Appendix 26. Model Archival Summary for Suspended-Sediment Concentration at U.S. Geological Survey Site 06892350, Kansas River at De Soto, Kansas, during September 2013 through September 2019

This model archival summary summarizes the suspended-sediment concentration (SSC; U.S. Geological Survey [USGS] parameter code 80154) model developed to compute 15-minute SSC from September 2013 onward. This model supersedes all previous models.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Site and Model Information

Site number: 06892350
Site name: Kansas River at De Soto, Kansas
Location: Lat 38°59'00", long 94°57'52" referenced to North American Datum of 1927, in NE 1/4 SE 1/4 SE 1/4 sec.28, T.12 S., R.22 E., Leavenworth County, Kans., hydrologic unit 10270104.

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 and phycocyanin fluorescence was installed during June 2014 through September 2019. A Hach Nitratax plus sc sensor (5-millimeter path length) that monitors ultraviolet (UV) nitrate concentrations was installed from June 2013 through September 2019. The monitors were housed in side-by-side 4-inch-diameter galvanized steel pipes. Readings from the water-quality and nitrate plus nitrite monitors were recorded every 15 minutes and transmitted by way of satellite, hourly.

Date model was created: April 3, 2020

Model calibration data period: September 23, 2013, through September 24, 2019

Model application date: September 23, 2013, 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, chlorophyll and phycocyanin fluorescence, and UV nitrate sensor data. 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 105 concurrent measurements of SSC and sensor-measured TBY during September 23, 2013, through September 24, 2019. Samples were collected throughout the range of continuously observed hydrologic conditions. No samples had concentrations below the laboratory detection limits. 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. One of the SSC results, from April 21, 2014, was deemed an outlier and removed from the model calibration dataset due to evidence of contamination from streambed material which likely introduced a high bias to this result. SSC results from January 13, 2014; February 10, 2014; and January 11, 2016, were deemed outliers and removed from the model calibration dataset due to irregular sample collection method during icy conditions. All other 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 De Soto, 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.

Suspended-Sediment Concentration 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 SSC at the USGS Iowa Sediment Laboratory in Iowa City, Iowa.

Model Development

Ordinary least squares regression analysis was done using R programming language (R Core Team, 2020) to relate discretely collected SSC to sensor-measured TBY. 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 was selected as a good surrogate for SSC 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 SSC at USGS site 06892350:

SSC-based model:

$$\log SSC = 1.05 \times \log TBY + 0.275$$

where

log = logarithm base 10;

SSC = suspended-sediment concentration, in milligrams per liter; and

TBY = turbidity, in formazin nephelometric units.

TBY makes physical and statistical sense as an explanatory variable for SSC because of its positive correlation with suspended material.

The logarithmically (log) transformed model may be retransformed to the original units so that SSC 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 1.07. The retransformed model, accounting for BCF is as follows:

$$SSC = 1.07 \times (TBY^{1.05} \times 10^{0.275})$$

Previous Models

Start Year	End Year	Model Equation	Reference
2012	2019	logSSC = 0.942logTBY + 0.441	Foster and Graham (2016)
1999	2003	logSSC = 0.904logTBY + 0.264	Rasmussen and others (2005)

Model Statistics, Data, and Plots

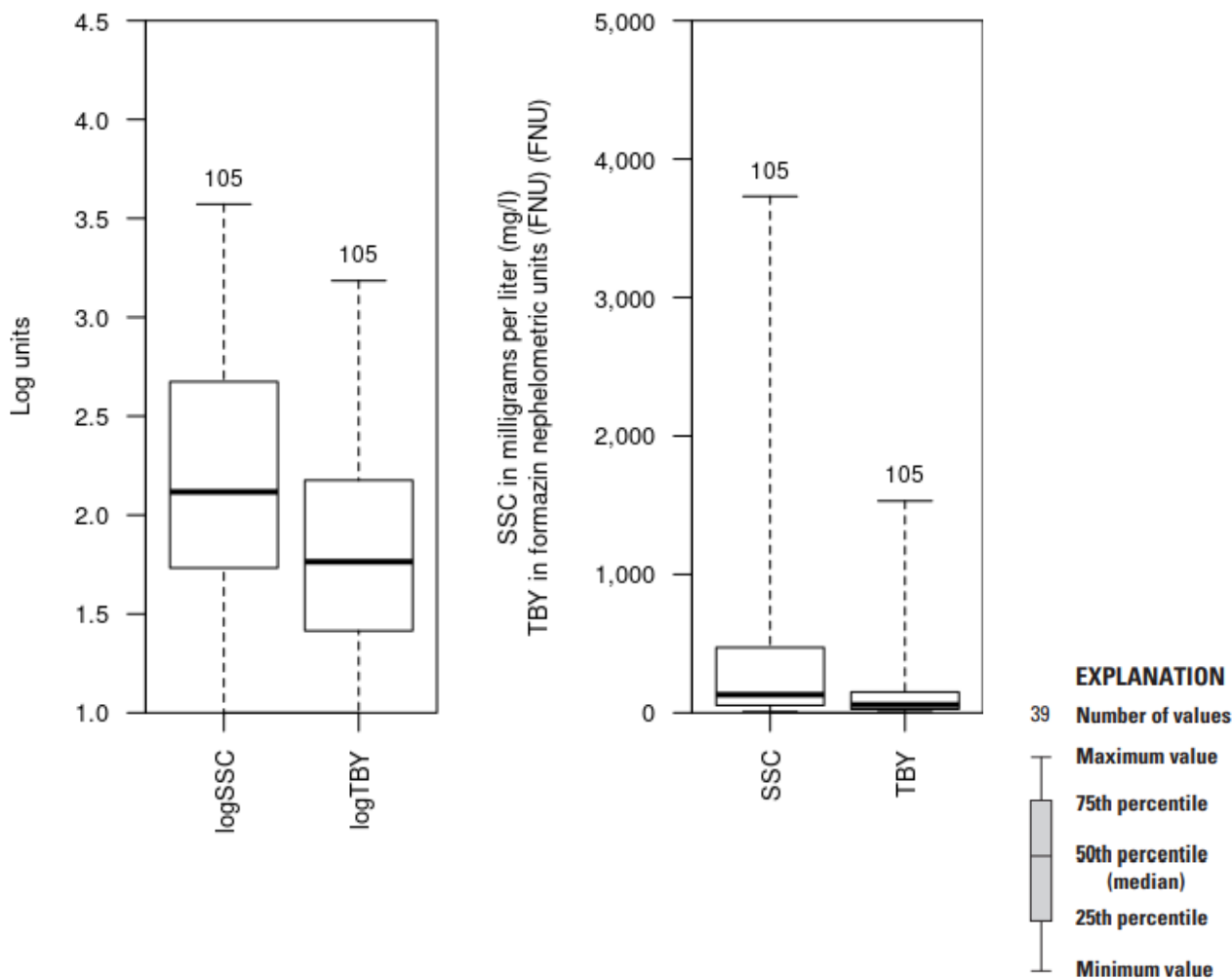## Model

logSSC = + 1.05 * logTBY + 0.275

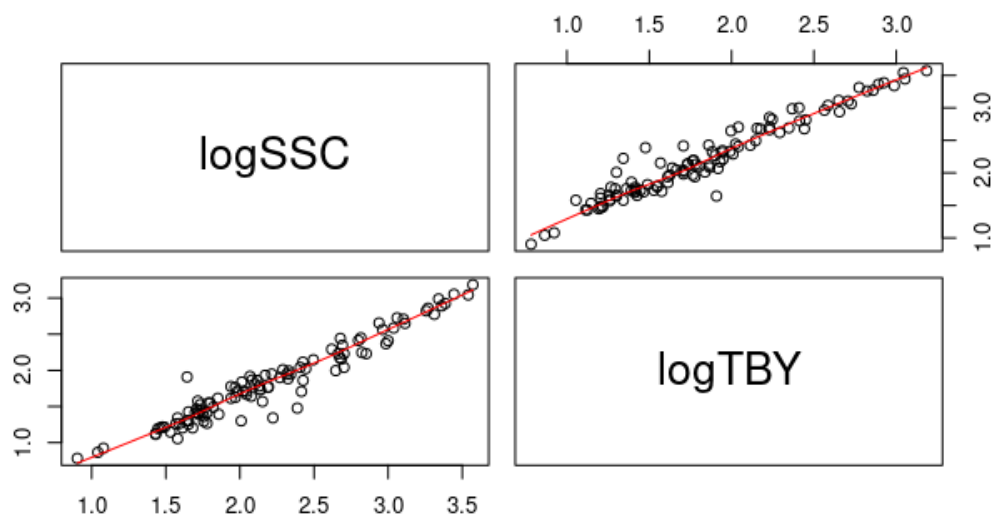## Variable Summary Statistics

```
              logSSC   SSC logTBY      TBY
Minimum        0.903     8  0.782     6.06
1st Quartile   1.730    54  1.410    26.00
Median         2.120   131  1.760    58.10
Mean           2.210   437  1.840   165.00
3rd Quartile   2.670   472  2.180   150.00
Maximum        3.570  3730  3.180  1530.00
```

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                           105
Standard error (RMSE)                          0.156
Average Model standard percentage error (MSPE)  36.6
Coefficient of determination (R²)              0.934
Adjusted Coefficient of Determination (Adj. R²) 0.933
Bias Correction Factor (BCF)                    1.07
```

Explanatory Variables

	Coefficients	Standard Error	t value	Pr(>|t|)
(Intercept)	0.275	0.0529	5.2	1.03e-06
logTBY	1.050	0.0276	38.2	1.23e-62

Correlation Matrix

	Intercept	E.vars
Intercept	1.000	-0.958
E.vars	-0.958	1.000

Outlier Test Criteria

Leverage	Cook's D	DFFITS
0.0571	0.1944	0.2760

Flagged Observations

	logSSC	Estimate	Residual	Standard Residual	Studentized Residual	Leverage	Cook's D	DFFITS
201311181400	2.220	1.69	0.5340	3.460	3.660	0.01720	0.10500	0.484
201312160800	2.390	1.83	0.5560	3.600	3.830	0.01360	0.08920	0.450
201403241250	2.010	1.65	0.3630	2.360	2.410	0.01850	0.05240	0.331
201406111600	3.570	3.63	-0.0582	-0.387	-0.386	0.06670	0.00536	-0.103

```
201406301220  1.640     2.29  -0.6420           -4.150           -4.520  0.00969  0.08410 -0.447
201801101030  0.903     1.10  -0.1960           -1.290           -1.290  0.04440  0.03860 -0.279
```

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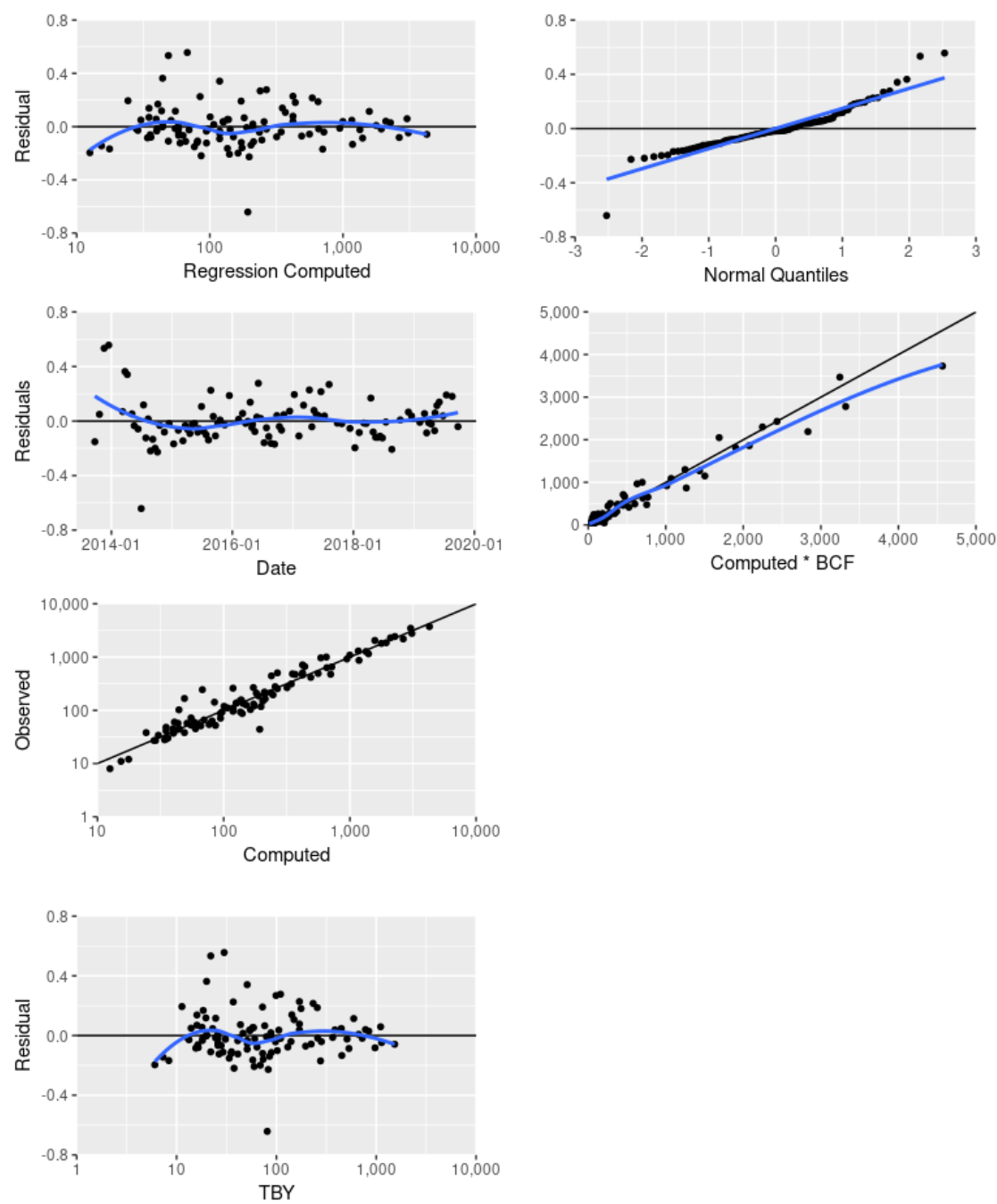
First row (left): Residual SSC related to regression computed SSC with local polynomial regression fitting, or locally estimated scatterplot smoothing (LOESS), indicated by the blue line.

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

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

Third row: Observed SSC related to regression computed SSC.

Fourth row: Residual SSC related to TBY with LOESS, indicated by the blue line.

EXPLANATION

39   Number of values

⊤   Maximum value

■   75th percentile

■   50th percentile
      (median)

■   25th percentile

⊥   Minimum value

EXPLANATION

39   Number of values

⊤   Maximum value

■   75th percentile

■   50th percentile
      (median)

■   25th percentile

⊥   Minimum value
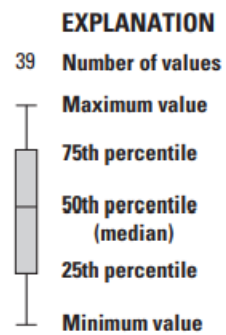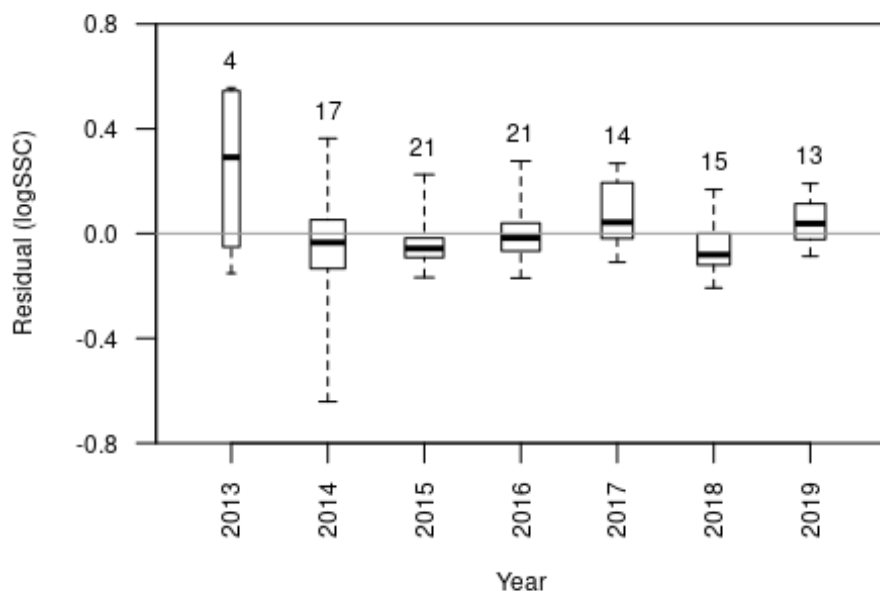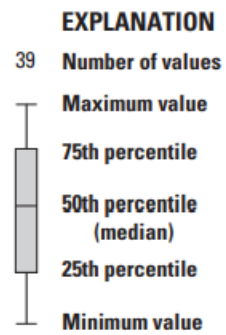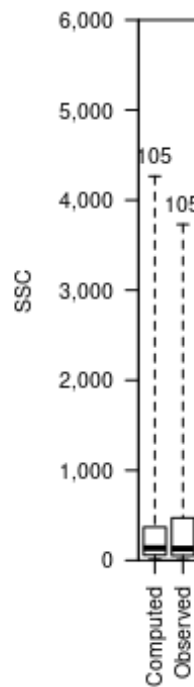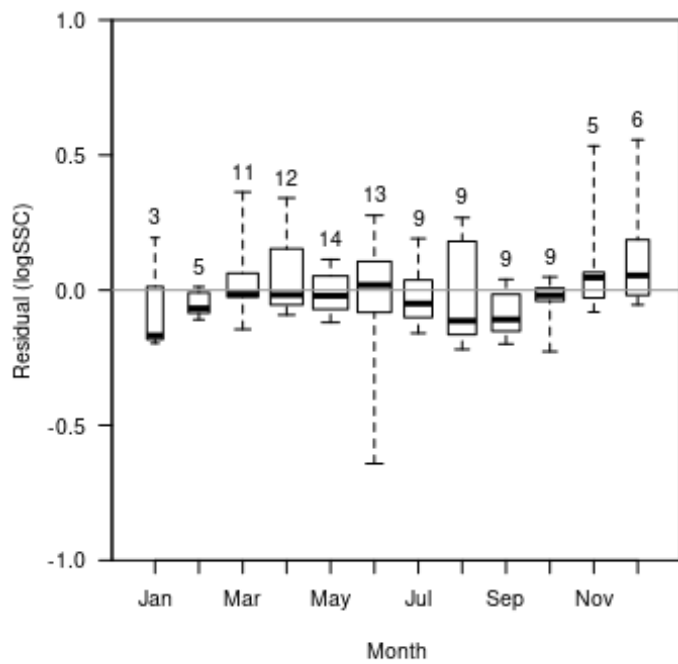
Cross-Validation
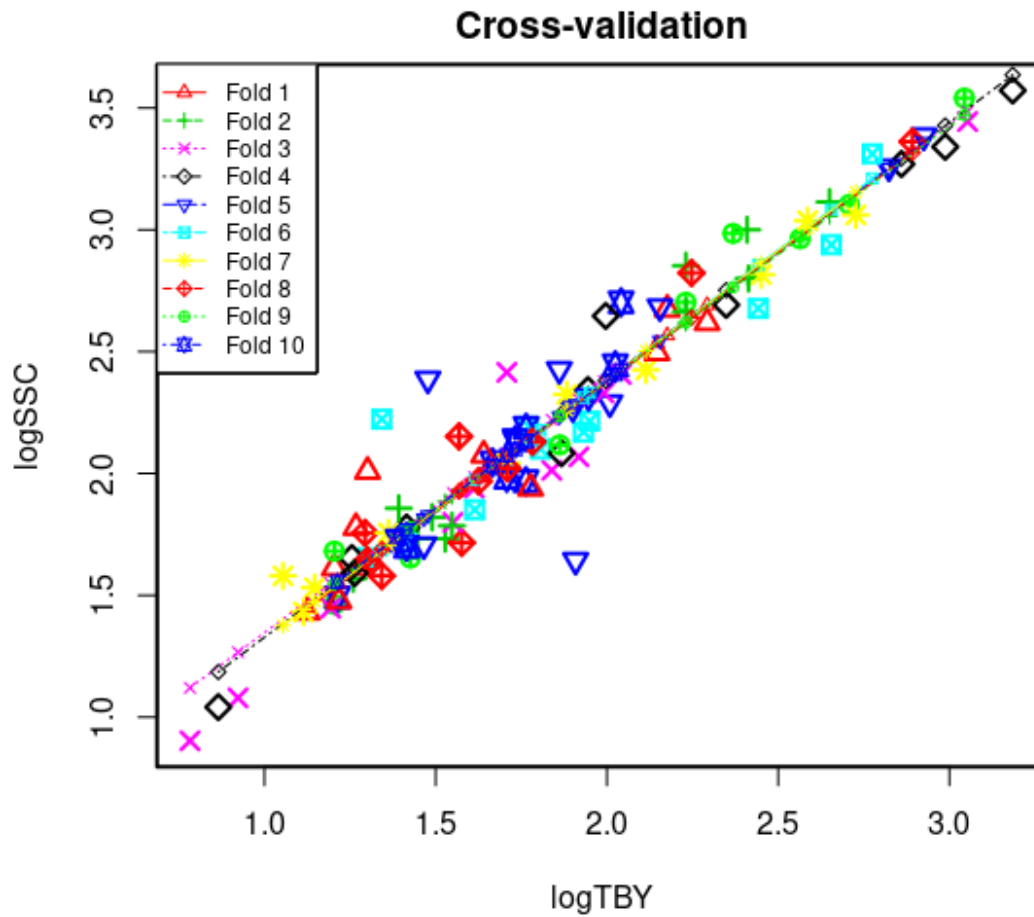
Fold - equal partition of the data (10 percent of the data).

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:  0.00711
            Mean MSE of folds:  0.02390
          Median MSE of folds:  0.01530
         Maximum MSE of folds:  0.07310
 (Mean MSE of folds) / (Model MSE):  0.98800
```
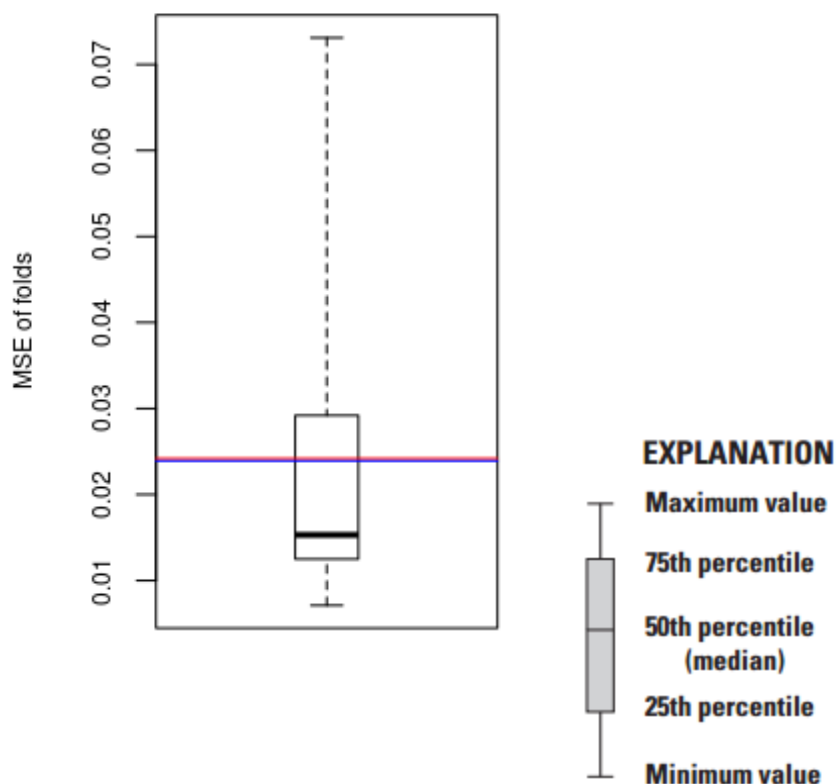
Red line - Model MSE

Blue line - Mean MSE of folds

Model-Calibration Dataset

	Date	logSSC	logTBY	SSC	TBY	Computed logSSC	Computed SSC	Residual	Normal Quantiles	Censored Values
0										
1	2013-09-23	1.73	1.53	54	33.7	1.88	82	-0.152	-1.28	--
2	2013-10-21	1.53	1.15	34	14	1.48	32.5	0.0493	0.607	--
3	2013-11-18	2.22	1.34	167	22	1.69	52.3	0.534	2.16	--
4	2013-12-16	2.39	1.48	244	30	1.83	72.6	0.556	2.53	--
5	2014-03-10	1.61	1.2	41	16	1.54	37.4	0.0695	0.79	--
6	2014-03-24	2.01	1.3	102	20	1.65	47.3	0.363	1.96	--
7	2014-04-07	2.41	1.71	260	51	2.07	127	0.341	1.82	--
8	2014-05-05	2.19	1.77	156	59	2.14	148	0.0528	0.636	--
9	2014-05-19	1.94	1.61	87	41	1.97	101	-0.0343	-0.216	--
10	2014-06-11	3.57	3.18	3730	1530	3.63	4570	-0.0582	-0.417	--
11	2014-06-30	1.64	1.91	44	81	2.29	207	-0.642	-2.53	--
12	2014-07-14	1.76	1.29	57	19.7	1.64	46.5	0.118	1	--
13	2014-07-28	1.65	1.43	45	26.7	1.78	64.1	-0.124	-1.09	--
14	2014-08-11	2.05	1.67	111	46.3	2.03	115	0.0155	0.315	--
15	2014-08-25	1.72	1.58	52	37.7	1.94	92.2	-0.219	-1.96	--
16	2014-09-08	2.94	2.66	868	452	3.07	1260	-0.133	-1.13	--
17	2014-09-22	2.01	1.84	103	69	2.21	175	-0.199	-1.71	--
18	2014-10-06	2.07	1.92	117	82.8	2.3	211	-0.227	-2.16	--
19	2014-10-20	2.04	1.71	110	51	2.07	127	-0.0323	-0.168	--
20	2014-11-17	1.46	1.2	29	16	1.54	37.4	-0.0809	-0.636	--

21	2014-12-15	1.97	1.63	93	42.2	1.99	104	-0.0186	-0.0238	--
22	2015-01-12	1.08	0.923	12	8.37	1.25	18.9	-0.168	-1.46	--
23	2015-02-09	1.73	1.45	54	28	1.8	67.5	-0.0669	-0.496	--
24	2015-03-09	1.04	0.865	11	7.33	1.19	16.5	-0.145	-1.23	--
25	2015-03-23	1.57	1.26	37	18.2	1.6	42.8	-0.033	-0.192	--
26	2015-04-06	1.49	1.21	31	16.3	1.55	38.2	-0.0614	-0.443	--
27	2015-04-20	1.98	1.71	96	51	2.07	127	-0.0914	-0.758	--
28	2015-05-04	1.82	1.49	66	30.9	1.84	74.8	-0.0246	-0.119	--
29	2015-05-18	3.27	2.86	1860	724	3.29	2080	-0.0181	0	--
30	2015-06-06	3.34	2.99	2190	972	3.42	2830	-0.082	-0.666	--
31	2015-06-15	2.69	2.35	492	223	2.75	601	-0.0567	-0.391	--
32	2015-06-29	2.67	2.18	472	150	2.57	396	0.107	0.892	--
33	2015-07-13	2.42	2.11	266	130	2.5	340	-0.077	-0.551	--
34	2015-07-27	2.29	2.01	195	102	2.39	263	-0.101	-0.79	--
35	2015-08-10	2.17	1.93	148	85.3	2.31	218	-0.139	-1.18	--
36	2015-08-24	2.15	1.57	142	37	1.93	90.5	0.225	1.46	--
37	2015-09-08	2.14	1.74	137	54.3	2.1	136	0.0341	0.391	--
38	2015-09-21	1.8	1.55	63	35.5	1.91	86.7	-0.109	-0.823	--
39	2015-10-05	1.75	1.41	56	26	1.77	62.4	-0.0172	0.0477	--
40	2015-10-19	1.65	1.3	45	20	1.65	47.3	0.00783	0.241	--
41	2015-11-16	1.43	1.12	27	13.3	1.46	30.9	-0.0285	-0.143	--
42	2015-12-14	3	2.41	1000	257	2.81	697	0.187	1.23	--
43	2016-02-08	1.78	1.41	60	26	1.77	62.4	0.0127	0.29	--
44	2016-03-03	1.65	1.26	45	18	1.6	42.4	0.056	0.696	--
45	2016-03-21	1.43	1.11	27	13	1.45	30.1	-0.0169	0.0715	--
46	2016-04-04	1.64	1.3	44	20	1.65	47.3	-0.00193	0.216	--
47	2016-04-18	1.68	1.2	48	16	1.54	37.4	0.138	1.04	--
48	2016-04-28	3.44	3.05	2780	1130	3.49	3320	-0.0472	-0.315	--
49	2016-05-02	3.1	2.71	1270	510	3.13	1440	-0.0235	-0.0955	--
50	2016-05-16	2.1	1.81	126	64	2.18	161	-0.0772	-0.579	--
51	2016-05-28	3.39	2.93	2430	842	3.36	2430	0.0291	0.365	--
52	2016-06-06	2.7	2.04	504	110	2.43	285	0.277	1.71	--
53	2016-06-20	2.34	1.94	220	88	2.32	226	0.0191	0.34	--
54	2016-07-11	2.08	1.87	121	73.7	2.24	187	-0.159	-1.33	--
55	2016-07-25	1.72	1.41	52	26	1.77	62.4	-0.0494	-0.34	--
56	2016-08-08	2.21	1.95	164	89	2.33	228	-0.114	-0.928	--
57	2016-08-22	1.97	1.76	93	58	2.13	145	-0.164	-1.39	--
58	2016-09-12	2.68	2.44	476	277	2.85	754	-0.17	-1.53	--
59	2016-09-26	3.36	2.89	2300	780	3.32	2250	0.0401	0.523	--
60	2016-10-11	2.5	2.15	313	140	2.54	368	-0.0402	-0.241	--
61	2016-10-24	1.7	1.41	50	26	1.77	62.4	-0.0665	-0.469	--
62	2016-11-07	1.76	1.36	57	23	1.71	54.9	0.0465	0.551	--
63	2016-12-12	2.08	1.64	119	43.7	2	108	0.0729	0.823	--
64	2017-01-09	1.58	1.05	38	11.3	1.39	26	0.194	1.33	--
65	2017-02-06	1.58	1.34	38	22	1.69	52.3	-0.109	-0.857	--
66	2017-03-06	1.86	1.39	72	24.7	1.74	59	0.116	0.965	--
67	2017-04-10	2.85	2.23	712	170	2.62	451	0.228	1.53	--
68	2017-04-25	2.33	1.99	214	98	2.37	253	-0.0421	-0.29	--
69	2017-05-08	2.7	2.23	504	170	2.62	451	0.0778	0.857	--
70	2017-05-22	3.11	2.65	1300	447	3.07	1250	0.0474	0.579	--
71	2017-06-05	2.66	2.23	460	170	2.62	451	0.0382	0.469	--
72	2017-06-19	2.98	2.37	966	233	2.77	630	0.216	1.39	--
73	2017-07-10	2.14	1.73	137	53.9	2.1	135	0.0374	0.443	--
74	2017-08-07	2.65	2	443	99.2	2.38	256	0.268	1.61	--
75	2017-09-26	1.72	1.39	53	24.6	1.74	58.8	-0.0152	0.0955	--

76	2017-10-23	2.41	2.04	255	110	2.43	285	-0.019	-0.0477	--
77	2017-12-11	2.02	1.71	105	51.2	2.08	127	-0.0541	-0.365	--
78	2018-01-10	0.903	0.782	8	6.06	1.1	13.5	-0.196	-1.61	--
79	2018-02-05	1.45	1.19	28	15.6	1.53	36.4	-0.0845	-0.696	--
80	2018-03-05	1.59	1.26	39	18.3	1.61	43.2	-0.0145	0.119	--
81	2018-03-20	2.8	2.41	631	259	2.82	703	-0.0173	0.0238	--
82	2018-04-16	1.78	1.27	60	18.5	1.61	43.6	0.168	1.13	--
83	2018-04-30	1.48	1.22	30	16.5	1.56	38.7	-0.0802	-0.607	--
84	2018-05-15	2.12	1.86	131	72.8	2.24	185	-0.119	-0.965	--
85	2018-05-29	1.79	1.55	61	35.3	1.9	86.1	-0.12	-1	--
86	2018-06-11	1.71	1.47	51	29.2	1.82	70.6	-0.111	-0.892	--
87	2018-06-25	1.85	1.61	71	41.1	1.97	101	-0.124	-1.04	--
88	2018-07-16	2.27	1.9	186	79.5	2.28	203	-0.00745	0.192	--
89	2018-08-21	1.94	1.78	87	59.9	2.15	150	-0.208	-1.82	--
90	2018-10-11	3.26	2.82	1810	666	3.25	1900	0.00845	0.265	--
91	2018-11-29	2.32	1.88	211	76.4	2.26	194	0.0659	0.758	--
92	2018-12-18	2.44	2.02	278	106	2.41	274	0.0366	0.417	--
93	2019-02-06	2.32	1.95	207	88.3	2.33	226	-0.00906	0.168	--
94	2019-03-06	2.19	1.76	154	58.1	2.13	146	0.0544	0.666	--
95	2019-03-19	3.06	2.73	1150	533	3.15	1500	-0.0867	-0.726	--
96	2019-04-01	2.96	2.56	919	366	2.98	1010	-0.0125	0.143	--
97	2019-04-16	2.13	1.78	135	60.6	2.15	152	-0.0223	-0.0715	--
98	2019-05-06	2.62	2.29	416	196	2.69	525	-0.0708	-0.523	--
99	2019-05-09	3.54	3.04	3470	1110	3.48	3240	0.059	0.726	--
100	2019-05-20	3.31	2.77	2050	595	3.2	1690	0.114	0.928	--
101	2019-06-03	2.68	2.15	483	143	2.54	376	0.139	1.09	--
102	2019-06-26	3.04	2.59	1090	385	3	1070	0.0382	0.496	--
103	2019-07-16	2.43	1.86	267	72.6	2.24	184	0.191	1.28	--
104	2019-08-20	2.82	2.25	665	177	2.64	470	0.181	1.18	--
105	2019-09-24	2.82	2.45	654	282	2.86	770	-0.041	-0.265	--

Definitions

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

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

E.vars: Explanatory variables.

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).

SSC: Suspended-sediment concentration, in milligrams per liter (80154).

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).

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