Appendix 2.21. Model Archive Summary for Total Phosphorus Concentration at U.S. Geological Survey site 07144100; Little Arkansas River near Sedgwick, Kansas, during October 2014 through December 2019

This model archive summary summarizes the total phosphorus model developed to compute hourly or daily total phosphorus. This model supersedes all models used during 1999 through 2014. Model development methods follow U.S. Geological Survey (USGS) guidance from Office of Surface Water/Office of Water Quality Technical Memoranda and USGS Techniques and Methods, book 3, chap. C4 (Rasmussen and others, 2009).

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Site and Model Information

Site Number: 07144100

Site Name: Little Arkansas River near Sedgwick, Kansas

Location: Latitude 37°52'59", longitude 97°25'27" referenced to North American Datum of 1927, in NE 1/4 NW 1/4 NW 1/4 sec.15, T.25 S., R.1 W., Sedgwick County, Kansas; hydrologic unit 11030012.

Equipment: A Sutron Satlink II High Data Rate Collection Platform and a Design Analysis Water Log H350/355 nonsubmersible pressure transducer transfers real-time stage and water-quality data via satellite. The primary reference gage is a Type-A wire-weight gage located on the downstream bridge handrail. Check-bar elevation is 33.614 feet. The orifice is enclosed in a well-screen and attached to a concrete pier on the left downstream side of the bridge. Gage height was measured during October 2014 through December 2019. A YSI 6600 water-quality monitor equipped with water temperature, specific conductance, pH, dissolved oxygen, and turbidity (a YSI Model 6026 [September 1998 through December 2006] and YSI Model 6136 [July 2004 through March 2015]) sensors collected data during April 1998 through March 2015. A YSI EXO2 water-quality monitor equipped with water temperature, specific conductance, pH, dissolved oxygen, turbidity, and fluorescent dissolved organic matter sensors collected data during September 2014 through December 2019. A Hach Nitratax monitor collected nitrate data during March 2012 through December 2019.

Date model was developed: June 1, 2020

Model calibration data period: October 16, 2014 through December 11, 2019

Model Data

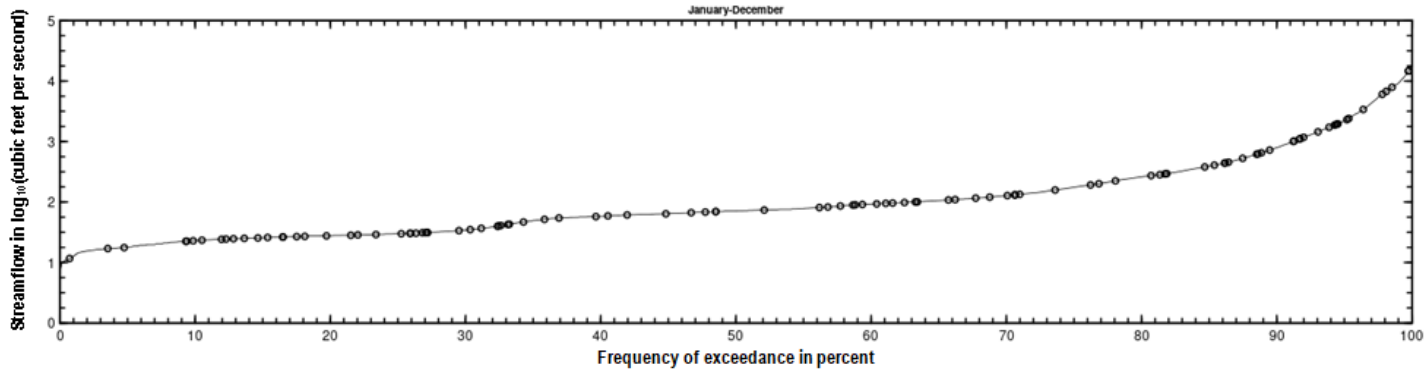
All data were collected using USGS protocols (U.S. Geological Survey, variously dated; Wagner and others, 2006; Sauer and Turnipseed, 2010; Turnipseed and Sauer, 2010) and are stored in the National Water Information System (NWIS) database (U.S. Geological Survey, 2021). Explanatory variables were evaluated individually and in combination. Potential explanatory variables included streamflow, water temperature, specific conductance, pH, dissolved oxygen, YSI EXO2 turbidity, nitrate, and fluorescent dissolved organic matter. Seasonal components (sine and cosine variables) also were evaluated as explanatory variables.

The regression model is based on 111 concomitant values of discretely collected total phosphorus and continuously measured turbidity during October 2014 through December 2019. Discrete samples were collected over a range of streamflow and turbidity conditions. No samples had concentrations that were below laboratory detection limits. Summary statistics and the complete model-calibration dataset are provided below. Outliers and influential points were identified using studentized residuals, DFITS, Cook's D (Cook, 1977), and leverage. Outliers in previously published versions of this model (Christensen and others, 2003; Rasmussen and others, 2016) were examined and retained in the dataset if there were no clear issues, explanations, or conditions that would cause a result to be invalid for model calibration. All samples were retained in the dataset.

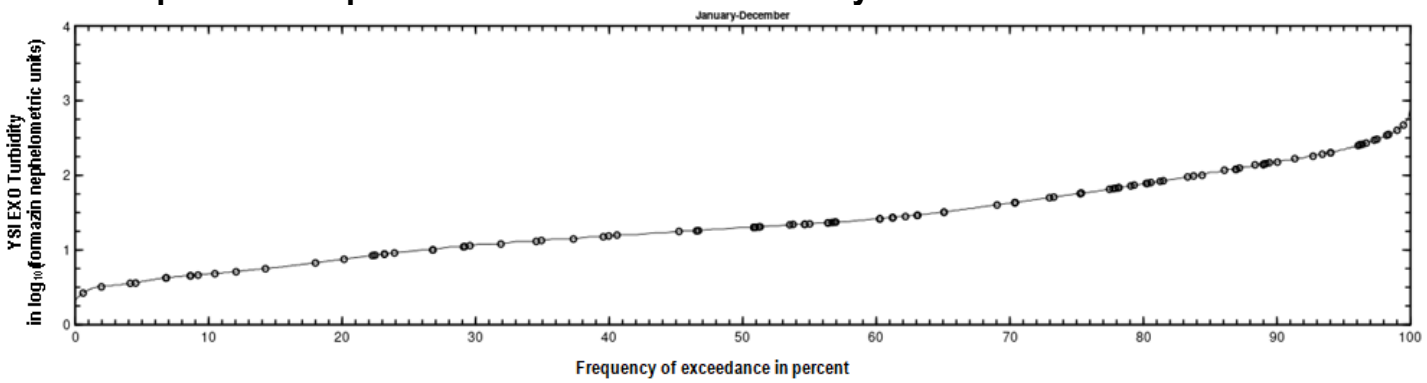
Total Phosphorus

Discrete samples were collected from the downstream side of the bridge or instream within 50 feet of the bridge using equal-width-increment, multi-vertical, single vertical or grab-dip methods following U.S. Geological Survey (variously dated) and Rasmussen and others (2014). Discrete samples were collected on a semifixed to event-based schedule ranging from 5 to 17 samples per year with a FISP US DH–95 or D–95 with a Teflon bottle, cap, and nozzle depth-integrating sampler, a DH–81 with a Teflon bottle, cap, and nozzle hand sampler or a grab sample with a Teflon bottle depending on sample location. Samples were analyzed for total phosphorus by the USGS National Water Quality Laboratory according to standard methods (American Public Health Association and others, 1995).

Total Phosphorus Samples Plotted on Streamflow Duration Curve



Total Phosphorus Samples Plotted on YSI EXO Turbidity Duration Curve



Continuous Data

Concomitant turbidity values were time interpolated. If no concomitant continuous data were available within 2 hours of sample collection, the sample was not included in the dataset.

Model Development

Ordinary least squares regression analysis was done using R (version 4.0.0) programming language (R Core Team, 2020) to relate discretely collected total phosphorus to turbidity and other continuously measured data. The distribution of residuals was examined for normality and plots of residuals (the difference between the measured and model calculated values) compared to model-computed total phosphorus were examined for homoscedasticity (departures from zero did not change substantially over the range of model calculated values). Previously published explanatory variables were also strongly considered for continuity; however, the best explanatory variable(s) were ultimately selected.

Turbidity was selected as the best predictor of total phosphorus based on residual plots, high coefficient of determination (R^2), and low model standard percentage error (MSPE). Turbidity was positively correlated with total phosphorus because turbidity measures light scattered by particulates in water.

Model Summary

Summary of final total phosphorus regression analysis at USGS site number 07144100:

Total phosphorus-based model:

$$\log_{10}(TP) = 0.236 \times \log_{10}(TBY) - 0.613$$

where,

$\log_{10}$ = logarithm base 10;
TP = total phosphorus, in milligrams per liter (mg/L); and
TBY = turbidity, in formazin nephelometric units (FNU)

The log-transformed model may be retransformed to original units so that TP 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:

$$TP = 0.2487 \times TBY^{0.236}$$

Model Statistics, Data, and Plots

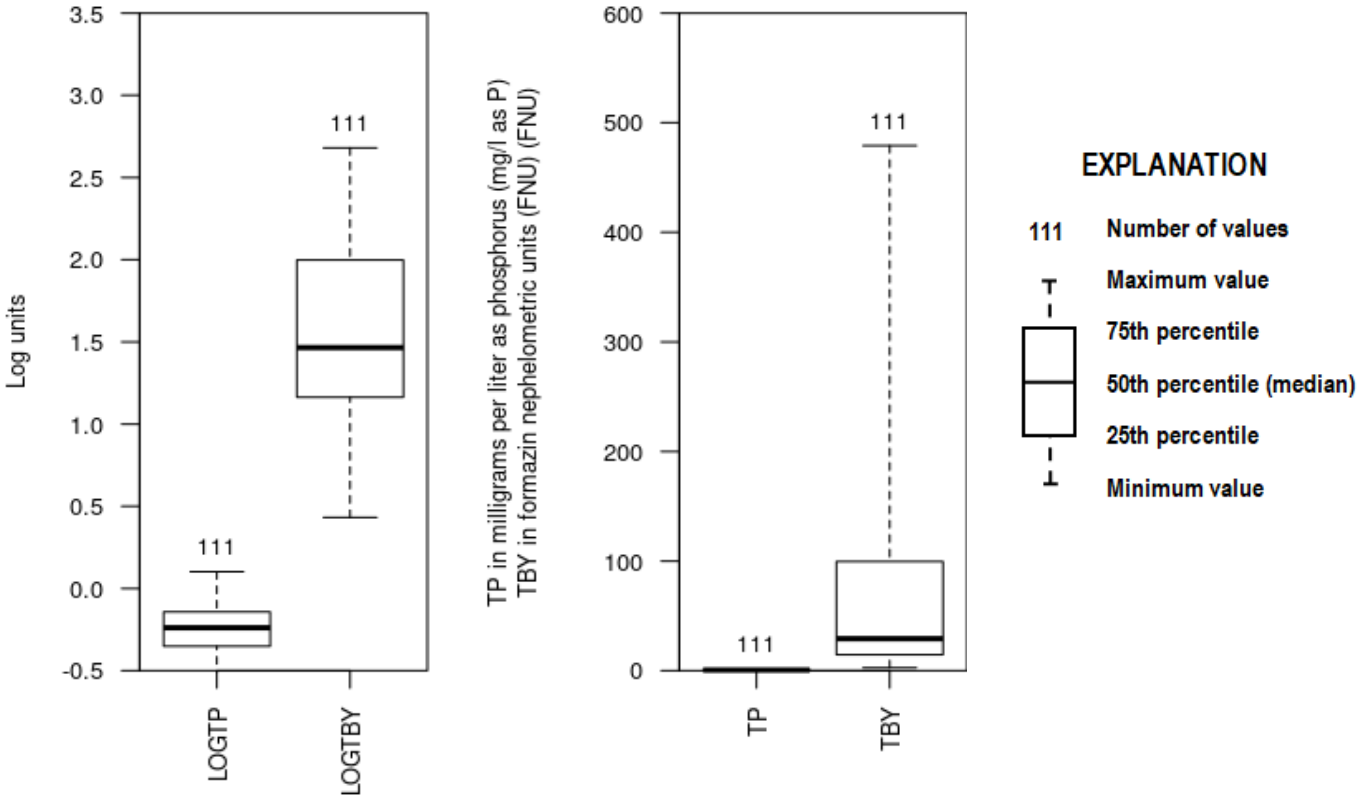
Model

LOGTP = + 0.236 * LOGTBY - 0.613

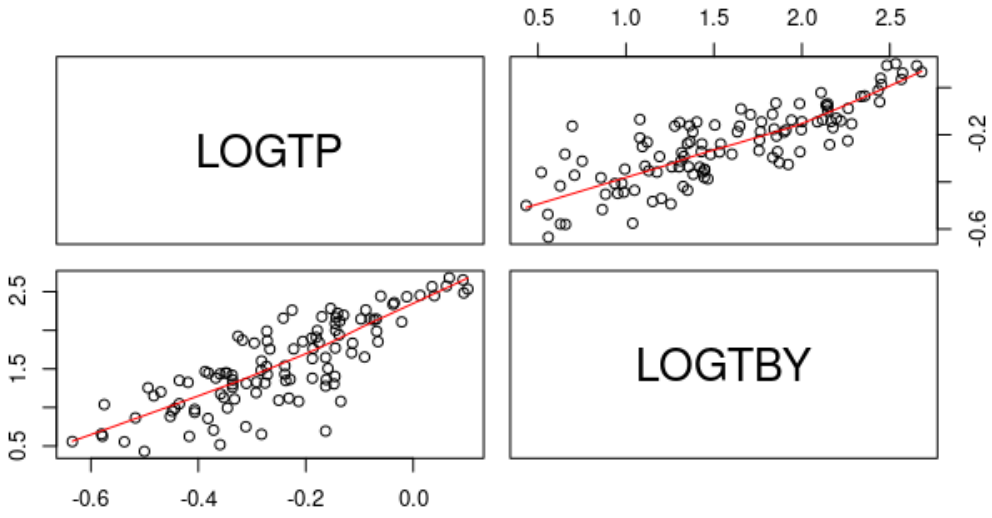
Variable Summary Statistics

	LOGTP	TP	LOGTBY	TBY
Minimum	-0.635	0.232	0.432	2.71
1st Quartile	-0.353	0.444	1.150	14.20
Median	-0.239	0.577	1.470	29.20
Mean	-0.243	0.612	1.570	79.20
3rd Quartile	-0.141	0.723	2.000	100.00
Maximum	0.102	1.260	2.680	479.00

Box Plots



Exploratory Plots



Basic Model Statistics

Number of Observations	111
Standard error (RMSE)	0.0926
Average Model standard percentage error (MSPE)	21.5
Coefficient of determination (R^2)	0.675
Adjusted Coefficient of Determination (Adj. R^2)	0.672
Bias Correction Factor (BCF)	1.02

Explanatory Variables

	Coefficients	Standard Error	t value	Pr(>|t|)
(Intercept)	-0.613	0.0262	-23.4	2.16e-44
LOGTBY	0.236	0.0157	15.1	2.25e-28

Correlation Matrix

	Intercept	E.vars
Intercept	1.000	-0.942
E.vars	-0.942	1.000

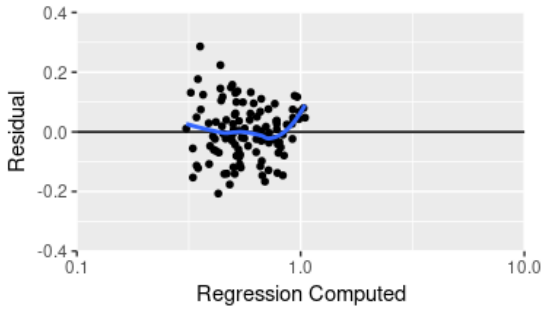
Outlier Test Criteria

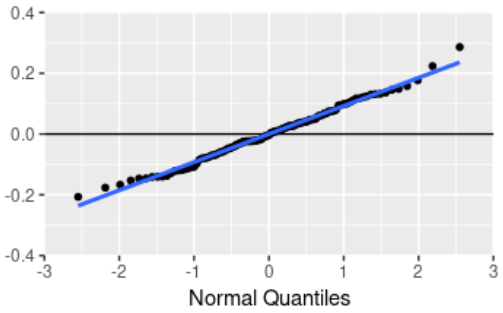
Leverage	Cook's D	DFFITS
0.0541	0.1944	0.2685

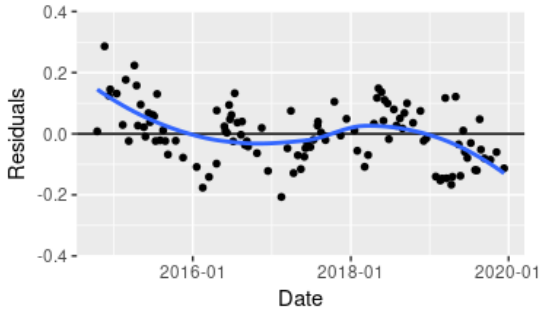
Flagged Observations

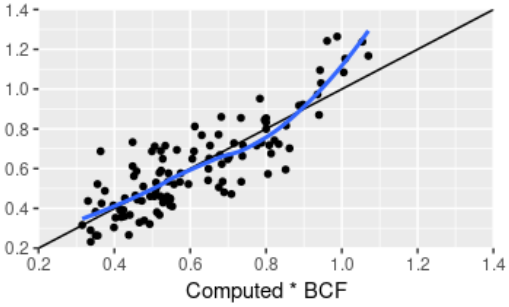
	LOGTP	Estimate	Residual	Standard Residual	Studentized Residual	Leverage	Cook's D	DFFITS
11/19/2014 10:30	-0.163	-0.449	0.286	3.14	3.28	0.031	0.158	0.586
1/14/2015 9:20	-0.36	-0.491	0.131	1.45	1.46	0.0407	0.0445	0.3
2/25/2015 11:20	-0.282	-0.459	0.177	1.94	1.97	0.0331	0.0645	0.364
4/6/2015 12:35	-0.135	-0.359	0.224	2.43	2.49	0.0159	0.0479	0.317
2/14/2017 11:10	-0.575	-0.368	-0.207	-2.25	-2.3	0.0171	0.0442	-0.303
2/19/2019 10:30	-0.635	-0.481	-0.153	-1.69	-1.7	0.0383	0.0566	-0.339

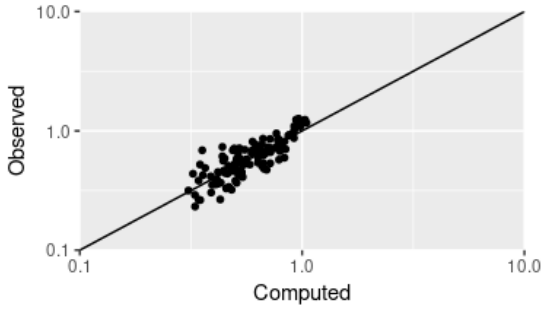
Statistical Plots

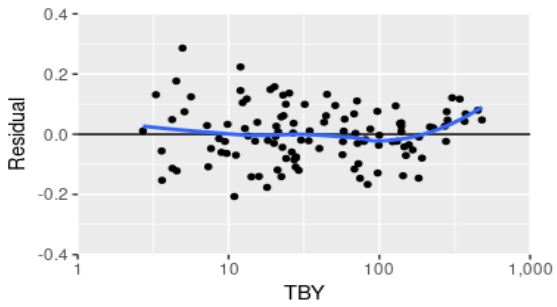


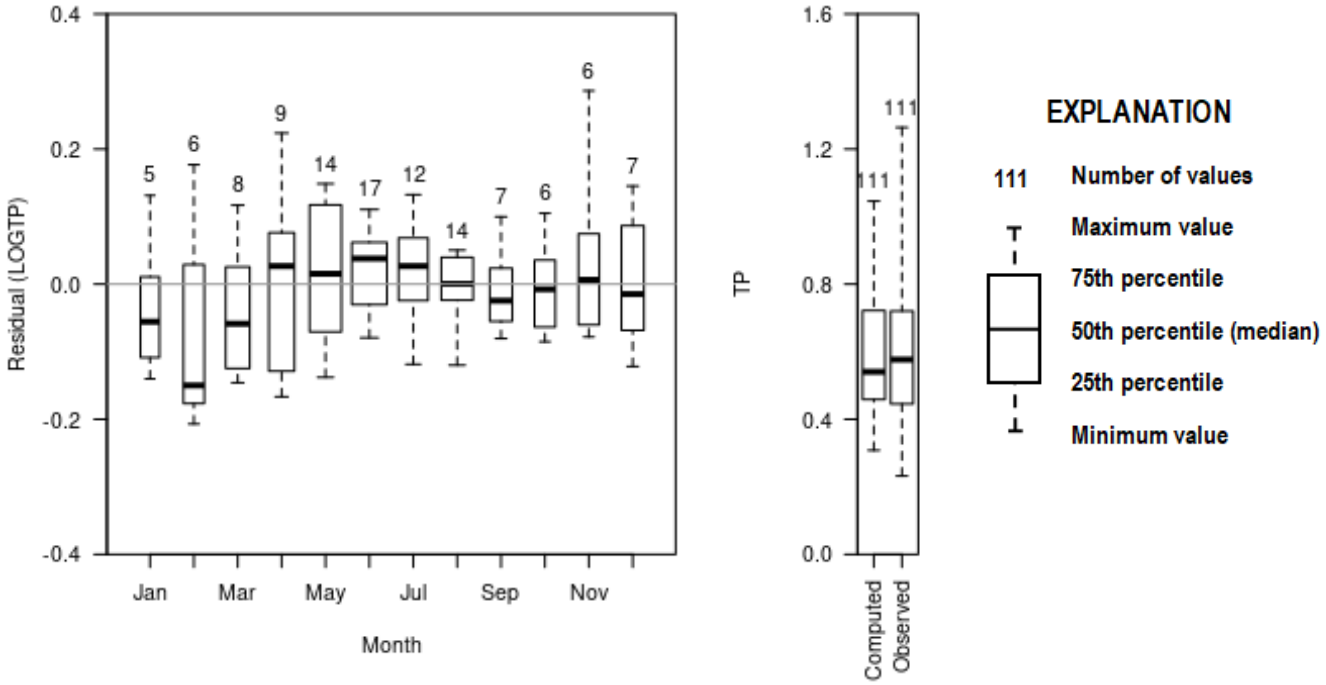


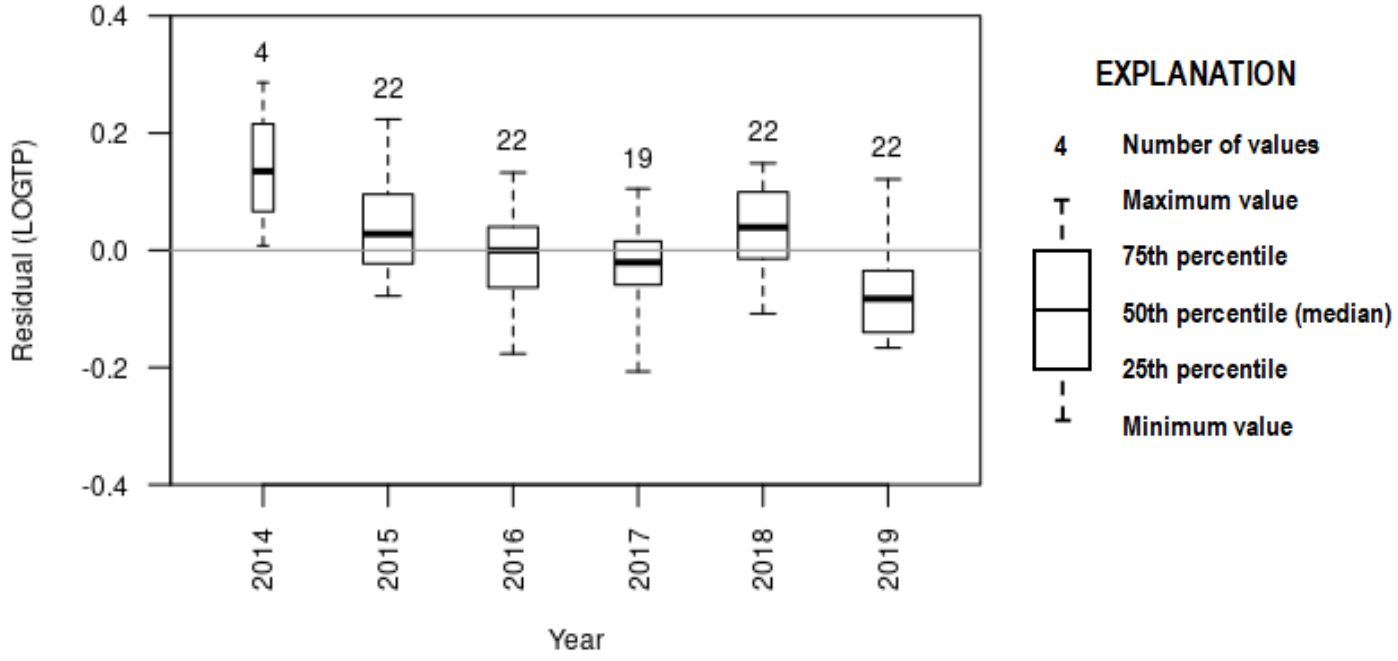




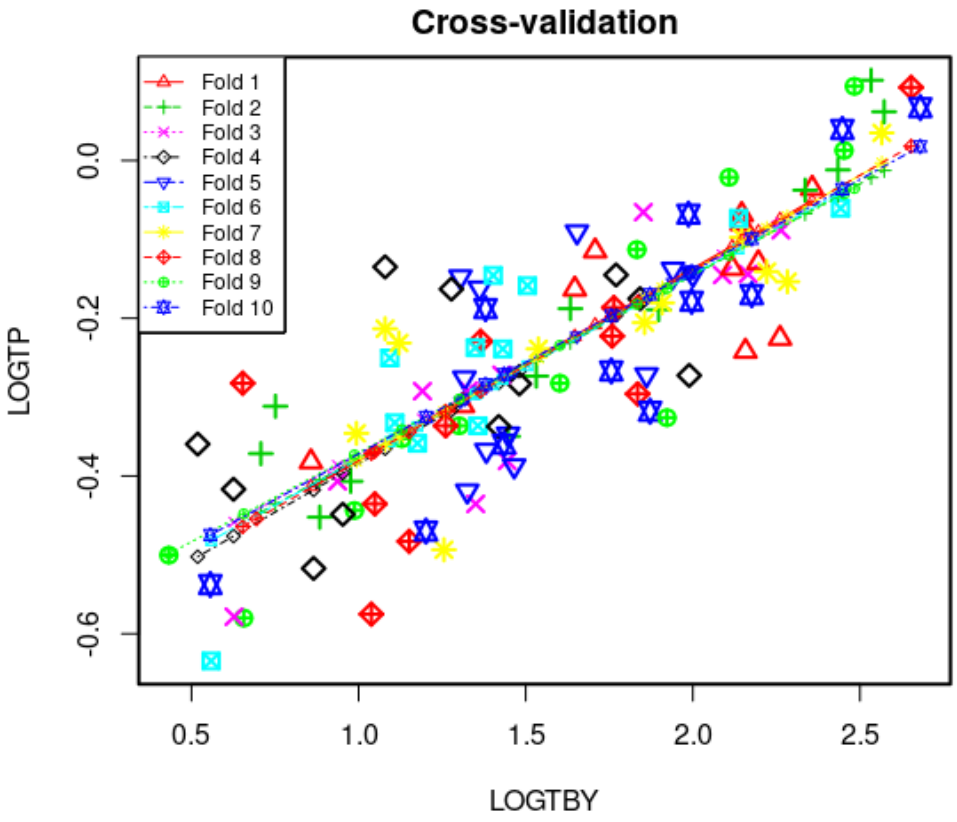





Residual (LOGTP)
0.4
0.2
0.0
-0.2
-0.4
5
6
8
9
14
17
12
14
7
6
6
7
Jan
Mar
May
Jul
Sep
Nov
Month
TP
1.6
1.2
0.8
0.4
0.0
111
111
Computed
Observed
EXPLANATION
111
Number of values
Maximum value
75th percentile
50th percentile (median)
25th percentile
Minimum value


Residual (LOGTP)
0.4
0.2
0.0
-0.2
-0.4
4
22
22
19
22
22
2014
2015
2016
2017
2018
2019
Year
EXPLANATION
4
Number of values
Maximum value
75th percentile
50th percentile (median)
25th percentile
Minimum value

Cross Validation

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             Minimum MSE of folds:  0.00457
                Mean MSE of folds:  0.00872
              Median MSE of folds:  0.00763
             Maximum MSE of folds:  0.01880
(Mean MSE of folds) / (Model MSE):  1.02000
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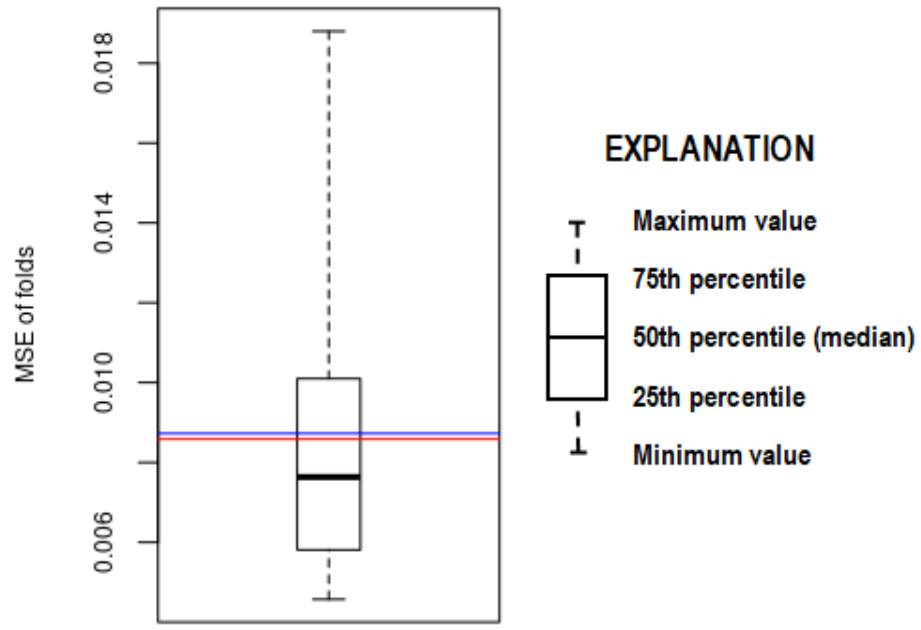


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Red line - Model MSE

Blue line - Mean MSE of folds
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Model-Calibration Dataset

	Date	LOGTP	LOGTBY	TP	TBY	Computed LOGTP	Computed TP	Residual	Normal Quantiles
1	10/16/2014	-0.292	1.33	0.511	21.3	-0.3	0.513	0.00794	0.0677
2	11/19/2014	-0.163	0.695	0.687	4.95	-0.449	0.364	0.286	2.55
3	12/9/2014	-0.312	0.751	0.488	5.64	-0.436	0.375	0.124	1.31
4	12/15/2014	-0.213	1.08	0.612	12	-0.359	0.448	0.145	1.64
5	1/14/2015	-0.36	0.519	0.437	3.3	-0.491	0.33	0.131	1.42
6	2/11/2015	-0.382	0.857	0.415	7.2	-0.411	0.397	0.0289	0.345
7	2/25/2015	-0.282	0.653	0.522	4.5	-0.459	0.355	0.177	1.99
8	3/11/2015	-0.407	0.976	0.392	9.47	-0.383	0.424	-0.0239	-0.297
9	4/6/2015	-0.135	1.08	0.733	12	-0.359	0.448	0.224	2.19
10	4/16/2015	-0.148	1.3	0.712	20.2	-0.305	0.506	0.158	1.85
11	4/22/2015	-0.0799	2.15	0.832	140	-0.107	0.8	0.0267	0.274
12	5/5/2015	-0.115	1.71	0.768	51	-0.21	0.631	0.0955	0.965
13	5/20/2015	-0.0353	2.36	0.922	228	-0.0568	0.897	0.0216	0.227
14	5/27/2015	-0.0883	2.26	0.816	183	-0.079	0.853	-0.00936	-0.0677
15	6/10/2015	-0.113	1.83	0.771	68	-0.181	0.675	0.0677	0.738
16	6/17/2015	-0.0685	2.15	0.854	140	-0.107	0.8	0.0381	0.442
17	6/29/2015	-0.229	1.36	0.59	23.2	-0.291	0.523	0.0619	0.709
18	7/6/2015	-0.237	1.35	0.579	22.3	-0.295	0.519	0.0575	0.652
19	7/13/2015	-0.189	1.9	0.647	79	-0.165	0.699	-0.0238	-0.274
20	7/20/2015	-0.162	1.36	0.689	23	-0.292	0.522	0.13	1.36
21	8/3/2015	-0.273	1.53	0.533	34	-0.252	0.573	-0.0215	-0.181
22	8/17/2015	-0.239	1.54	0.577	34.5	-0.25	0.575	0.0114	0.158
23	8/27/2015	-0.0605	2.44	0.87	277	-0.0368	0.94	-0.0237	-0.251
24	9/8/2015	-0.267	1.76	0.541	57	-0.199	0.647	-0.0681	-0.709
25	10/14/2015	-0.359	1.18	0.438	15	-0.336	0.472	-0.0229	-0.204
26	11/17/2015	-0.35	1.45	0.447	28	-0.272	0.547	-0.0781	-0.83
27	1/19/2016	-0.381	1.44	0.416	27.8	-0.272	0.547	-0.109	-1.04
28	2/16/2016	-0.493	1.26	0.321	18	-0.317	0.493	-0.177	-2.19
29	3/16/2016	-0.483	1.15	0.329	14.2	-0.341	0.466	-0.141	-1.56
30	4/20/2016	-0.272	1.86	0.535	72.7	-0.174	0.685	-0.0978	-0.965
31	4/21/2016	-0.068	1.99	0.855	97	-0.144	0.734	0.0762	0.862
32	5/26/2016	-0.0376	2.34	0.917	217	-0.0618	0.887	0.0242	0.251
33	5/31/2016	-0.0975	2.15	0.799	140	-0.107	0.8	0.00915	0.0903
34	6/7/2016	-0.175	1.84	0.668	69.5	-0.178	0.678	0.00319	0.0225
35	6/17/2016	-0.0214	2.11	0.952	128	-0.116	0.784	0.0942	0.93
36	6/21/2016	0.0128	2.45	1.03	283	-0.0343	0.945	0.0472	0.544
37	6/28/2016	-0.163	1.65	0.687	44.3	-0.225	0.61	0.0615	0.68
38	7/6/2016	-0.145	2.09	0.716	123	-0.12	0.775	-0.0248	-0.345
39	7/13/2016	-0.0904	1.65	0.812	45	-0.223	0.612	0.133	1.49
40	7/25/2016	-0.239	1.43	0.577	27	-0.275	0.543	0.0365	0.418
41	8/11/2016	-0.144	2	0.717	100	-0.141	0.739	-0.00337	0
42	8/16/2016	-0.188	1.63	0.649	43	-0.228	0.606	0.0399	0.493
43	8/29/2016	-0.178	2	0.663	99.2	-0.142	0.738	-0.0365	-0.442
44	9/7/2016	-0.223	1.76	0.599	57.3	-0.198	0.648	-0.0244	-0.321
45	9/13/2016	-0.144	2.17	0.718	146	-0.102	0.809	-0.0417	-0.467
46	10/24/2016	-0.444	0.988	0.36	9.72	-0.38	0.426	-0.0635	-0.68
47	11/15/2016	-0.333	1.11	0.465	12.8	-0.352	0.455	0.0191	0.204
48	12/14/2016	-0.58	0.656	0.263	4.53	-0.458	0.356	-0.122	-1.26
49	2/14/2017	-0.575	1.04	0.266	10.9	-0.368	0.438	-0.207	-2.55
50	3/14/2017	-0.452	0.884	0.353	7.65	-0.405	0.403	-0.0475	-0.544
51	3/30/2017	0.0394	2.45	1.09	280	-0.0355	0.943	0.0749	0.83
52	4/11/2017	-0.272	1.99	0.534	97.5	-0.144	0.735	-0.129	-1.31
53	5/1/2017	-0.17	2.18	0.676	150	-0.0995	0.813	-0.0705	-0.768

54	5/15/2017	-0.296	1.83	0.506	68.3	-0.18	0.676	-0.116	-1.12
55	5/31/2017	-0.347	1.45	0.45	28	-0.272	0.547	-0.0752	-0.799
56	6/5/2017	-0.282	1.6	0.522	40	-0.235	0.595	-0.0473	-0.518
57	6/13/2017	-0.336	1.3	0.461	20	-0.306	0.505	-0.0302	-0.369
58	6/28/2017	-0.336	1.36	0.461	22.8	-0.293	0.521	-0.0434	-0.493
59	7/13/2017	-0.283	1.48	0.521	30.2	-0.264	0.557	-0.0194	-0.136
60	7/31/2017	-0.276	1.32	0.53	20.7	-0.302	0.51	0.0268	0.321
61	8/2/2017	-0.292	1.19	0.51	15.5	-0.332	0.476	0.0397	0.467
62	8/16/2017	-0.272	1.43	0.535	26.8	-0.276	0.542	0.00448	0.0451
63	8/30/2017	-0.311	1.31	0.489	20.5	-0.304	0.509	-0.00717	-0.0451
64	9/6/2017	-0.336	1.26	0.461	18.2	-0.316	0.494	-0.0206	-0.158
65	10/17/2017	-0.25	1.09	0.562	12.4	-0.355	0.451	0.105	1.08
66	11/15/2017	-0.353	1.13	0.444	13.5	-0.347	0.46	-0.00594	-0.0225
67	12/12/2017	-0.417	0.626	0.383	4.22	-0.466	0.35	0.0488	0.597
68	1/18/2018	-0.5	0.432	0.316	2.71	-0.511	0.315	0.011	0.136
69	1/31/2018	-0.538	0.556	0.29	3.6	-0.482	0.337	-0.0556	-0.597
70	3/6/2018	-0.517	0.865	0.304	7.33	-0.409	0.399	-0.108	-1
71	3/22/2018	-0.435	1.05	0.367	11.2	-0.366	0.441	-0.0696	-0.738
72	4/18/2018	-0.346	0.993	0.451	9.85	-0.379	0.428	0.0329	0.369
73	5/2/2018	-0.231	1.12	0.587	13.2	-0.349	0.458	0.117	1.21
74	5/9/2018	-0.163	1.28	0.687	18.9	-0.312	0.499	0.149	1.74
75	5/23/2018	-0.146	1.4	0.715	25.3	-0.282	0.534	0.136	1.56
76	6/1/2018	0.035	2.57	1.08	367	-0.00766	1.01	0.0427	0.518
77	6/6/2018	-0.0655	1.85	0.86	71.1	-0.176	0.682	0.111	1.12
78	6/20/2018	-0.159	1.51	0.694	32	-0.258	0.565	0.0993	1
79	6/26/2018	-0.18	1.91	0.66	80.9	-0.163	0.703	-0.0177	-0.113
80	7/19/2018	0.0927	2.65	1.24	450	0.0131	1.05	0.0797	0.896
81	7/31/2018	-0.0119	2.43	0.973	272	-0.0386	0.936	0.0267	0.297
82	8/16/2018	-0.145	1.77	0.716	58.9	-0.195	0.652	0.0503	0.624
83	8/28/2018	-0.138	1.94	0.728	87.2	-0.155	0.716	0.0173	0.181
84	9/6/2018	0.0618	2.57	1.15	373	-0.00601	1.01	0.0678	0.768
85	9/18/2018	-0.188	1.38	0.649	24	-0.288	0.528	0.0998	1.04
86	10/16/2018	-0.0731	2.14	0.845	137	-0.109	0.796	0.0357	0.393
87	11/19/2018	-0.372	0.708	0.425	5.1	-0.446	0.366	0.0746	0.799
88	12/4/2018	-0.137	2.12	0.73	131	-0.113	0.788	-0.0234	-0.227
89	12/17/2018	-0.407	0.937	0.392	8.65	-0.392	0.415	-0.0146	-0.0903
90	1/29/2019	-0.47	1.2	0.339	15.9	-0.33	0.479	-0.14	-1.42
91	2/19/2019	-0.635	0.559	0.232	3.62	-0.481	0.338	-0.153	-1.85
92	2/27/2019	-0.318	1.87	0.481	74.5	-0.171	0.689	-0.147	-1.74
93	3/14/2019	0.102	2.53	1.26	341	-0.0152	0.988	0.117	1.16
94	3/19/2019	-0.225	2.26	0.595	182	-0.0795	0.852	-0.146	-1.64
95	4/11/2019	-0.326	1.92	0.472	83.7	-0.159	0.709	-0.167	-1.99
96	4/16/2019	-0.435	1.35	0.367	22.4	-0.295	0.519	-0.141	-1.49
97	5/1/2019	0.0941	2.48	1.24	304	-0.027	0.961	0.121	1.26
98	5/15/2019	-0.13	2.2	0.742	157	-0.0949	0.822	-0.0347	-0.418
99	5/23/2019	-0.242	2.16	0.573	144	-0.104	0.805	-0.138	-1.36
100	6/5/2019	-0.186	1.76	0.651	58	-0.197	0.65	0.0105	0.113
101	6/12/2019	-0.337	1.42	0.46	26.3	-0.278	0.539	-0.059	-0.624
102	6/24/2019	-0.154	2.28	0.702	192	-0.0743	0.862	-0.0793	-0.862
103	7/10/2019	-0.206	1.86	0.623	71.7	-0.175	0.683	-0.0303	-0.393
104	7/30/2019	-0.419	1.32	0.381	21.1	-0.3	0.512	-0.119	-1.16
105	8/7/2019	-0.387	1.47	0.41	29.2	-0.267	0.553	-0.12	-1.21
106	8/20/2019	0.0671	2.68	1.17	479	0.0195	1.07	0.0475	0.57
107	8/26/2019	-0.141	2.22	0.723	166	-0.0889	0.834	-0.0519	-0.57
108	9/11/2019	-0.368	1.38	0.429	24.1	-0.287	0.528	-0.0805	-0.896
109	10/9/2019	-0.36	1.44	0.437	27.2	-0.274	0.544	-0.085	-0.93

110	11/6/2019	-0.449	0.953	0.356	8.97	-0.388	0.418	-0.0602	-0.652
111	12/11/2019	-0.578	0.627	0.264	4.24	-0.465	0.35	-0.113	-1.08

Definitions

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TP: Phosphorus in mg/L as P (00665)
TBY: Turbidity in FNU (63680)
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