	-0.938	3.15	190	1.4	0.479	3.06	0.0197	0.119	--
2	2014-06-30	0.32	1.7	0.182	0.0258	-1	2.09	50.2	1.52	0.286	1.97	0.0333	0.291	--
3	2014-07-14	0.134	1.59	0.969	-0.214	-0.977	1.36	39	9.31	0.0932	1.26	0.0407	0.436	--
4	2014-07-28	-0.133	1.36	0.72	-0.441	-0.898	0.737	23	5.25	0.0589	1.16	-0.191	-2.02	--
5	2014-08-11	0.0354	1.57	0.792	-0.642	-0.767	1.08	37	6.2	0.0901	1.25	-0.0546	-0.715	--
6	2014-08-25	0.138	1.72	0.914	-0.806	-0.591	1.37	52	8.21	0.0985	1.28	0.0398	0.362	--
7	2014-09-08	0.377	1.93	0.286	-0.924	-0.382	2.38	86	1.93	0.269	1.89	0.108	1.44	--
8	2014-09-22	0.254	1.9	0.667	-0.989	-0.15	1.79	80.3	4.64	0.187	1.57	0.0663	0.806	--
9	2014-10-06	0.331	2.28	0.803	-0.996	0.0903	2.14	190	6.35	0.268	1.89	0.0629	0.76	--
10	2014-10-20	0.292	1.83	0.297	-0.946	0.325	1.96	67	1.98	0.24	1.77	0.0527	0.631	--
11	2014-11-17	0.234	1.61	0.0816	-0.687	0.727	1.71	40.4	1.21	0.239	1.76	-0.00442	-0.153	--
12	2014-12-15	0.205	1.58	0.142	-0.272	0.962	1.61	38	1.39	0.251	1.81	-0.0459	-0.59	--
13	2015-01-12	0.138	0.971	-0.237	0.205	0.979	1.37	9.36	0.58	0.184	1.56	-0.0461	-0.631	< 0.03
14	2015-02-09	0.0667	1	0.383	0.635	0.772	1.17	10	2.41	0.108	1.3	-0.041	-0.473	--
15	2015-03-09	0.141	0.97	0.184	0.921	0.39	1.38	9.33	1.53	0.154	1.45	-0.013	-0.291	--
16	2015-04-06	0.0338	0.87	0.679	0.997	-0.0817	1.08	7.42	4.77	0.0368	1.11	-0.00296	-0.0846	--
17	2015-05-04	0.301	1.79	0.71	0.845	-0.534	2	62	5.13	0.276	1.92	0.0245	0.221	--
18	2015-05-18	0.559	2.47	0.0492	0.693	-0.721	3.63	295	1.12	0.577	3.84	-0.0171	-0.362	--
19	2015-06-01	0.389	2.36	-0.00436	0.501	-0.865	2.45	230	0.99	0.541	3.54	-0.153	-1.66	--
20	2015-06-15	0.434	2.25	0.0594	0.28	-0.96	2.72	180	1.15	0.483	3.09	-0.0491	-0.672	--
21	2015-06-29	0.355	2.26	0.118	0.043	-0.999	2.26	180	1.31	0.455	2.9	-0.1	-1.07	--
22	2015-07-13	0.319	2.08	0.25	-0.197	-0.98	2.08	120	1.78	0.364	2.35	-0.0455	-0.55	--
23	2015-07-27	0.248	1.64	0.37	-0.425	-0.905	1.77	44	2.34	0.204	1.63	0.0447	0.511	--
24	2015-08-10	0.291	1.94	0.425	-0.629	-0.778	1.95	88	2.66	0.264	1.87	0.0263	0.256	--
25	2015-08-24	0.022	1.7	0.974	-0.796	-0.605	1.05	50	9.41	0.0834	1.23	-0.0614	-0.76	--
26	2015-09-08	0.116	1.54	0.8	-0.924	-0.382	1.31	35	6.31	0.0642	1.18	0.052	0.59	--
27	2015-09-21	0.111	1.34	0.617	-0.986	-0.167	1.29	22	4.14	0.0383	1.11	0.0726	0.903	--
28	2015-10-05	0.128	1.26	0.851	-0.997	0.0731	1.34	18.3	7.1	-0.0265	0.957	0.155	1.81	--

29	2015-10-19	-0.101	1.26	0.688	-0.951	0.309	0.793	18	4.87	0.0065	1.03	-0.107	-1.27	--
30	2015-11-16	0.0195	1.15	0.49	-0.699	0.715	1.05	14	3.09	0.0329	1.1	-0.0134	-0.327	--
31	2015-12-14	0.565	2.75	0.461	-0.288	0.957	3.67	557	2.89	0.519	3.36	0.0457	0.55	--
32	2016-01-11	0.404	1.61	-0.0862	0.188	0.982	2.53	41	0.82	0.336	2.2	0.068	0.853	--
33	2016-02-08	0.366	1.36	0.0086	0.622	0.783	2.32	23	1.02	0.277	1.93	0.089	1.2	--
34	2016-03-03	0.311	1.15	0.555	0.884	0.467	2.05	14	3.59	0.133	1.38	0.178	2.4	--
35	2016-04-04	0.211	1.04	0.515	0.998	-0.0645	1.62	11	3.27	0.115	1.33	0.0953	1.35	--
36	2016-05-02	0.613	2.51	0.281	0.854	-0.52	4.1	320	1.91	0.557	3.66	0.0562	0.672	--
37	2016-05-16	0.609	2.27	0.0253	0.706	-0.709	4.06	188	1.06	0.527	3.42	0.0818	1.13	--
38	2016-06-06	0.421	1.96	-0.0284	0.409	-0.912	2.64	91.3	0.937	0.426	2.71	-0.00466	-0.187	--
39	2016-06-20	0.428	1.78	-0.0933	0.18	-0.984	2.68	59.7	0.807	0.369	2.38	0.059	0.715	--
40	2016-07-11	0.247	1.76	0.415	-0.18	-0.984	1.77	58	2.6	0.246	1.79	0.000775	-0.0507	--
41	2016-07-25	0.121	1.55	0.664	-0.409	-0.912	1.32	35.3	4.62	0.124	1.35	-0.00317	-0.119	--
42	2016-08-08	0.438	2.32	0.0086	-0.615	-0.788	2.74	210	1.02	0.448	2.86	-0.0107	-0.256	--
43	2016-08-22	0.362	2.2	0.279	-0.786	-0.619	2.3	160	1.9	0.354	2.3	0.0078	0.0846	--
44	2016-09-12	0.486	2.51	0.0958	-0.954	-0.301	3.06	323	1.25	0.464	2.96	0.0217	0.187	--
45	2016-09-26	0.275	2.18	-0.0269	-0.998	-0.0645	1.89	150	0.94	0.391	2.5	-0.116	-1.44	--
46	2016-10-11	0.23	1.81	-0.119	-0.981	0.192	1.7	65	0.76	0.309	2.07	-0.0787	-0.955	--
47	2016-10-24	-0.134	1.38	0.878	-0.914	0.405	0.735	24	7.54	0.00986	1.04	-0.144	-1.54	--
48	2016-11-07	-0.0799	1.3	0.923	-0.791	0.612	0.832	20	8.37	-0.0105	0.993	-0.0693	-0.806	--
49	2016-12-12	0.195	1.47	0.0253	-0.305	0.952	1.57	29.7	1.06	0.24	1.77	-0.0452	-0.511	--
50	2017-01-09	0.112	1.01	-0.357	0.154	0.988	1.29	10.2	0.44	0.213	1.66	-0.101	-1.13	--
51	2017-02-06	0.273	1.36	0.225	0.595	0.804	1.87	23	1.68	0.236	1.75	0.0369	0.327	--
52	2017-03-06	0.234	1.45	0.989	0.9	0.437	1.71	28.3	9.75	0.14	1.4	0.0944	1.27	--
53	2017-04-10	0.483	1.98	0.0632	0.989	-0.15	3.04	96	1.16	0.462	2.95	0.0213	0.153	--
54	2017-05-08	0.519	1.94	0.017	0.806	-0.591	3.31	86.7	1.04	0.442	2.81	0.0775	0.955	--
55	2017-05-22	0.606	2.62	0.126	0.642	-0.767	4.04	420	1.34	0.602	4.06	0.00485	0.0169	--
56	2017-06-05	0.461	2.18	0.0875	0.441	-0.898	2.89	150	1.22	0.468	2.99	-0.00657	-0.221	--
57	2017-06-19	0.488	1.87	0.0253	0.214	-0.977	3.08	74	1.06	0.376	2.42	0.112	1.54	--
58	2017-08-07	0.204	2.08	0.605	-0.588	-0.809	1.6	121	4.02	0.273	1.91	-0.0698	-0.853	--
59	2017-09-26	0.11	1.27	0.808	-0.997	-0.0817	1.29	18.8	6.43	-0.0163	0.98	0.127	1.66	--
60	2017-10-23	0.283	1.71	0.122	-0.928	0.374	1.92	51.8	1.32	0.242	1.78	0.0406	0.399	--
61	2018-03-20	-0.0246	1.11	0.904	0.978	0.209	0.945	12.8	8.02	0.0626	1.17	-0.0872	-1.01	--
62	2018-05-29	0.0682	1.69	0.991	0.545	-0.838	1.17	49.1	9.8	0.172	1.51	-0.104	-1.2	--
63	2018-06-25	0.34	2.43	0.643	0.112	-0.994	2.19	269	4.39	0.412	2.63	-0.0717	-0.903	--
64	2018-10-11	0.638	2.65	0.247	-0.984	0.176	4.35	450	1.77	0.478	3.06	0.161	2.02	--
65	2018-11-28	0.179	1.7	0.0068	-0.538	0.843	1.51	50.1	1.02	0.29	1.98	-0.111	-1.35	--
66	2018-12-17	0.39	2.01	0.0849	-0.239	0.971	2.45	102	1.22	0.385	2.47	0.00449	-0.0169	--
67	2019-02-05	0.249	1.74	0.749	0.581	0.814	1.78	54.8	5.61	0.244	1.79	0.00516	0.0507	--
68	2019-03-18	0.609	2.75	0.233	0.97	0.243	4.06	557	1.71	0.646	4.51	-0.0379	-0.436	--
69	2019-04-15	0.139	1.89	0.541	0.972	-0.234	1.38	76.9	3.47	0.345	2.25	-0.206	-2.4	--
70	2019-05-09	0.607	2.74	0.232	0.796	-0.605	4.05	554	1.7	0.628	4.32	-0.0206	-0.399	--
71	2019-06-25	0.598	2.56	0.0751	0.112	-0.994	3.96	367	1.19	0.555	3.65	0.0429	0.473	--
72	2019-07-15	0.381	1.63	-0.108	-0.23	-0.973	2.4	42.7	0.78	0.302	2.04	0.0793	1.07	--
73	2019-08-19	0.415	1.94	-0.00436	-0.741	-0.671	2.6	87.3	0.99	0.335	2.2	0.0792	1.01	--
74	2019-09-23	0.208	2.17	0.121	-0.991	-0.133	1.62	149	1.32	0.363	2.35	-0.155	-1.81	--

Definitions

Cook's D: Cook's distance (Helsel and others, 2020).

D: Date, in decimal years.

DFFITS: Difference in fits statistic (Helsel and others, 2020).

E.vars: Explanatory variables.

fCHL: Chlorophyll fluorescence, in relative fluorescence units (32320).

Leverage: An outlier's measure in the x direction (Helsel and others, 2020).

LOESS: Local polynomial regression fitting, or locally estimated scatterplot smoothing (Helsel and others, 2020).

LOWESS: Locally weighted scatterplot smoothing (Cleveland, 1979; Helsel and others, 2020).

MSE: Model standard error (Helsel and others, 2020).

MSPE: Model standard percentage error (Helsel and others, 2020).

Probability(>|t|): The probability that the independent variable has no effect on the dependent variable (Helsel and others, 2020).

RMSE: Root mean square error (Helsel and others, 2020).

SC: Specific conductance, in microsiemens per centimeter at 25 degrees Celsius (00095).
t value: Student's t value; the coefficient divided by its associated standard error (Helsel and others, 2020).
TBY: Turbidity, in formazin nephelometric units (63680).
TN: total particulate nitrogen (49570) plus total dissolved nitrogen (62854), in milligrams per liter.

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