Model Archive Summary for Suspended-Sediment Concentration at Station 05321195; Blue Earth River at Highway 169 at Mankato, Minnesota

This model archive summary (MAS) documents the suspended-sediment concentration (SSC) model developed to compute SSC from turbidity readings. This is the first model developed for the site.

SITE AND MODEL INFORMATION

Site number: 05321995
Site name: Blue Earth River at Highway 169 at Mankato, Minnesota (MN), Blue Earth County
Location: Latitude N 44°09'15.6", Longitude W 94°01'59.6", referenced to NAD83
Hydrologic Unit: 07020009
Drainage area: 3,550 square miles

Date rating model was created: 3/24/2017
Model calibration data period: 5/28/2015–9/26/2016
Model application date: 4/1/2017
Computed by: Joel Groten (jgroten@usgs.gov), Hydrologist, Minnesota Water Science Center
Reviewed by: Chris Ellison (cellison@usgs.gov), Supervisory Hydrologist, Wyoming-Montana Water Science Center
Reviewed by: Jeffrey Ziegeweid (jrziege@usgs.gov), Hydrologist, Minnesota Water Science Center
Approved by: James Stark (stark@usgs.gov), Center Director, Minnesota Water Science Center

Additional Information

Type	Scheme	Key
doi	http://dx.doi.org	doi:10.5066/F7GH9G61
IPDS	https://ipds.usgs.gov	IP-086084

PHYSICAL SAMPLING EQUIPMENT AND SAMPLING DETAILS

Samples were collected 10 times per year during the open-water season (April through September) throughout the range of continuously observed hydrologic conditions. No samples were collected during the winter months because sediment transport is low (Tornes, 1986) in Minnesota when streamflow is generally contained under ice and receives little sediment input from the surrounding landscape. Water samples were collected using isokinetic samplers and equal-width-increment (EWI) and depth-integrating techniques, following procedures by Edwards and Glysson (1999). Most samples were collected using a D-74 rigid bottle sampler suspended from the downstream side of the U.S. Highway 169 Bridge. The total stream width was divided into 10 equal-width increments, and individual depth-integrated samples were collected at the centroid of each increment. Following collection, samples were transported to the USGS Sediment Laboratory in Iowa City, Iowa, where they were composited into a single sample and analyzed for suspended-sediment concentration (SSC) and percent of particle-size fractions less than 0.0625 millimeters (fines). Analyses results were stored in the National Water Information System (NWIS) database (U.S. Geological Survey, 2017) and can be found at http://mn.water.usgs.gov.

SURROGATE EQUIPMENT AND SETUP DETAILS

A HACH® Solitax turbidity sensor is installed at the site. The turbidity sensor is suspended from the downstream side of the U.S. Highway 169 Bridge and is positioned to collect turbidity readings in the thalweg. The turbidity sensor is housed inside a stainless steel pipe to protect it. The depth of the turbidity sensor in the water column may be adjusted by adjusting the chain length to keep the bottom of the sensor a few feet under water. The battery and datalogger are located in an enclosure mounted on the bridge.

Turbidity Sensor Manufactured characteristics and configuration	
Make	HACH®
Model	Solitax Turbidity
Serial number	1525726
Measuring Technique	Infrared Duo scattered light technique for color-independent turbidity measurement
Measuring Range	0.001 to 4,000 FNU
Measuring Accuracy	Turbidity up to 1,000 FNU: <1% of the measured value ± 0.01 FNU
Reproducibility	< 1%
Ambient Temperature	32˚F to 104˚F
Response Time	1 sec < T90 > 300 sec (adjustable)

MODEL-CALIBRATION DATASET

All data are stored in the National Water Information System (NWIS) database (U.S. Geological Survey, 2017). The complete water-quality record can be found at http://mn.water.usgs.gov. The regression model dataset considered 20 concurrent measurements of SSC and turbidity (TURB) data collected from 5/28/2015 through 9/26/2016. Out of the 21 sampling events during the period while the turbidity sensor was deployed, only 1 SSC value (9/23/2016) was not considered for data analysis because it was collected a day after a previous sample, and it was removed to reduce autocorrelation.

During 2015 and 2016, two sets of EWI samples were collected during each sampling event. Each set (sets A and B) were analyzed individually for SSC and the average of the two sets was used for the model-calibration dataset. The only SSC that was not averaged was on 9/22/2016 because the power supply to the power-reel malfunctioned before the sample was attempted, preventing an isokinetic, EWI sample from being collected. Instead, only one grab sample was obtained from the site. This sample had the highest SSC and TURB values from the two years of data collection. It is thought to be representative because this sampling event had elevated streamflow and the higher velocities would provide a representative mixture of suspended sand in the water column.

This site is not a USGS stream gaging station, so streamflow was not explored as an explanatory variable. There are two upstream USGS streamgages that are used as a reference for estimating streamflow at the sampling location. The two streamgages are Blue Earth River near Rapidan, MN (USGS station 05320000) and the Le Sueur River near Rapidan, MN (USGS station 05320500). Streamflows from the upstream gages contribute to the total streamflow at the sampling site.

MODEL DEVELOPMENT

An ordinary linear least squares regression analysis was carried out in the R open source environment (R Development Core Team, 2011), using different combinations of untransformed (Appendix 1) and $\log_{10}$-transformed data. SSC concentrations were evaluated for normal distribution of the data and potential outliers. The outlier test criteria flagged potential outliers and were further investigated. No outliers were removed from the dataset. The distribution of residuals were examined for normality, and plots of residuals (the difference between the measured and predicted values) as compared to predicted SSC were examined for homoscedasticity (meaning that their departures from zero did not change substantially over the range of predicted values). This comparison indicated that the data were not normally distributed and led to the conclusion that the most appropriate and reliable model would be one that estimated $\log_{10}$(SSC).

An ordinary linear least squares regression analysis with $\log_{10}$-transformed data was performed. Log_{10}(TURB) was selected as the best predictor of $\log_{10}$(SSC) based on residual plots, relatively high adjusted coefficient of determination (adjusted R^2), and relatively low model standard percentage error (MSPE). Values of the aforementioned statistics and metrics were computed and are included below, along with all relevant sample data and more in-depth statistical information.

MODEL SUMMARY

Summary of final regression analysis for suspended-sediment concentration at site number 05321995. In the figures and tables below, the "log" in the R outputs refers to "$\log_{10}$". Suspended-sediment concentration-based model:
$\log_{10}(SSC) = [(0.853)\log_{10}(TURB)] + 0.777$,

where
SSC = suspended-sediment concentration, in milligrams per liter (mg/L); and,
TURB = Turbidity, in formazin nephelometric units (FNU).

The use of turbidity as an explanatory variable is appropriate physically and statistically. Turbidity makes sense physically because suspended sediment is composed of particles that scatter light in water. The relation between turbidity and SSC can vary given varying concentrations of organic suspended particles that increase turbidity, but analysis of organic suspended particles was not included in the SSC analysis. The 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 1.01. The retransformed model, accounting for BCF is:

$$SSC = 5.98 \times TURB^{0.853} \times 1.01.$$

Model Statistics, Data, and Plots (In the figures and tables below, the "log" in the R outputs refers to "$\log_{10}$")

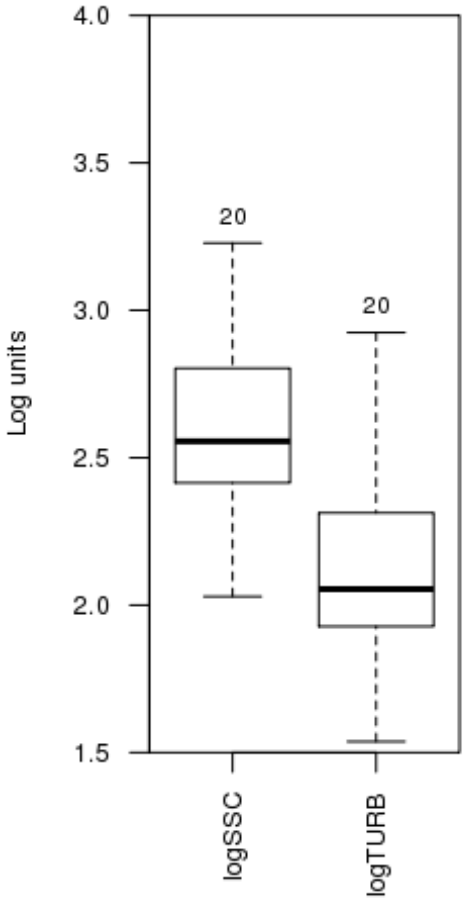
Model

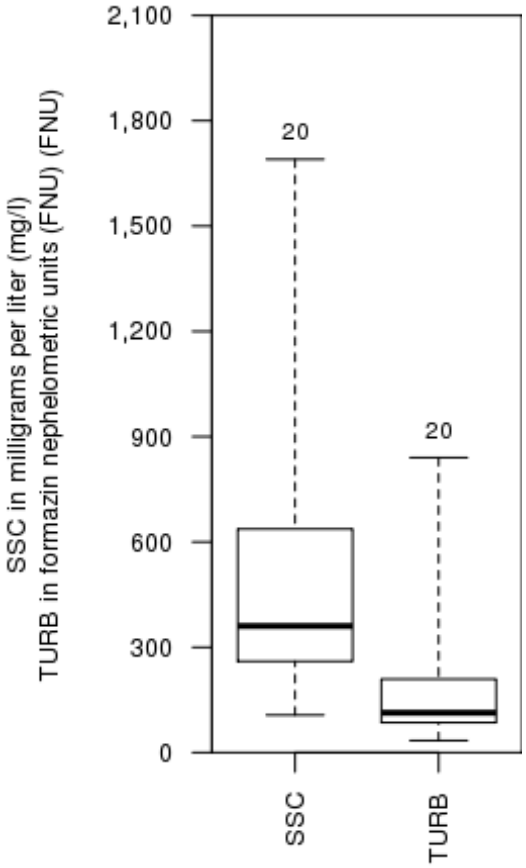
$\log_{10}(SSC) = [(0.853)\log_{10}(TURB)] + 0.777$

Variable Summary Statistics

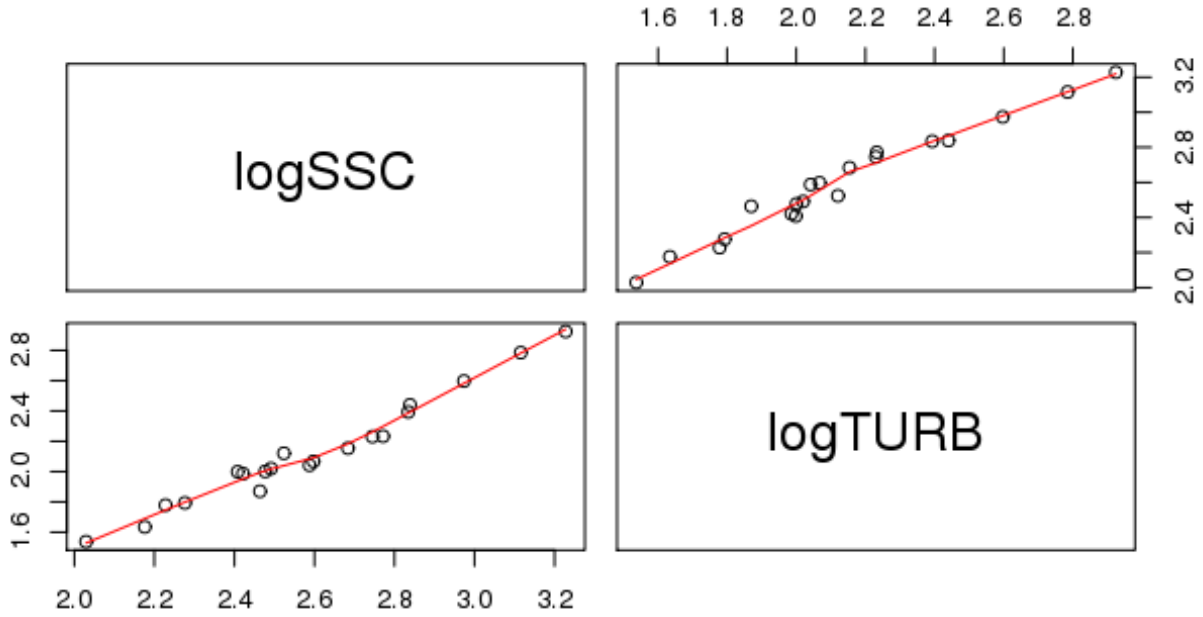
	logSSC	SSC	logTURB	TURB
Minimum	2.03	107	1.54	34.5
1st Quartile	2.41	260	1.93	85.5
Median	2.56	361	2.05	113.0
Mean	2.59	505	2.13	194.0
3rd Quartile	2.80	637	2.31	209.0
Maximum	3.23	1690	2.92	840.0

Box Plots





Exploratory Plots



Basic Model Statistics

```
Number of Observations                                20
Standard error (RMSE)                             0.0571
Average Model standard percentage error (MSPE)    13.2
Coefficient of determination (R²)                 0.968
Adjusted Coefficient of Determination (Adj. R²)   0.966
Bias Correction Factor (BCF)                      1.01
```

Explanatory Variables

```
            Coefficients Standard Error t value Pr(>|t|)
(Intercept)        0.777         0.0788    9.87 1.10e-08
logTURB            0.853         0.0365   23.40 6.45e-15
```

Correlation Matrix

```
Intercept E.vars
Intercept     1.000 -0.987
E.vars       -0.987  1.000
```

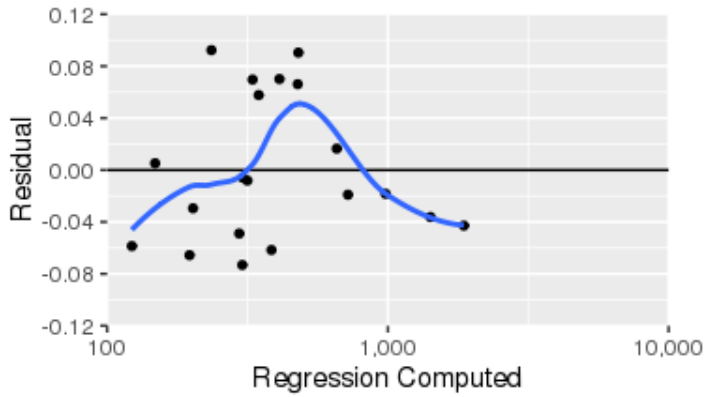
Outlier Test Criteria

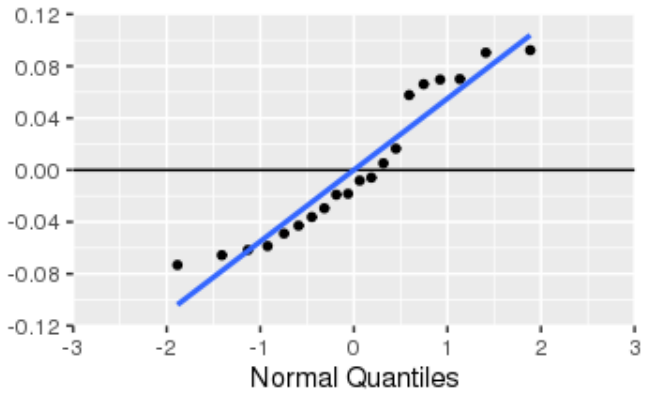
```
Leverage Cook's D   DFFITS
   0.150    0.106    0.447
```

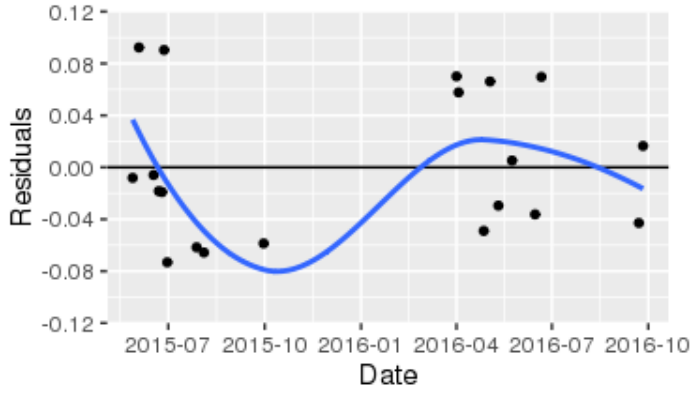
Flagged Observations

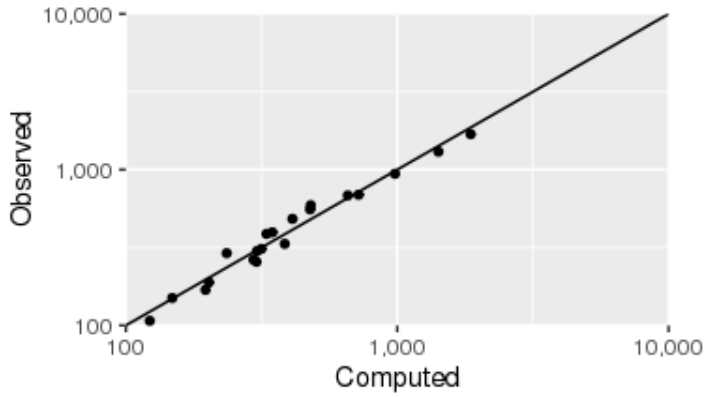
	logSSC	Estimate	Residual	Standard Residual	Studentized Residual	Leverage	Cook's D	DFFITS
6/3/2015 9:47	2.46	2.37	0.09230	1.6900	1.7800	0.0777	0.120000	0.5180
9/30/2015 11:07	2.03	2.09	-0.05860	-1.1400	-1.1600	0.1940	0.157000	-0.5660
5/24/2016 16:07	2.18	2.17	0.00521	0.0992	0.0964	0.1500	0.000871	0.0406
6/15/2016 17:30	3.12	3.15	-0.03630	-0.7220	-0.7120	0.2250	0.075800	-0.3840
9/22/2016 16:20	3.23	3.27	-0.04290	-0.9030	-0.8980	0.3080	0.181000	-0.5990

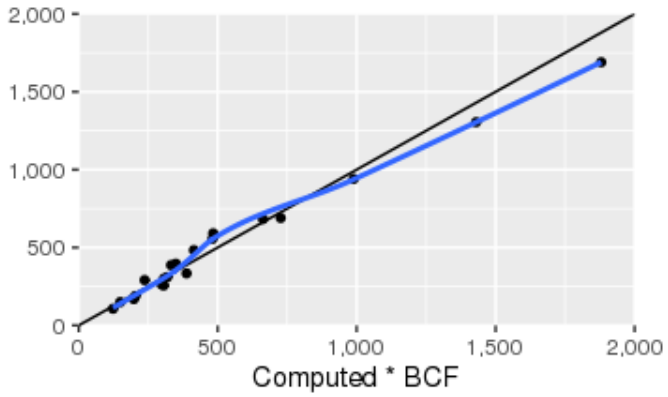
Statistical Plots

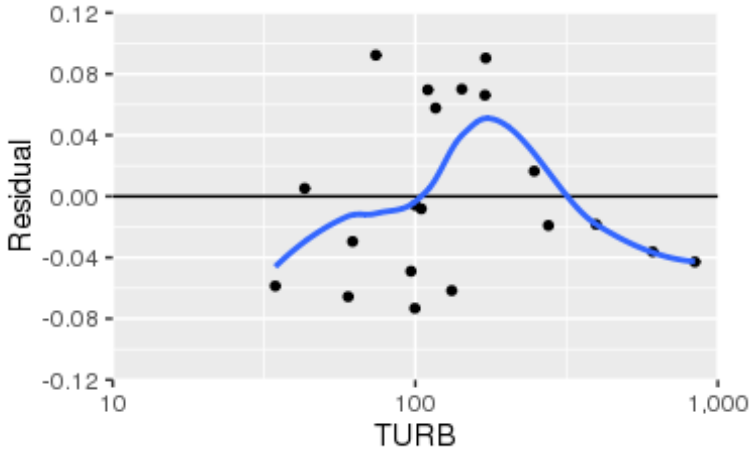


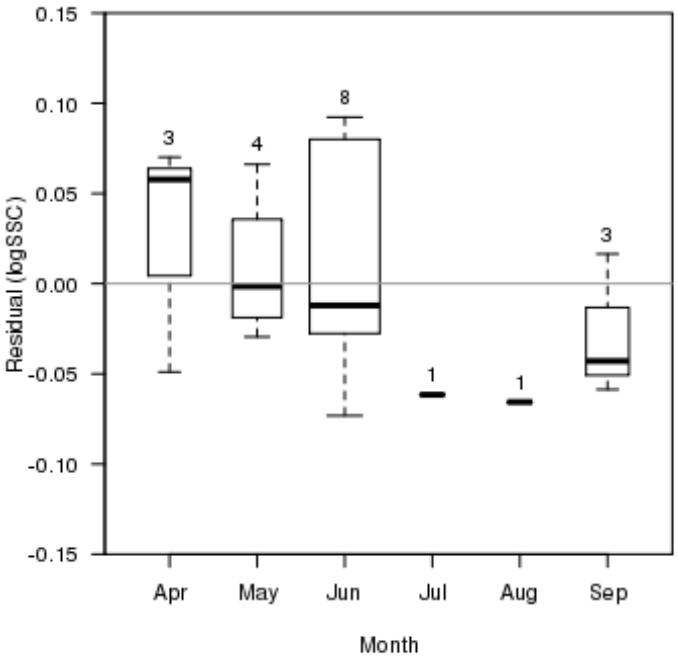


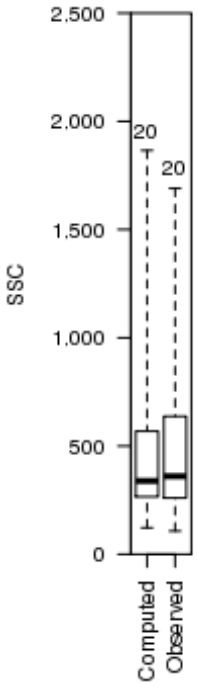


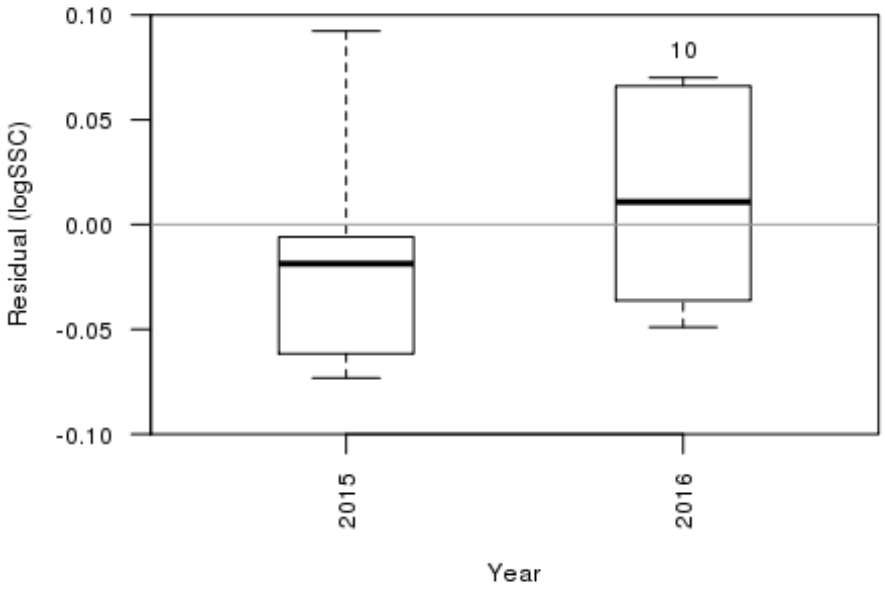




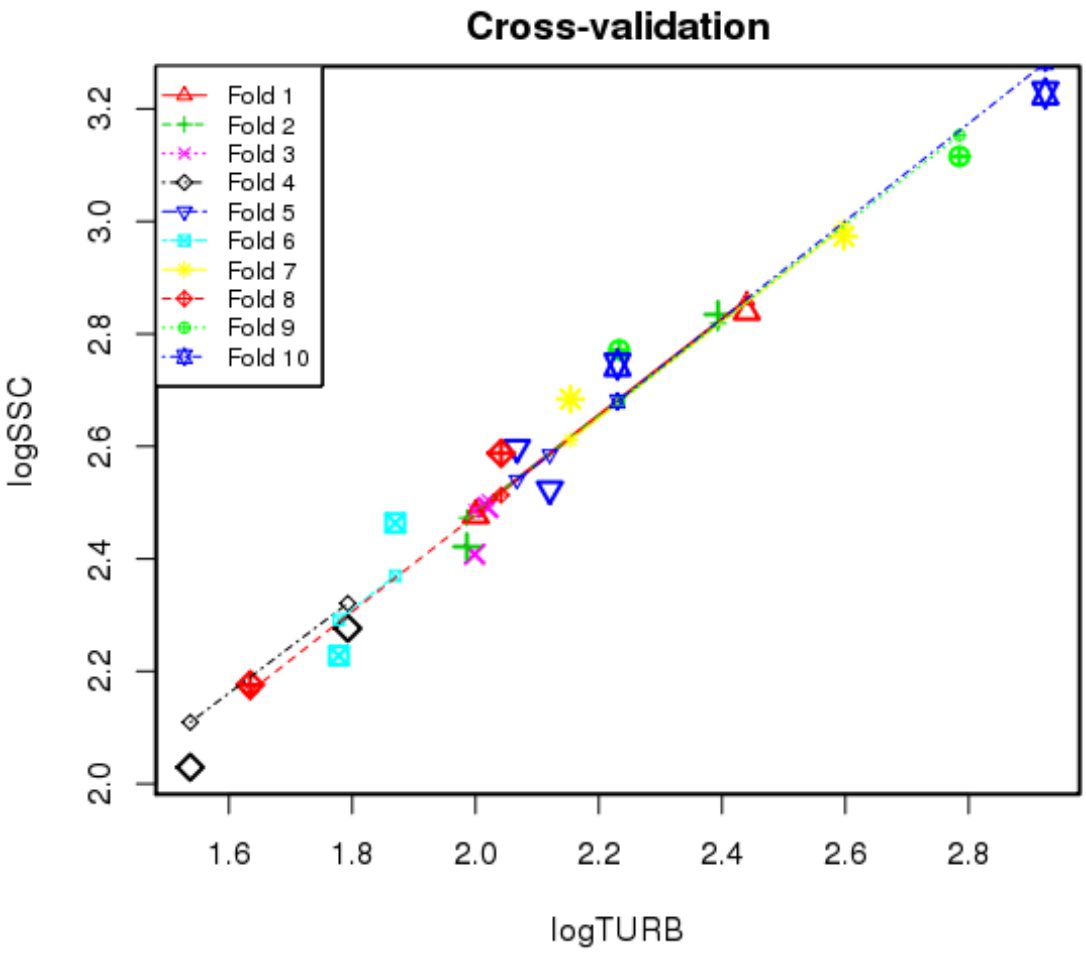

0.12
0.08
0.04
0.00
-0.04
-0.08
-0.12
Residual
10
100
1,000
TURB


0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
Residual (bgSSC)
3
4
8
1
1
3
Apr
May
Jun
Jul
Aug
Sep
Month

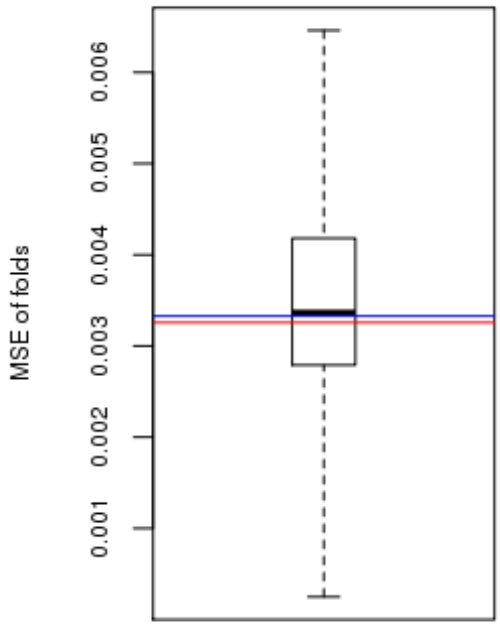

2,500
2,000
1,500
1,000
500
0
SSC
20
20
Computed
Observed



Cross-Validation




```
              Minimum MSE of folds:  0.000249
                 Mean MSE of folds:  0.003330
               Median MSE of folds:  0.003360
              Maximum MSE of folds:  0.006460
(Mean MSE of folds) / (Model MSE):  1.020000
```




```
Red line - Model MSE

Blue line - Mean MSE of folds
```

Model-Calibration Data Set

	Date	logSSC	logTURB	SSC	TURB	Computed logSSC	Computed SSC	Residual	Normal Quantiles	Censored Values
1	2015-05-28	2.49	2.02	310	105	2.5	318	-0.00814	0.0621	--
2	2015-06-03	2.46	1.87	291	74.1	2.37	237	0.0923	1.89	--
3	2015-06-17	2.48	2	300	100	2.48	307	-0.00589	0.187	--
4	2015-06-22	2.97	2.6	941	396	2.99	989	-0.0183	-0.0621	--
5	2015-06-25	2.84	2.44	690	276	2.86	727	-0.0191	-0.187	--
6	2015-06-27	2.77	2.23	591	171	2.68	484	0.0904	1.41	--
7	2015-06-30	2.41	2	256	99.7	2.48	305	-0.0732	-1.89	--
8	2015-07-28	2.52	2.12	334	132	2.59	388	-0.0616	-1.13	--
9	2015-08-04	2.23	1.78	169	60	2.29	198	-0.0656	-1.41	--
10	2015-09-30	2.03	1.54	107	34.5	2.09	123	-0.0586	-0.922	--
11	2016-04-01	2.68	2.15	483	143	2.61	414	0.0701	1.13	--
12	2016-04-03	2.6	2.07	396	117	2.54	349	0.0577	0.591	--
13	2016-04-27	2.42	1.99	264	96.8	2.47	298	-0.049	-0.746	--
14	2016-05-03	2.75	2.23	556	170	2.68	481	0.0661	0.746	--

```
 15 2016-05-11   2.28    1.79  189 62.1     2.31       204  -0.0295    -0.315       --
 16 2016-05-24   2.18    1.63  150 43.1     2.17       149  0.00521     0.315       --
 17 2016-06-15   3.12    2.78 1310  609     3.15      1430  -0.0363    -0.449       --
 18 2016-06-21   2.59    2.04  387  110     2.52       332   0.0697     0.922       --
 19 2016-09-22   3.23    2.92 1690  840     3.27      1880  -0.0429    -0.591       --
 20 2016-09-26   2.83    2.39  683  247     2.82       663   0.0165     0.449       --
```

Definitions

```
SSC: Suspended sediment concentration (SSC) in mg/l (80154)
TURB: Turbidity in FNU (63680)
```

App Version 1.0

References

Duan, Naihua, 1983, Smearing estimate—A nonparametric retransformation method: Journal of the American Statistical Association, v. 78, no. 383, p. 605–610. [Also available at http://dx.doi.org/10.2307/2288126.]

Edwards, T.K., and Glysson, G.D., 1999, Field methods for measurement of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. C2, 89 p. [Also available at http://pubs.usgs.gov/twri/twri3-c2/.]

R Development Core Team, 2011, R installation and administration, Version 2.14.1, 2011-12-22: 73 p. [Also available at http://streaming.stat.iastate.edu/CRAN/doc/manuals/Radmin.pdf.]

Tornes, L.H., 1986, Suspended sediment in Minnesota streams: U.S. Geological Survey Water-Resources Investigations Report 85–4312, 33 p. [Also available at http://pubs.er.usgs.gov/publication/wri854312.]

U.S. Geological Survey, 2017, National Water Information System (NWISWeb)—USGS surface-water data for Minnesota: U.S. Geological Survey database, accessed January, 2017, at http://waterdata.usgs.gov/mn/nwis/sw/. [Also available at http://dx.doi.org/10.5066/F7P55KJN.]

Appendix 1

Model Statistics, Data, and Plots

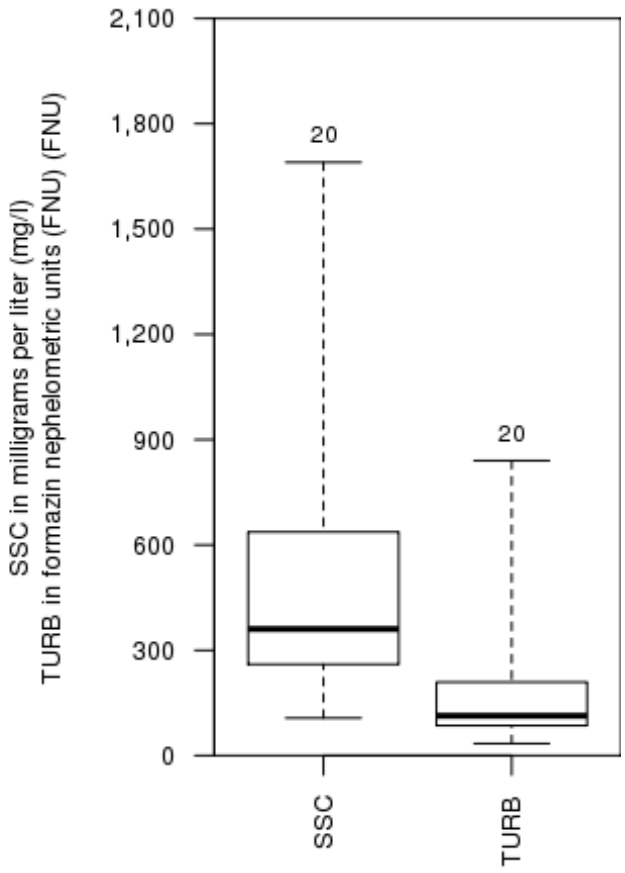
Model

SSC = + 1.95 * TURB + 125

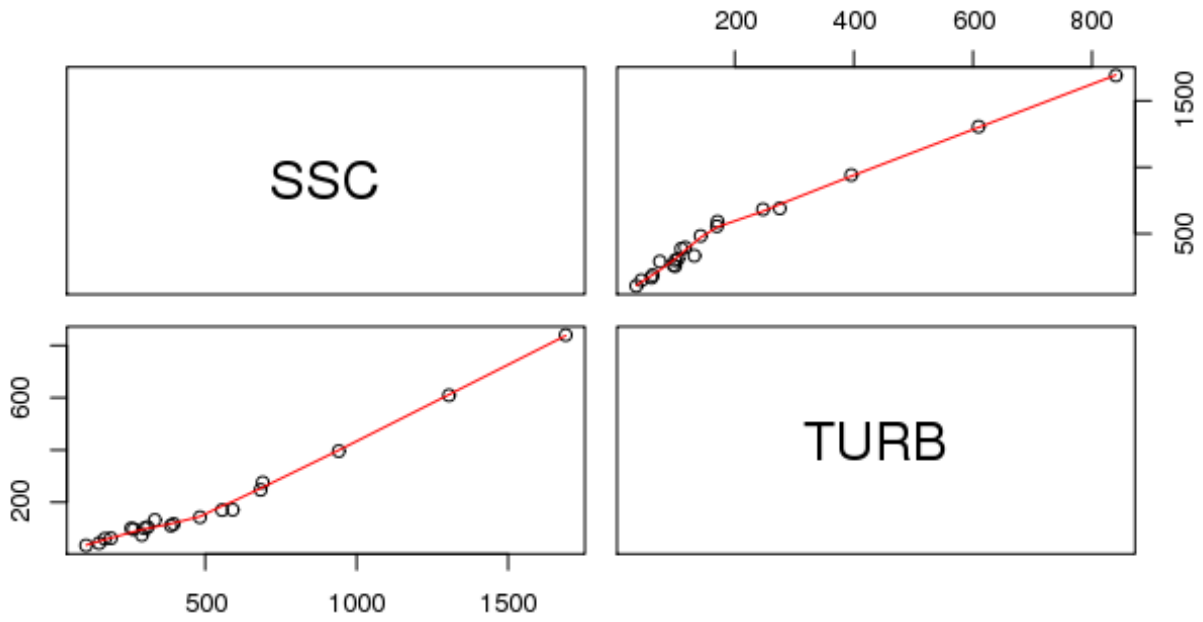
Variable Summary Statistics

	SSC	TURB
Minimum	107	34.5
1st Quartile	260	85.5
Median	360	113.0
Mean	505	194.0
3rd Quartile	637	209.0
Maximum	1690	840.0

Box Plots



Exploratory Plots



Basic Model Statistics

```
Number of Observations                              20
Standard error (RMSE)                             67.2
Average Model standard percentage error (MSPE)    13.3
Coefficient of determination (R²)                0.974
Adjusted Coefficient of Determination (Adj. R²) 0.972
```

Explanatory Variables

```
            Coefficients Standard Error t value Pr(>|t|)
(Intercept)       125.00        21.0000    5.96 1.21e-05
TURB                1.95         0.0754   25.90 1.08e-15
```

Correlation Matrix

```
           Intercept E.vars
Intercept      1.000 -0.698
E.vars        -0.698  1.000
```

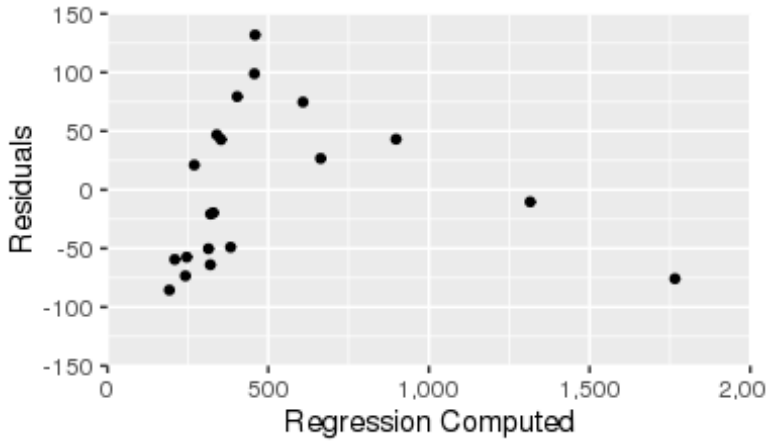
Outlier Test Criteria

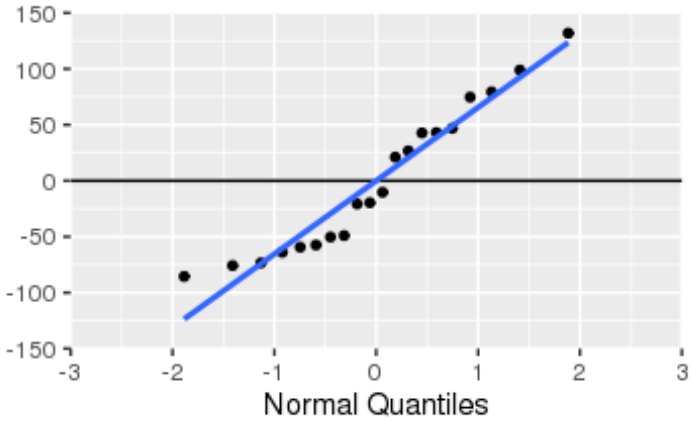
```
Leverage Cook's D   DFFITS
   0.150    0.106    0.447
```

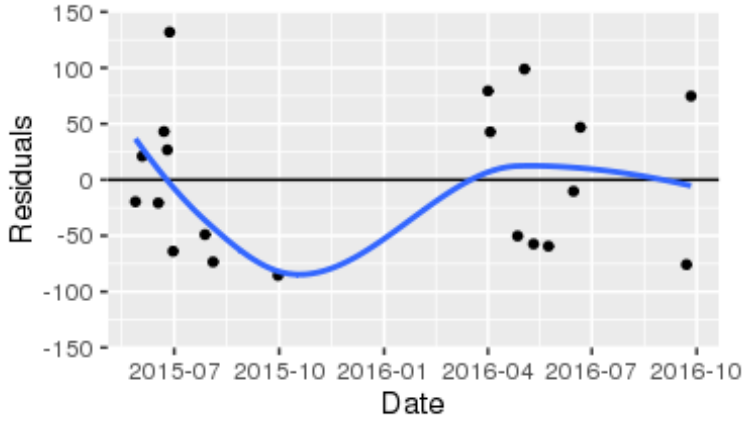
Flagged Observations

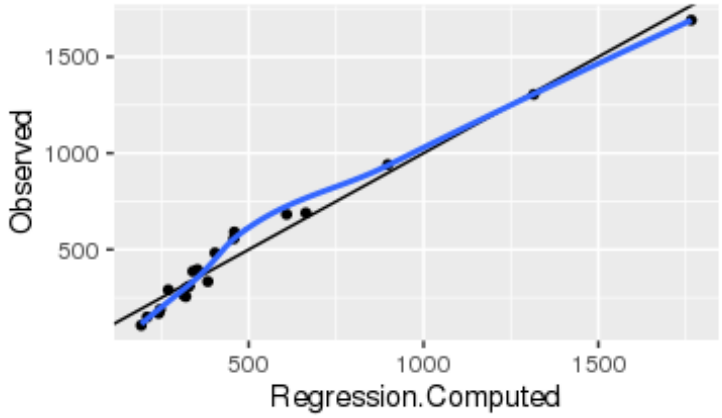
	SSC	Estimate	Residual	Standard Residual	Studentized Residual	Leverage	Cook's D	DFFITS
6/27/2015 11:07	591	459	132.0	2.010	2.220	0.0507	0.10800	0.514
6/15/2016 17:30	1300	1320	-10.3	-0.179	-0.174	0.2670	0.00585	-0.105
9/22/2016 16:20	1690	1770	-75.8	-1.730	-1.840	0.5750	2.03000	-2.140

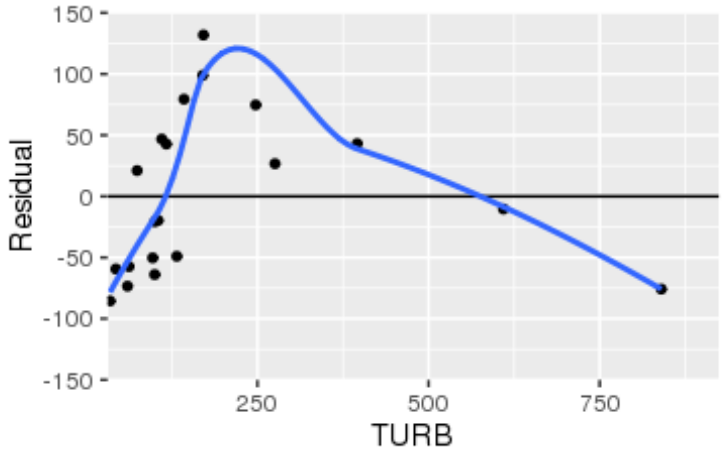
Statistical Plots

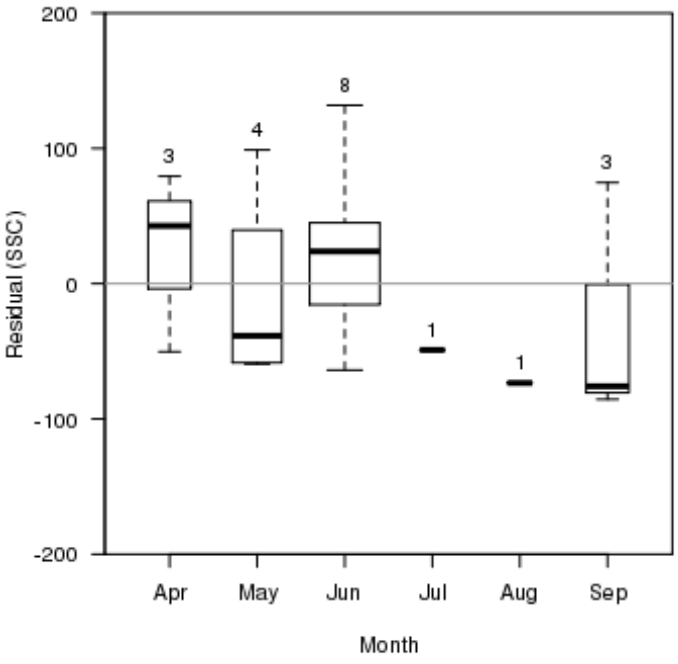


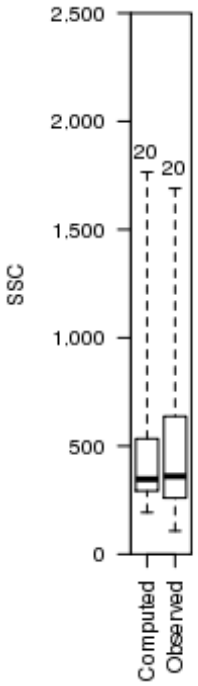


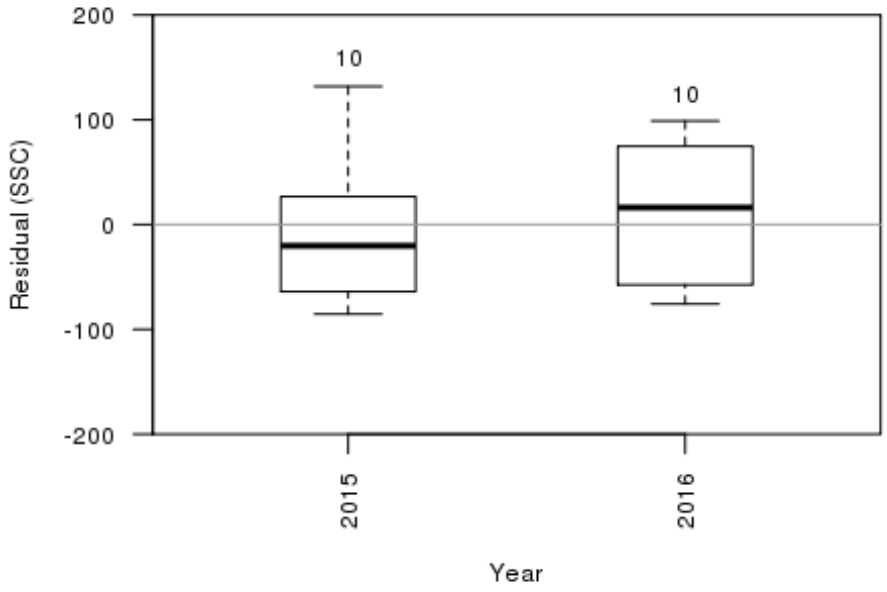




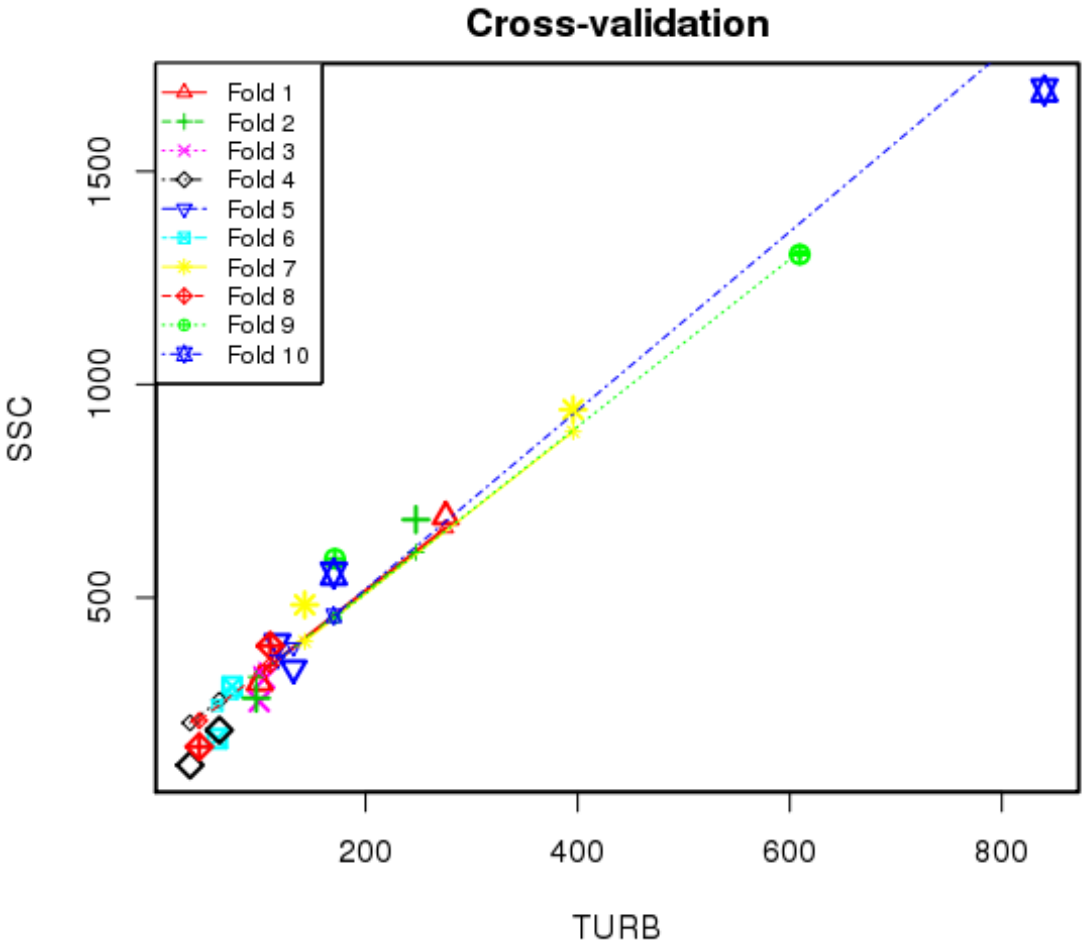

150
100
50
0
-50
-100
-150
Residual
250
500
750
TURB


200
100
0
-100
-200
Residual (SSC)
3
4
8
1
1
3
Apr
May
Jun
Jul
Aug
Sep
Month

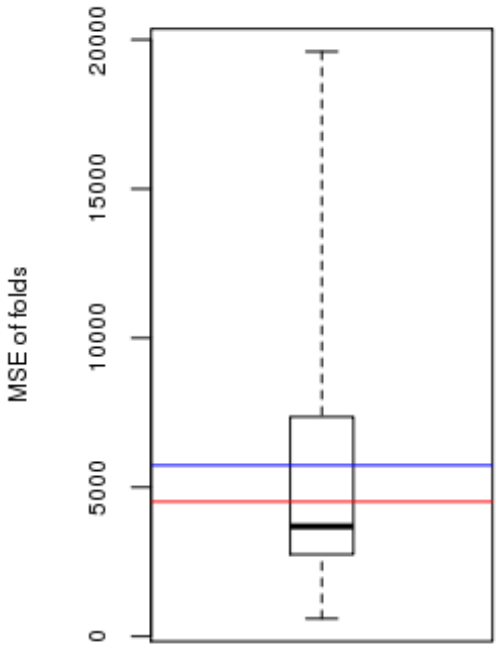

2,500
2,000
1,500
1,000
500
0
SSC
20
20
Computed
Observed



Cross Validation



```
             Minimum MSE of folds:    596.00
                Mean MSE of folds:   5740.00
              Median MSE of folds:   3680.00
             Maximum MSE of folds:  19600.00
(Mean MSE of folds) / (Model MSE):      1.27
```




```
Red line - Model MSE

Blue line - Mean MSE of folds
```

Model-Calibration Data Set

	Date	SSC	TURB	Computed SSC	Residual	Normal Quantiles	Censored Values
1	2015-05-28	310	105	330	-19.6	-0.0621	--
2	2015-06-03	291	74.1	270	21.1	0.187	--
3	2015-06-17	300	100	321	-20.7	-0.187	--
4	2015-06-22	941	396	898	43.1	0.591	--
5	2015-06-25	690	276	663	26.7	0.315	--
6	2015-06-27	591	171	459	132	1.89	--
7	2015-06-30	256	99.7	320	-63.9	-0.922	--

```
 8 2015-07-28  334  132      383      -49    -0.315       --
 9 2015-08-04  169   60      242    -73.4     -1.13       --
10 2015-09-30  107 34.5      193    -85.5     -1.89       --
11 2016-04-01  483  143      404     79.4      1.13       --
12 2016-04-03  396  117      353     42.8     0.449       --
13 2016-04-27  264 96.8      314    -50.3    -0.449       --
14 2016-05-03  556  170      457     98.9      1.41       --
15 2016-05-11  189 62.1      246    -57.4    -0.591       --
16 2016-05-24  150 43.1      209    -59.4    -0.746       --
17 2016-06-15 1305  609     1320    -10.3    0.0621       --
18 2016-06-21  387  110      340     46.9     0.746       --
19 2016-09-22 1690  840     1770    -75.8     -1.41       --
20 2016-09-26  683  247      608     74.8     0.922       --
```

Definitions

```
SSC: Suspended sediment concentration (SSC) in mg/l (80154)
TURB: Turbidity in FNU (63680)
```

App Version 1.0