Appendix 1. Model Archive Summary for Suspended Sediment at U.S. Geological Survey Station 06856600, Republican River at Clay Center, Kansas, during July 2018 through March 2021

This model archive summary summarizes the suspended-sediment model developed to compute the 15-minute suspended-sediment concentration (SSC) from July 24, 2018, onward. This is the first model computing SSC that has been developed for this site. Model development was completed in accordance with Rasmussen and others (2009) and U.S. Geological Survey (2016).

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

Station number: 06856600

Site name: Republican River at Clay Center, Kansas

Location: Latitude 39°21'20", longitude 97°07'38", referenced to North American Datum of 1927, in Clay County, Kansas, hydrologic unit code 10250017.

Water-quality equipment: A YSI, Inc., EXO3 water-quality monitor (YSI, Inc., 2017) equipped with sensors for water temperature, specific conductance, dissolved oxygen, pH, and turbidity was installed July 24, 2018. The EXO3 was housed in a 4-inch-diameter metal pipe suspended from the downstream side of the bridge in the deepest and fastest flowing water. Measurements from the EXO3 were recorded every 15 minutes and transmitted hourly via satellite.

Date model was created: August 23, 2021

Model calibration data period: August 1, 2018, through March 25, 2021 (dataset consisted of 42 discrete water-quality samples collected).

Model application date: July 24, 2018, onward (date of continuous water-quality monitor installation).

Suspended-Sediment Concentration Data

Equal-width-increment samples (as described in U.S. Geological Survey, 2006) were collected from the downstream side of the bridge using a Federal Interagency Sedimentation Project US DH–95 depth-integrated sampler with a Teflon bottle, cap, and nozzle and a manually operated reel. Subsamples from 10 equally spaced verticals were composited. During July 2018 through June 2020, discrete water-quality samples were collected at Clay Center biweekly during May through October and monthly during November through April. During July 2020 through March 2021, discrete water-quality samples were collected about monthly. Samples were analyzed for SSC and percentage of fines (percentage of sediment particles less than 0.0625 millimeter in diameter; useful for quality assurance) at the U.S. Geological Survey (USGS) Sediment Laboratory in Iowa City, Iowa, using methods described by Guy (1969).

For the sample collected on October 24, 2018, the sediment results from the main environmental sample (12:40 collection time) were rejected because the low percentage of fines (6 percent) indicated that sand particles affected suspended-sediment analysis. When reviewing the SSC linear relationship with turbidity for all samples at this site, the 12:40 result from October 24, 2018, was a visual outlier. The sediment results from the replicate sample collected on October 24, 2018, with a sample time of 12:45 were used in the model calibration dataset. The 12:45 sample had 93-percent fines, and therefore, suspended-sediment analysis likely was not affected by sand particles. For the 12:45 sample, the SSC versus turbidity linear relationship was consistent with other samples collected at this site. Nutrient results from October 24, 2018, were not affected by sand.

Continuous Water-Quality Data

Continuously measured (15-minute) water-quality data collection at Clay Center began on July 24, 2018. During July 2018 through March 2021, a YSI, Inc., EXO3 multiparameter sonde measured water temperature, specific conductance, pH, dissolved oxygen, and turbidity (YSI, Inc., 2017). The water-quality

monitor was suspended from the downstream side of the bridge deck of Kansas Highway 18 in the deepest and fastest flowing water. The continuous water-quality monitor was operated and maintained according to standard USGS methods (Wagner and others, 2006; Bennett and others, 2014). All continuous water-quality data at Clay Center are available in near-real time (updated hourly) from the USGS National Water Information System database (U.S. Geological Survey, 2021) using the station number 06856600.

Model Data

All data were collected using USGS protocols (U.S. Geological Survey, 2006; Wagner and others, 2006; Bennett and others, 2014) and are stored in the USGS National Water Information System database (U.S. Geological Survey, 2021). The regression model is based on 42 concurrent measurements of SSC and continuously measured turbidity collected from August 1, 2018, through March 25, 2021. The potential explanatory variables were interpolated from the continuous record and paired based on discrete sample collection time. Daylight saving time was observed, so sample time was either central standard time or central daylight time. The maximum time span between two continuous data points used for interpolation was 5 hours. Samples were collected throughout the range of continuously observed hydrologic conditions. No samples had concentrations that were less than the laboratory reporting limit of 1 milligram per liter (mg/L). Summary statistics and the complete model-calibration dataset are provided below.

Potential outliers were identified as the data points for which both the studentized residual was greater than 3 or less than −3 and the Cook's D value exceeded the outlier test criteria, as described by Helsel and others (2020). This methodology resulted in one potential outlier: the sample collected on October 20, 2020. To investigate this potential outlier, the sample collection information sheets and laboratory reports were reviewed to check for data entry errors. Then, the percentage of fines result also was reviewed for this potential outlier, where a low (less than 80 percent) value could indicate that sand particles affected suspended-sediment analysis. The percentage of fines for this sample was 54 percent. Finally, the linear relationship of SSC versus turbidity at this site was examined. Because no data entry issues were discovered and the SSC versus turbidity linear relationship was consistent with other samples collected at this site and because the linear relationship

between SSC and turbidity may be affected at low concentrations by the ratio of sensor/laboratory resolution versus concentration, the October 20, 2020, result was retained. No potential outliers were removed from the model calibration dataset.

Model Development

All continuously measured water-quality parameters and streamflow were considered as explanatory variables for estimating SSC using ordinary least squares regression. All models that predict SSC and logarithm base 10 SCC ($\log_{10}$[SSC]) were evaluated from simple linear regression (SLR; single explanatory variable) and multiple linear regression (more than one explanatory variable) models. Potential regression models were evaluated based on normality and homoscedasticity in residual values. Residual values are the difference between the measured and predicted values. Homoscedastic plots are those in which the magnitude of residual values does not change substantially over the range of predicted values; that is, the magnitude of residual values neither increases nor decreases over the range of predicted values and the variance is constant. These comparisons led to the conclusion that the most appropriate and reliable model would be the SLR that estimated the $\log_{10}$(SSC).

Turbidity was selected as the best predictor of SSC in an SLR model transformed by $\log_{10}$ based on residual plots, fairly high adjusted coefficient of determination (R^2_{adj}) compared to other models considered, and fairly low model standard percentage error compared to other models considered. Additional explanatory variables in multiple linear regression models did not substantially increase the R^2_{adj} value. Values for the aforementioned statistics and metrics were computed and are included below along with all relevant sample data and more indepth statistical information.

Model Summary

Summary of final regression analysis for SSC at U.S. Geological Survey station 06856600.

SSC model:

$$log_{10}(SSC) = 0.934 \times log_{10}(TBY) + 0.608,$$

where

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

TBY = turbidity, YSI EXO3, in formazin nephelometric units.

Turbidity makes physical and statistical sense as an explanatory variable for SSC. Turbidity makes sense physically because suspended sediment is composed of particles that scatter light in water. The relation between turbidity and suspended sediment can vary given varying concentrations of organic suspended particles that increase turbidity, but these varying relations are not included in the suspended-sediment analysis. The model selected was the simplest model (one explanatory variable) and the best statistically.

The $\log_{10}$-transformed model may be retransformed to the original units so that SSC can be calculated directly. The retransformation introduces a negative bias in the retransformed calculated constituent (Helsel and others, 2020). This bias may be corrected using Duan's bias correction factor (BCF; Duan, 1983; Helsel and others, 2020). For this model, the calculated BCF was 1.03. The retransformed model, accounting for BCF, is as follows:

$$SSC = 4.18 \times TBY^{0.934}.$$

Suspended-Sediment Concentration Record

The SSC record is computed using this regression model and stored at the National Real-Time Water Quality website. Model-estimated concentrations in the National Real-Time Water Quality website are computed at hourly intervals. The complete water-quality record is available at https://nrtwq.usgs.gov/ks.

Remarks

All regression models were developed using R software environment (R Core Team, 2021).

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Model Statistics, Data, and Plots

Definitions for terms used in this output are provided at the end of this document.

Model

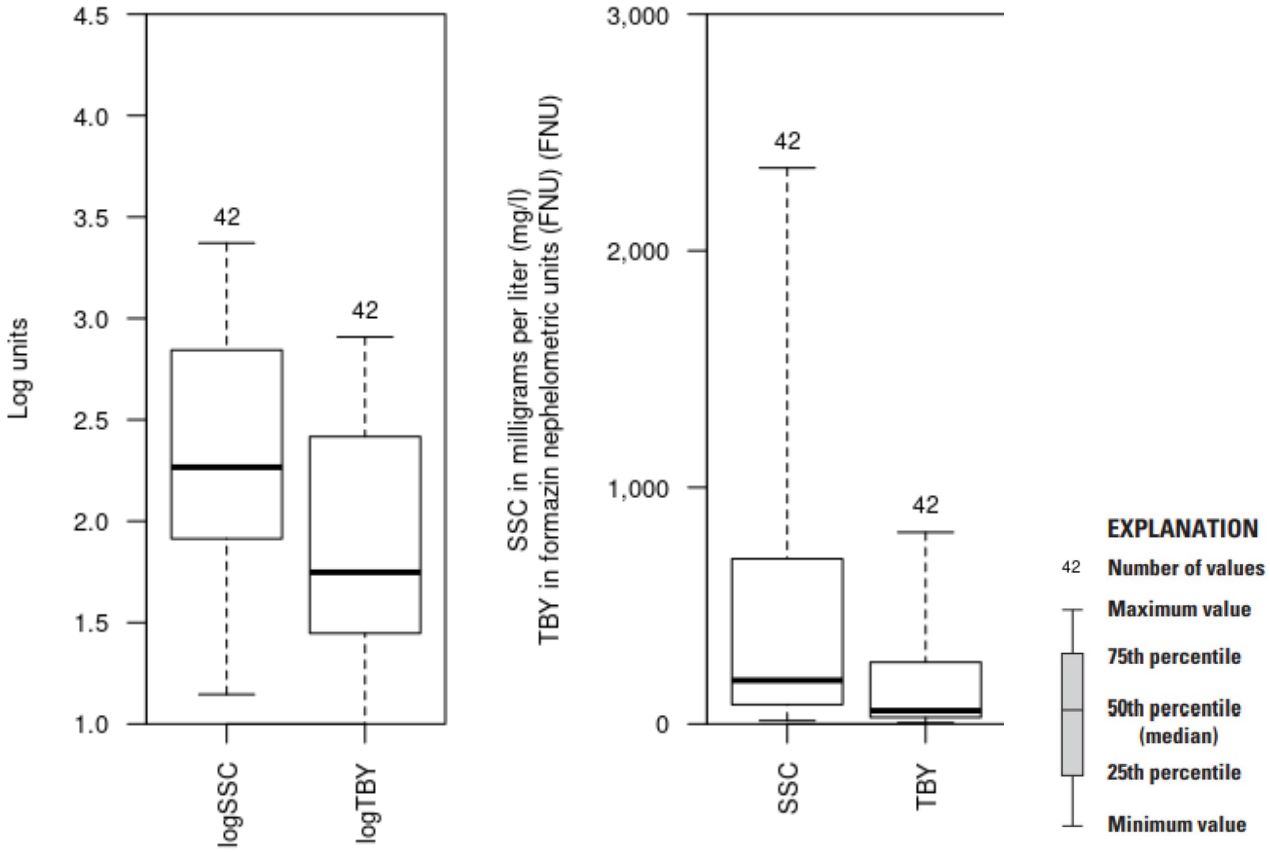
$\log SSC = +0.934 \times \log TBY + 0.608$

Variable Summary Statistics

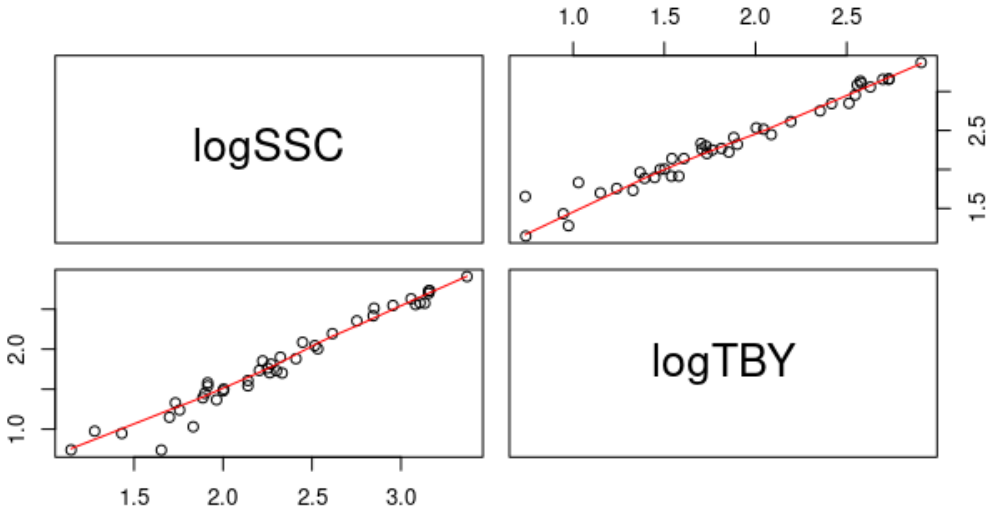
	logSSC	SSC	logTBY	TBY
Minimum	1.15	14	0.738	5.47
First Quartile	1.91	82	1.450	28.00
Median	2.27	185	1.750	56.00
Mean	2.33	449	1.840	155.00
Third Quartile	2.84	698	2.420	261.00
Maximum	3.37	2,350	2.910	810.00

SSC cannot be extrapolated more than 10 percent outside the range of sample data used to fit the model (U.S. Geological Survey, 2016). Because the maximum observed continuous turbidity value in the calibration dataset was 810 formazin nephelometric units (FNU), the maximum turbidity value for which this model is valid is 891 FNU. Less than 1 percent (59 of 84,392 15-minute measurements) of continuous turbidity measurements during the study period exceeded 891 FNU. Accounting for the BCF, at a turbidity of 891 FNU, the model-estimated SSC value is 2,380 mg/L.

Box Plots

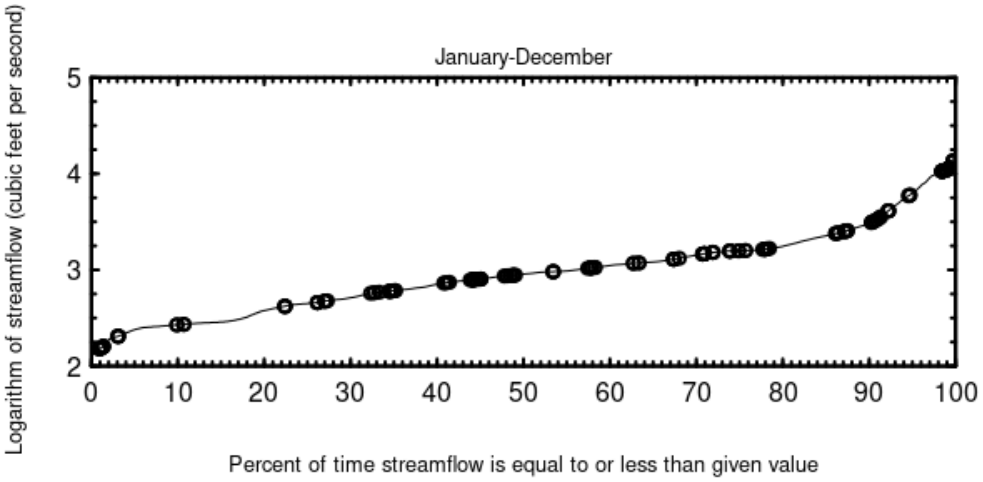


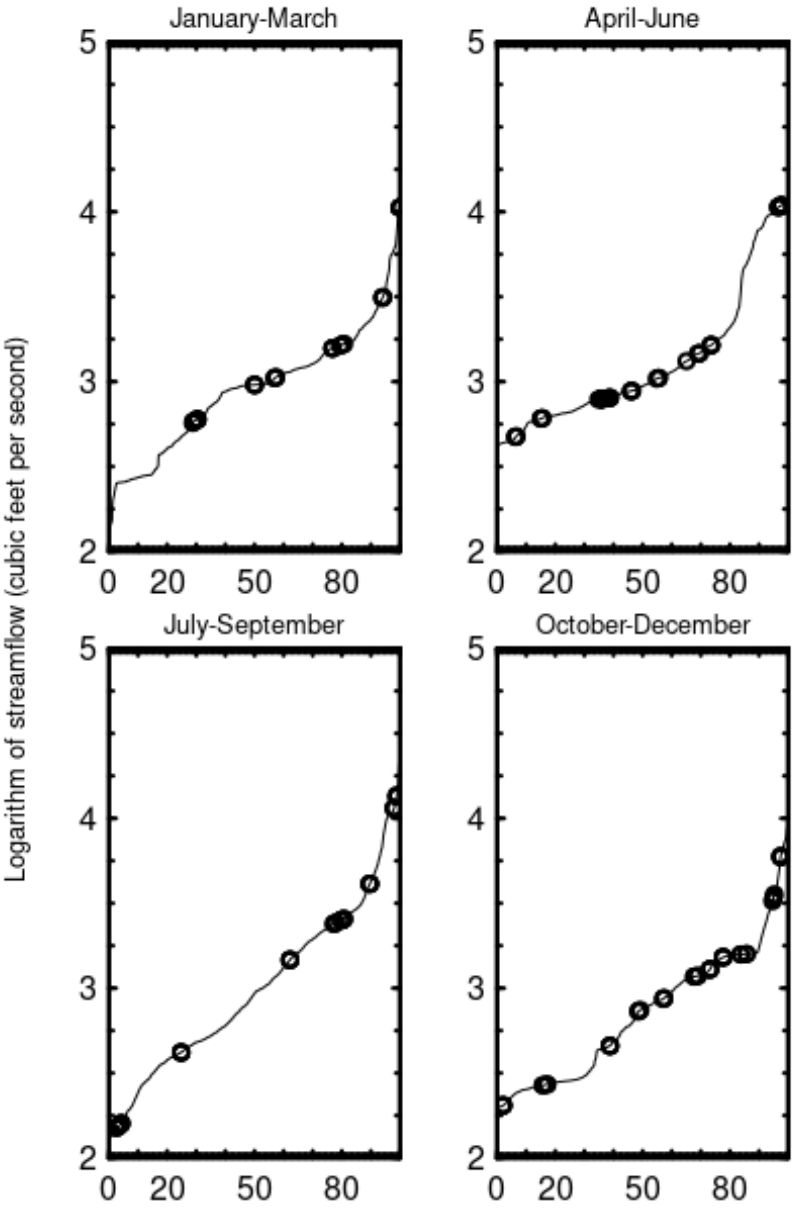
Exploratory Plots



Red lines show the locally weighted scatterplot smoothing (Cleveland, 1979; Helsel and others, 2020).

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


January-December
Logarithm of streamflow (cubic feet per second)
Percent of time streamflow is equal to or less than given value


January-March
April-June
July-September
October-December
Logarithm of streamflow (cubic feet per second)
Percent of time streamflow is equal to or less than given value

Basic Model Statistics

Number of observations	42
Standard error (root mean square error [RMSE])	0.109
Average model standard percentage error (MSPE)	25.4
Coefficient of determination (R^2)	0.964
Adjusted coefficient of determination (R^2_{adj})	0.963
Bias correction factor (BCF)	1.03

Explanatory Variables

	Coefficients	Standard Error	t value	$Pr(>\|t\|)$
(Intercept)	0.608	0.0554	11.0	1.22e−13
logTBY	0.934	0.0287	32.5	2.11e−30

Correlation Matrix

	Intercept	E.vars
Intercept	1.000	−0.953
E.vars	−0.953	1.000

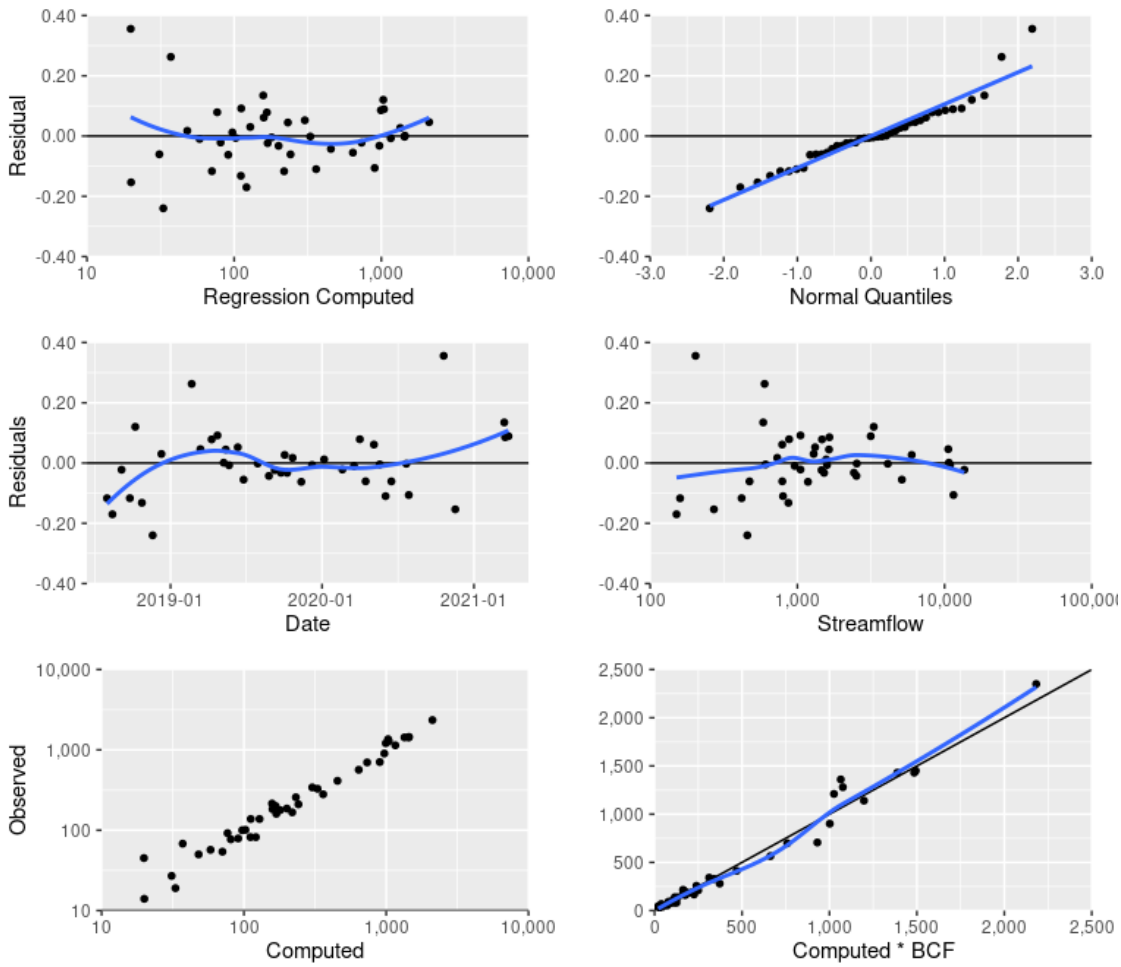
Outlier Test Criteria

Leverage	Cook's D	DFFITS
0.143	0.194	0.436

Flagged Observations

Date	logSSC	Estimate	Residual	Standard Residual	Studentized Residual	Leverage	Cook's D	DFFITS
11/19/2018 13:10	1.28	1.52	−0.240	−2.29	−2.42	0.0756	0.214	−0.694
2/21/2019 12:30	1.83	1.57	0.263	2.50	2.69	0.0693	0.232	0.733
10/20/2020 11:50	1.65	1.30	0.356	3.46	4.08	0.1080	0.723	1.420
11/17/2020 11:10	1.15	1.30	−0.154	−1.49	−1.52	0.1080	0.134	−0.526

Statistical Plots



First row (left): residual SSC (in log-space units) related to regression-computed SSC (in milligrams per liter) with local polynomial regression fitting, or locally estimated scatterplot smoothing (LOESS), indicated by the blue line.

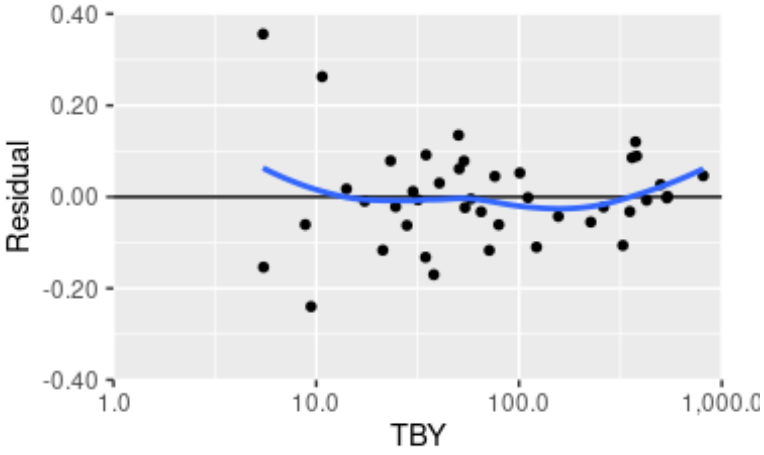
First row (right): residual SSC (in log-space units) related to the corresponding normal quantile (unitless) of the residual with simple linear regression indicated by the blue line.

Second row (left): residual SSC (in log-space units) related to date with LOESS indicated by the blue line.

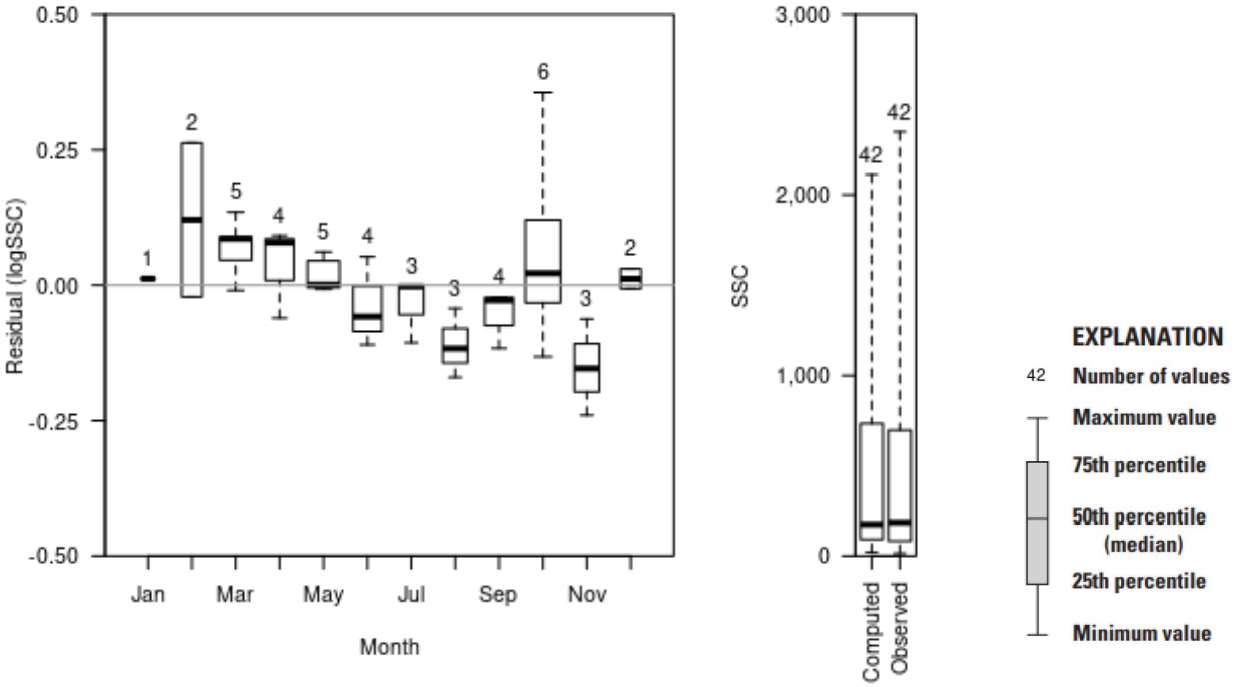
Second row (right): residual SSC (in log-space units) related to streamflow (in cubic feet per second) with LOESS indicated by the blue line.

Third row (left): observed SSC (in milligrams per liter) related to regression-computed SSC (in milligrams per liter).

Third row (right): observed SSC (in milligrams per liter) related to the product of regression-computed SSC (in milligrams per liter) and the BCF with LOESS indicated by the blue line.

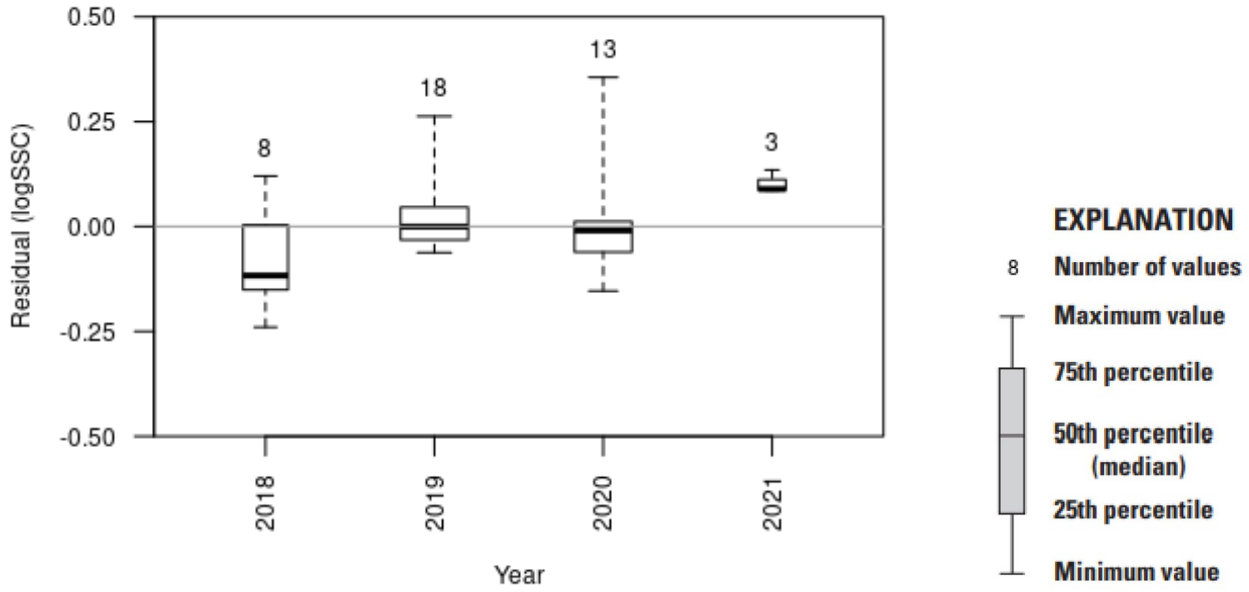


Residual SSC (in log-space units) related to TBY (in formazin nephelometric units) with LOESS indicated by the blue line.



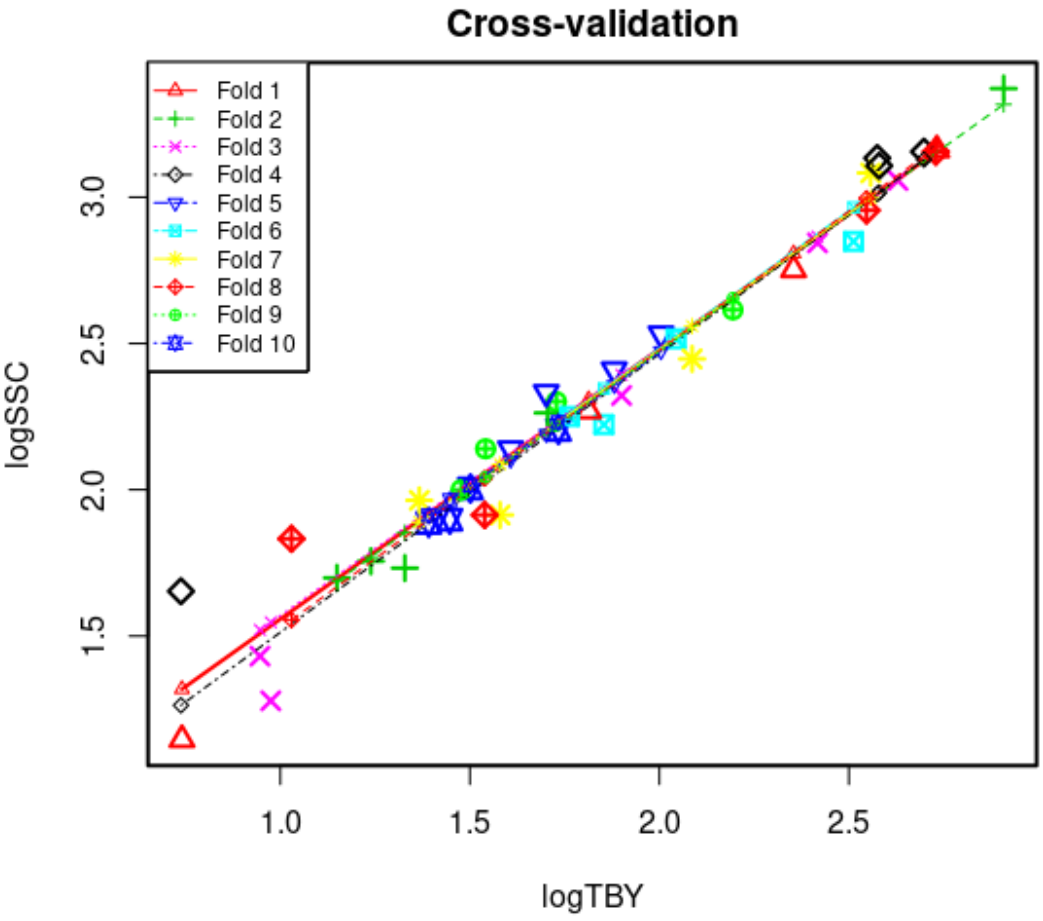
Left: residual SSC (in log-space units) by month.

Right: SSC (in milligrams per liter) in regression-computed and observed values.



Residual SSC (in log-space units) by year.

Cross Validation



SSC (in log-space units) related to TBY (in log-space units) for 10 folds of data. Each fold is an equal partition of the data (10 percent of the data). Large symbols are the observed values of data points removed in a fold and small symbols are the recomputed values of data points removed in a fold. Recomputed regression lines are adjusted regression lines with one fold removed.

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              Minimum MSE of folds:  0.00149
                 Mean MSE of folds:  0.01320
               Median MSE of folds:  0.00790
              Maximum MSE of folds:  0.04400
(Mean MSE of folds) / (Model MSE):  1.11000     (MSE ratio)
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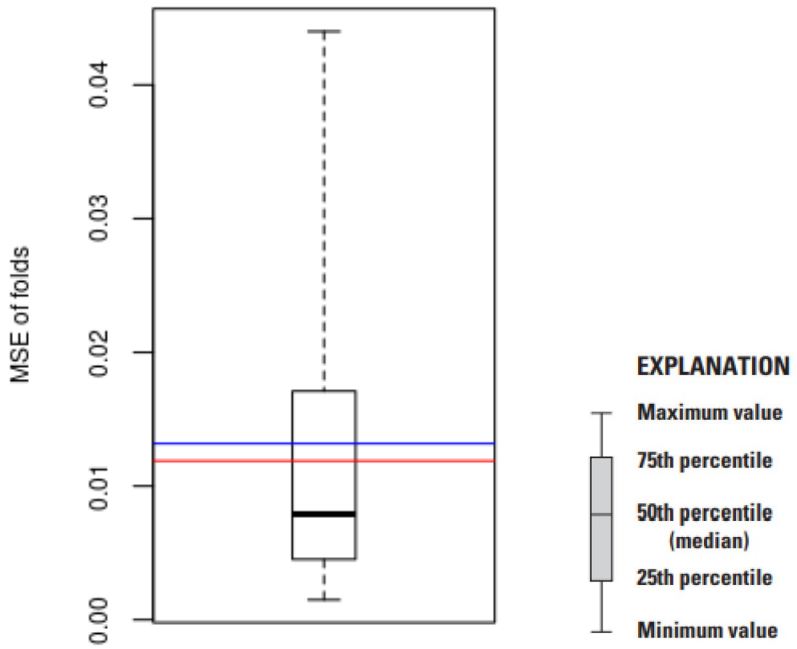


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Red line - Model MSE (unitless)
Blue line - Mean MSE of folds (unitless)
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Model-Calibration Dataset

	Date	logSSC	logTBY	SSC	TBY	Computed logSSC	Computed SSC	Residual	Normal Quantiles	Censored Values
1	2018-08-01	2.22	1.85	167	71.4	2.34	226	-0.117	-1.23	--
2	2018-08-14	1.91	1.58	82	38	2.08	125	-0.17	-1.78	--
3	2018-09-05	2.84	2.42	698	261	2.87	759	-0.0222	-0.271	--
4	2018-09-25	1.73	1.33	54	21.3	1.85	72.9	-0.117	-1.11	--
5	2018-10-08	3.13	2.57	1360	376	3.01	1,060	0.12	1.37	--
6	2018-10-24	1.91	1.54	82	34.6	2.05	115	-0.132	-1.37	--
7	2018-11-19	1.28	0.975	19	9.43	1.52	34.1	-0.24	-2.19	--
8	2018-12-10	2.14	1.61	138	40.5	2.11	133	0.0302	0.461	--
9	2019-02-21	1.83	1.03	68	10.7	1.57	38.3	0.263	1.78	--
10	2019-03-14	3.37	2.91	2350	810	3.32	2,180	0.0461	0.598	--

11	2019-04-10	2.3	1.73	200	53.5	2.22	172	0.0784	0.828	--
12	2019-04-24	2.14	1.54	138	34.8	2.05	115	0.0917	1.23	--
13	2019-05-09	3.16	2.73	1450	540	3.16	1,490	0.00118	0.209	--
14	2019-05-14	2.41	1.88	257	76	2.37	239	0.0449	0.528	--
15	2019-05-22	3.06	2.63	1140	426	3.06	1,200	-0.00735	-0.0892	--
16	2019-06-12	2.53	2	341	101	2.48	312	0.0524	0.671	--
17	2019-06-26	2.75	2.35	565	226	2.81	662	-0.0551	-0.598	--
18	2019-07-30	2.52	2.04	328	111	2.52	340	-0.00159	0.149	--
19	2019-08-26	2.61	2.19	412	156	2.66	469	-0.0427	-0.528	--
20	2019-09-09	2.2	1.73	160	54.2	2.23	174	-0.0235	-0.333	--
21	2019-09-24	2.95	2.55	901	352	2.99	1,000	-0.0321	-0.396	--
22	2019-10-03	3.16	2.7	1430	499	3.13	1,390	0.0269	0.396	--
23	2019-10-09	2.27	1.81	186	65.1	2.3	207	-0.0325	-0.461	--
24	2019-10-22	1.7	1.15	50	14.1	1.68	49.6	0.0173	0.333	--
25	2019-11-12	1.9	1.45	79	28	1.96	94.2	-0.0623	-0.828	--
26	2019-12-08	2	1.5	101	31.7	2.01	106	-0.00642	-0.0297	--
27	2020-01-06	2	1.48	100	30	1.99	100	0.012	0.271	--
28	2020-02-19	1.89	1.39	77	24.6	1.91	83.6	-0.0215	-0.209	--
29	2020-03-18	1.76	1.24	57	17.3	1.77	60.2	-0.00955	-0.149	--
30	2020-04-01	1.96	1.37	92	23.3	1.88	79.2	0.0789	0.915	--
31	2020-04-15	1.43	0.946	27	8.83	1.49	32.1	-0.0606	-0.671	--
32	2020-05-05	2.26	1.71	183	50.7	2.2	164	0.0614	0.747	--
33	2020-05-19	2.25	1.76	178	57.9	2.25	186	-0.00449	0.0297	--
34	2020-06-02	2.45	2.09	280	122	2.56	372	-0.11	-1.01	--
35	2020-06-16	2.32	1.9	210	79.5	2.38	250	-0.0609	-0.747	--
36	2020-07-22	3.16	2.73	1430	536	3.16	1,480	-0.00234	0.0892	--
37	2020-07-28	2.85	2.51	706	325	2.95	931	-0.106	-0.915	--
38	2020-10-20	1.65	0.738	45	5.47	1.3	20.5	0.356	2.19	--
39	2020-11-17	1.15	0.74	14	5.5	1.3	20.6	-0.154	-1.54	--
40	2021-03-15	2.33	1.7	215	50.3	2.2	163	0.135	1.54	--
41	2021-03-17	3.08	2.56	1210	361	3	1,030	0.0857	1.01	--
42	2021-03-25	3.11	2.58	1280	380	3.02	1,080	0.0891	1.11	--

Definitions

Cook’s D: Cook’s distance, a measure of influence (Helsel and others, 2020).

DFFITS: difference in fits, a measure of influence (Helsel and others, 2020).

E.vars: explanatory variables.

Leverage: a data point’s distance from the middle (mean) value in the x direction (Helsel and others, 2020).

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

MSE: model standard error, also known as standard error of the regression (Helsel and others, 2020).

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

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

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

SSC: suspended-sediment concentration, in milligrams per liter (U.S. Geological Survey pa
rameter code 80154) (U.S. Geological Survey method code SED16).

t value: Student's t value; the coefficient divided by its associated standard error (Hel
sel and others, 2020).

TBY: Turbidity, water, unfiltered, monochrome near infrared light-emitting diode, 780–900
nanometers, detection angle 90±2.5 degrees, in formazin nephelometric units (U.S. Geologi
cal Survey parameter code 63680) (U.S. Geological Survey method code TS213).
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App Version 1.0

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