Appendix 1. Model Archive Summary for Total Suspended Solids at U.S. Geological Survey Site 07144780, North Fork Ninnescah River above Cheney Reservoir, Kansas, during January 1, 1999, through October 16, 2009

This model archive summary summarizes the total suspended solids (TSS) model developed to compute hourly or daily TSS during January 1, 1999, through October 16, 2009. This model supersedes all prior models used during this period. The methods used follow U.S. Geological Survey (USGS) guidance as referenced in relevant Office of Surface Water/Office of Water Quality Technical Memoranda and USGS Techniques and Methods, book 3, chapter C4 (Rasmussen and others, 2009).

Site and Model Information

Site number: 07144780
Site name: North Fork Ninnescah River above Cheney Reservoir, Kansas
Location: Lat 37°51'45", long 98°00'49" referenced to North American Datum of 1927, in NE 1/4 SE 1/4 NE 1/4 sec.19, T.25 S., R.6 W., Reno County, Kans., Hydrologic Unit 11030014, on right bank at upstream side of county highway bridge, 10 miles south of Hutchinson, 18.1 miles upstream from Cheney Dam.

Equipment: A YSI 6600 Extended Deployment System water-quality monitor equipped with sensors for water temperature, specific conductance, pH, dissolved oxygen, and turbidity (a YSI Model 6026 turbidity sensor [November 9, 1998, to December 1, 2010] and a YSI Model 6136 turbidity sensor [October 17, 2009, to November 12, 2015; March 31, 2017, to June 7, 2017]) (YSI Incorporated, 2007, 2012). The YSI 6600 water-quality monitor was in operation during November 9, 1998, through November 12, 2015.

Date model was developed: April 26, 2019

Model calibration data period: January 26, 1999, to August 25, 2010

Model Data

All data were collected using USGS protocols (U.S. Geological Survey, 2006; Wagner and others, 2006; Sauer and Turnipseed, 2010; Turnipseed and Sauer, 2010) and are stored in the National Water Information System (NWIS) database (https://doi.org/10.5066/F7P55KJN; U.S. Geological Survey, 2020). Explanatory variables were evaluated individually and in combination. Potential explanatory variables included streamflow, water temperature, specific conductance, pH, dissolved oxygen, and turbidity. Seasonal components (sine and cosine variables) were also evaluated as explanatory variables.

The regression model is based on 77 concomitant values of discretely collected TSS and continuously measured turbidity during January 26, 1999, through August 25, 2010. Discrete samples were collected over a range of streamflows and turbidity conditions. No samples were less than laboratory detection limits. Summary statistics and the complete model-calibration data are provided below. Outliers were identified using studentized residuals (for values greater than 3 or less than −3). The sample collected on September 19, 2001, had large heterogeneity in the channel cross-sectional data during sample collection and was removed from the model calibration dataset. Outliers in previously published versions of this model (Christensen and others, 2006; Stone and others, 2013) 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.

Total Suspended Solids

Discrete samples were collected from the downstream side of the bridge or instream within 50 feet of the bridge using equal-width-increment, multiple vertical, single vertical or grab methods following U.S. Geological Survey (2006) and Rasmussen and others (2014). Discrete samples were collected on a semifixed to event-based schedule ranging from 2 to 17 samples per year with a Federal Interagency Sedimentation Project U.S. 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 TSS by the Wichita Municipal Water and Wastewater Laboratory in Wichita, Kans., according to standard methods (American Public Health Association and others, 1995).

Continuous Data

Turbidity was measured using a YSI model 6026 sensor installed during November 9, 1998, through December 1, 2010. Concomitant turbidity values were time interpolated. If continuous data were not available (2 or more hours of specific conductance values bracketing the sample collection time were missing) because of fouling, changes in equipment, or unsuitable site conditions, then the field monitor turbidity value measured during sampling was substituted. If no concomitant continuous data were available, the sample was not included in the dataset.

Model Development

Ordinary least squares regression analysis was done using R programming language (R Core Team, 2019) to relate discretely collected TSS 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 calculated TSS 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) was ultimately selected.

Turbidity and seasonality were selected as the best predictors of logarithm base 10 ($\log_{10}$) (TSS) based on residual plots, relatively high coefficient of determination (R^2), and relatively low model standard percentage error (MSPE).

Model Summary

Summary of final TSS regression analysis at USGS site 07144780:

TSS-based model:

$$\log_{10}(TSS) = 0.806 \times \log_{10}(TBY6026) + 0.135 \times \sin(2\pi D) - 0.0463 \times \cos(2\pi D) + 0.408,$$

where,

> TSS = total suspended solids, in milligrams per liter;
> $TBY6026$ = turbidity, YSI model 6026, in formazin nephelometric units; and
> D = date, in decimal years.

The use of turbidity and seasonality as explanatory variables 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 suspended-sediment concentration (SSC) can vary given varying concentrations of organic suspended particles that increase turbidity but are not included in the SSC analysis. Seasonality as an explanatory variable is appropriate statistically because rainfall and runoff typically vary during different seasons.

The log-transformed model may be retransformed to original units so that TSS 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 1.06. The retransformed model, accounting for BCF, is as follows:

$$TSS = (TBY6026^{0.806} \times 10^{[0.135\times\sin(2\pi D)]} \times 10^{[-0.0463\times\cos(2\pi D)]} \times 10^{0.408}) \times 1.06$$

Previous Models

Version	Model Equation	Reference
1.0	$\log_{10}(TSS) = 0.893 \times \log_{10}(TBY6026) + 0.253$	Christensen and others (2006)
1.1	$\log_{10}(TSS) = 0.903 \times \log_{10}(TBY6026) + 0.252$	Stone and others (2013)

Model Statistics, Data, and Plots

Definitions for terms used in this output can be found at the end of this document.

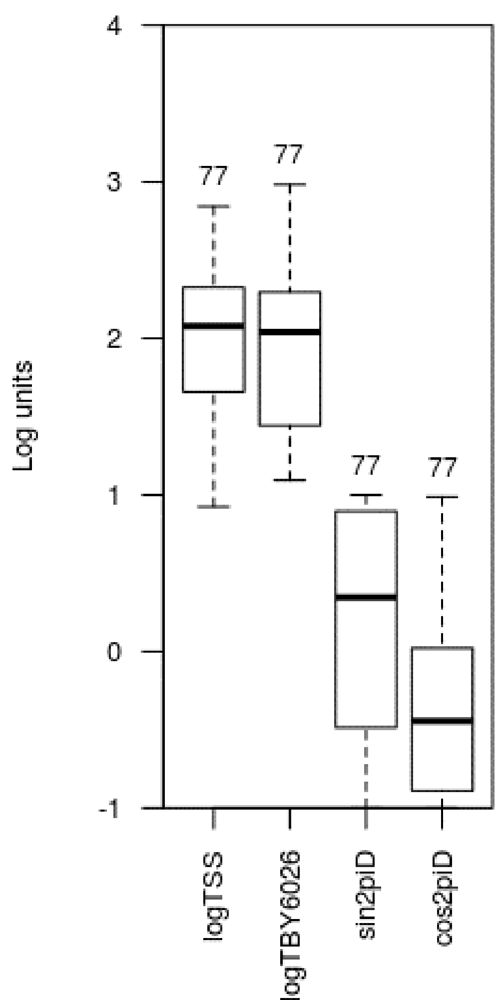
Model

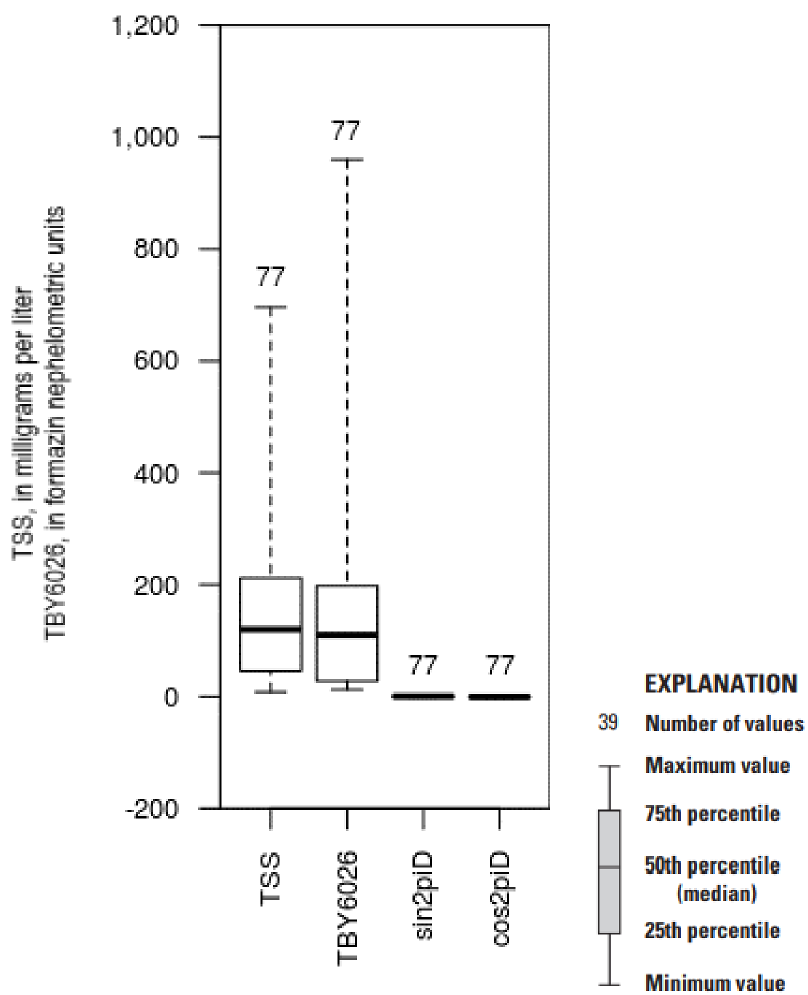
$\log TSS = + 0.806 * \log TBY6026 + 0.135 * \text{sin2pi}D - 0.0463 * \text{cos2pi}D + 0.408$

Variable Summary Statistics

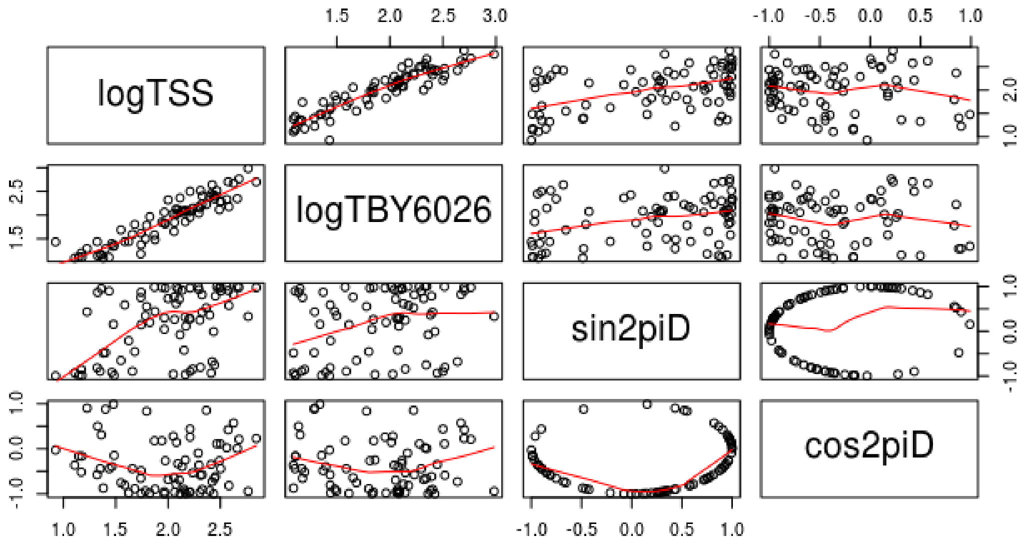
	logTSS	TSS	logTBY6026	sin2piD	cos2piD	TBY6026
Minimum	0.924	8.4	1.09	-1.000	-1.0000	12.4
1st Quartile	1.660	45.6	1.44	-0.486	-0.8900	27.7
Median	2.080	120.0	2.04	0.346	-0.4440	110.0
Mean	1.990	157.0	1.91	0.194	-0.3650	144.0
3d Quartile	2.330	212.0	2.30	0.896	0.0215	198.0
Maximum	2.840	696.0	2.98	1.000	0.9880	960.0

Box Plots





Exploratory Plots



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

Basic Model Statistics

For a detailed definition and explanation of the terms used below, refer to Helsel and Hirsch (2002).

```
Number of Observations                                    77
Standard error (RMSE)                                  0.153
Average Model standard percentage error (MSPE)          35.9
Coefficient of determination (R²)                      0.894
Adjusted Coefficient of Determination (Adj. R²)         0.89
Bias Correction Factor (BCF)                            1.06

Variance Inflation Factors (VIF)
logTBY6026    sin2piD    cos2piD
      1.11       1.13       1.05
```

Explanatory Variables

```
            Coefficients Standard Error t value Pr(>|t|)
(Intercept)       0.4080         0.0724    5.63 3.17e-07
logTBY6026        0.8060         0.0376   21.40 3.10e-33
sin2piD           0.1350         0.0256    5.26 1.39e-06
cos2piD          -0.0463         0.0322   -1.44 1.55e-01
```

Correlation Matrix

```
           Intercept logTBY6026 sin2piD cos2piD
Intercept     1.0000     -0.953   0.201  0.0499
logTBY6026   -0.9530      1.000  -0.303  0.1270
sin2piD       0.2010     -0.303   1.000 -0.1960
cos2piD       0.0499      0.127  -0.196  1.0000
```

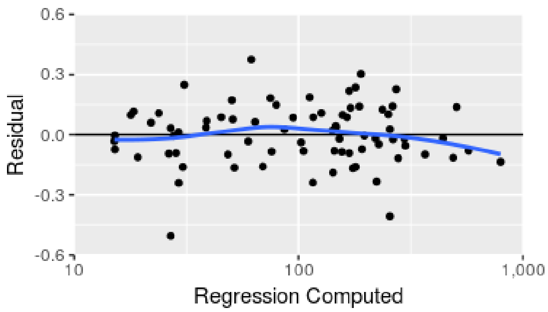
Outlier Test Criteria

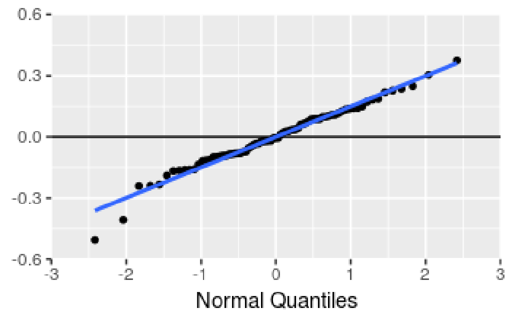
```
Leverage Cook's D   DFFITS
   0.156    0.319    0.456
```

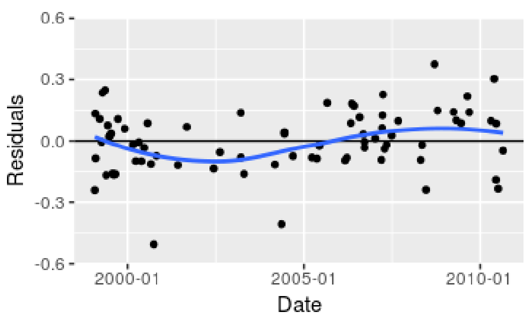
Flagged Observations

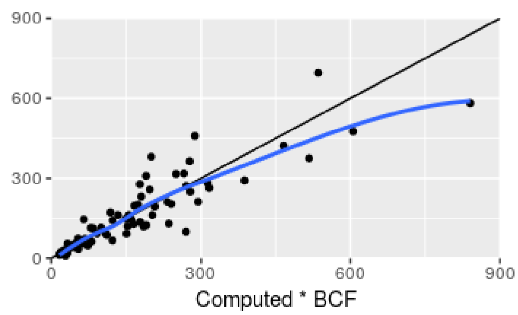
	logTSS	Estimate	Residual	Standard Residual	Studentized Residual	Leverage	Cook's D	DFFITS
1/26/1999 11:50	1.230	1.47	-0.241	-1.66	-1.68	0.0986	0.0752	-0.555
5/13/1999 10:25	1.740	1.49	0.249	1.69	1.71	0.0738	0.0570	0.484
9/28/2000 10:30	0.924	1.43	-0.505	-3.41	-3.70	0.0611	0.1900	-0.944
5/14/2004 10:35	2.000	2.41	-0.407	-2.71	-2.83	0.0307	0.0580	-0.504
9/15/2008 10:55	2.160	1.79	0.375	2.52	2.62	0.0519	0.0871	0.614

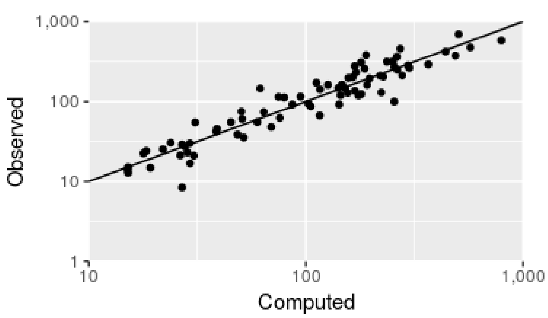
Statistical Plots

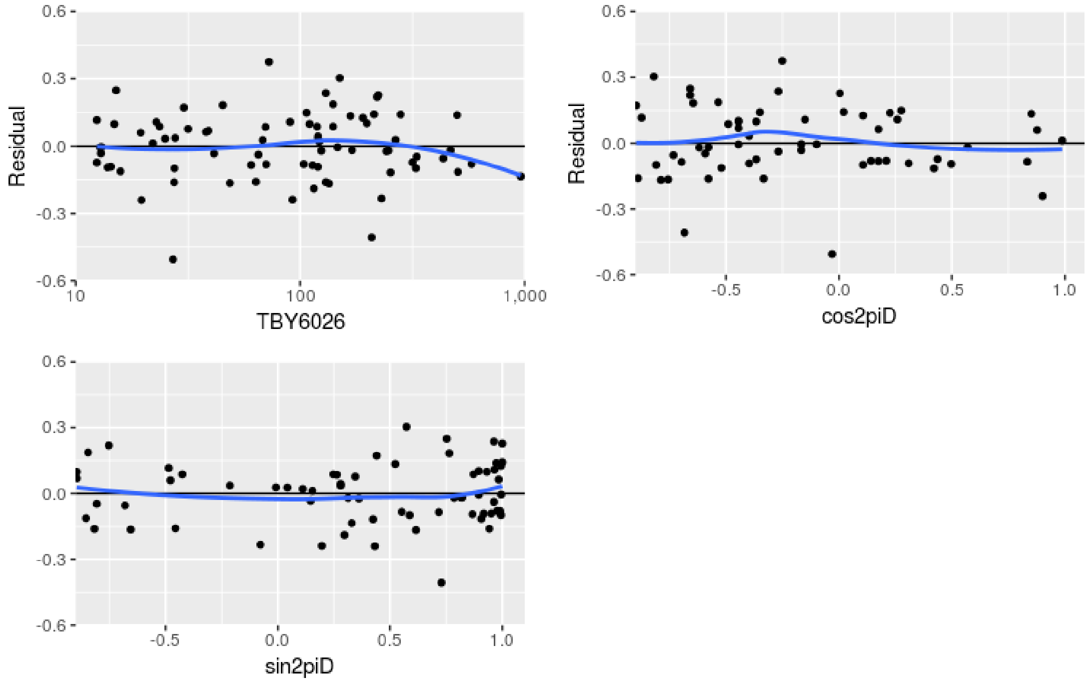


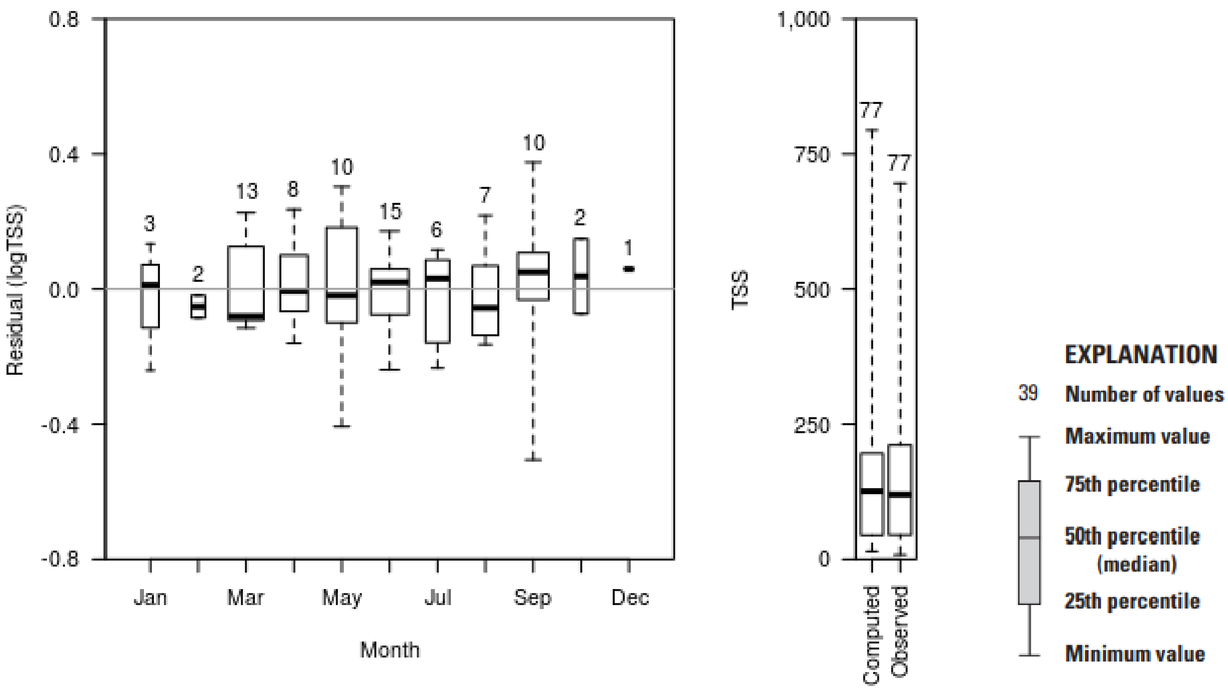


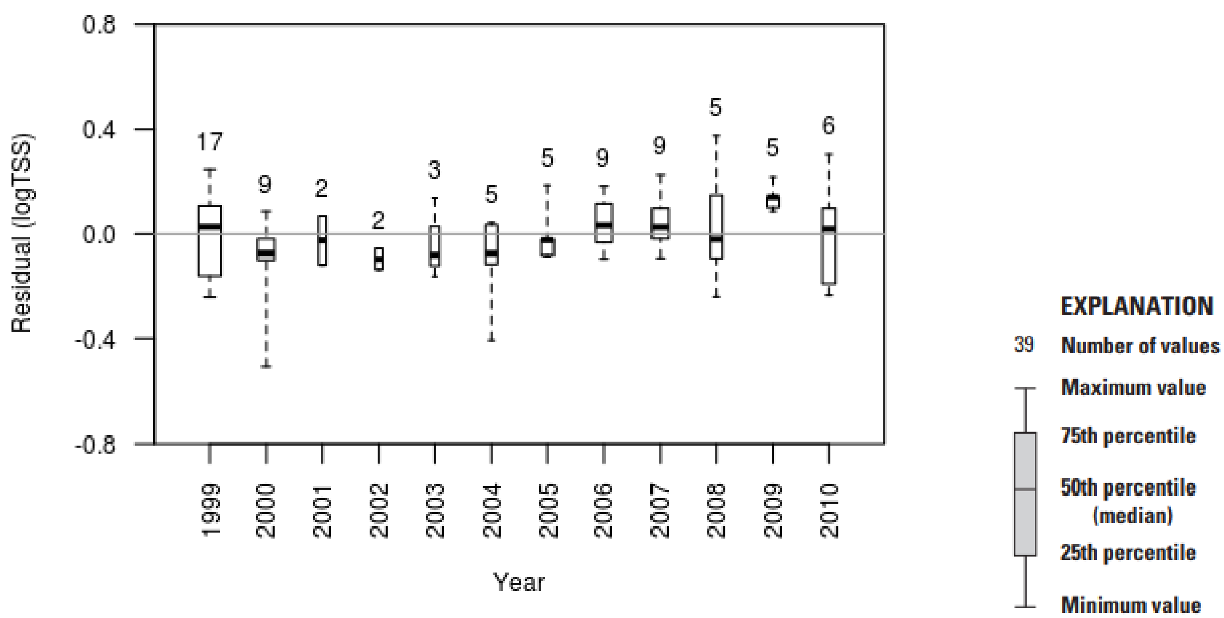




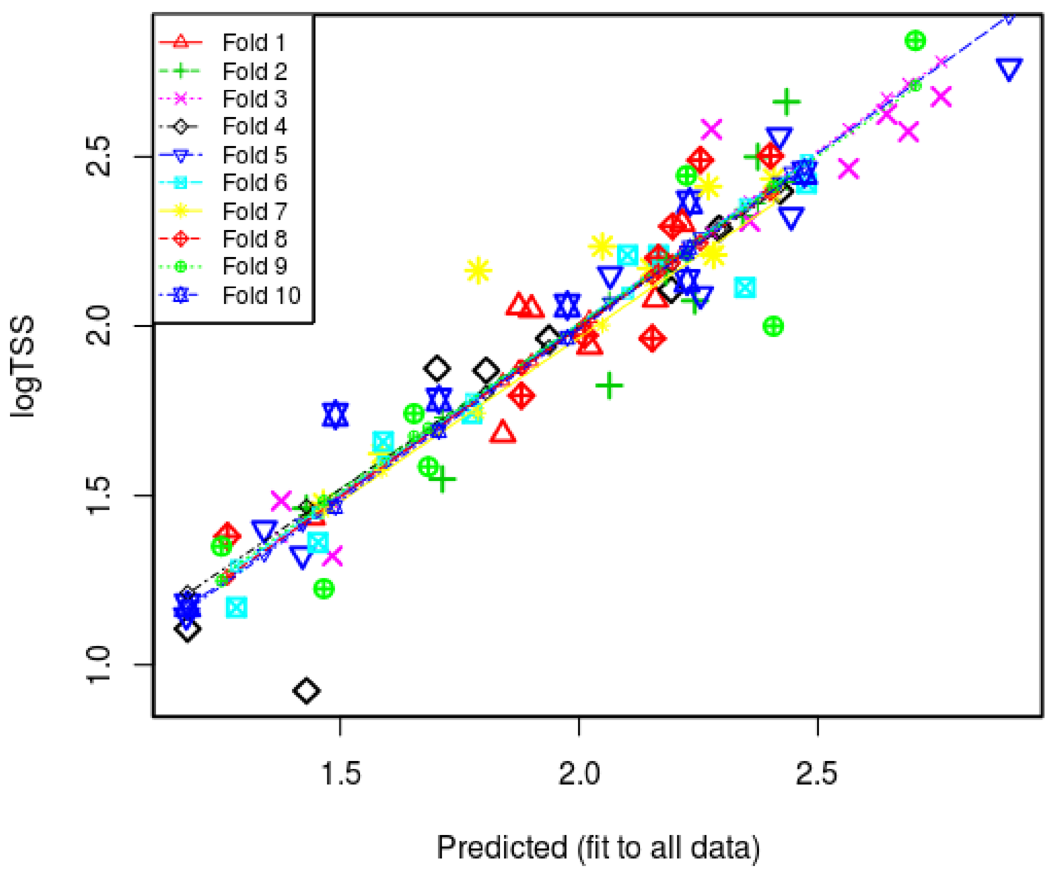



Residual
TBY6026
cos2piD
sin2piD
0.6
0.3
0.0
-0.3
-0.6
10
100
1,000
-0.5
0.5
1.0


Residual (logTSS)
Month
Jan
Mar
May
Jul
Sep
Dec
0.8
0.4
0.0
-0.4
-0.8
3
2
13
8
10
15
6
7
10
2
1
TSS
1,000
750
500
250
0
77
77
Computed
Observed
EXPLANATION
39 Number of values
Maximum value
75th percentile
50th percentile (median)
25th percentile
Minimum value



Cross Validation



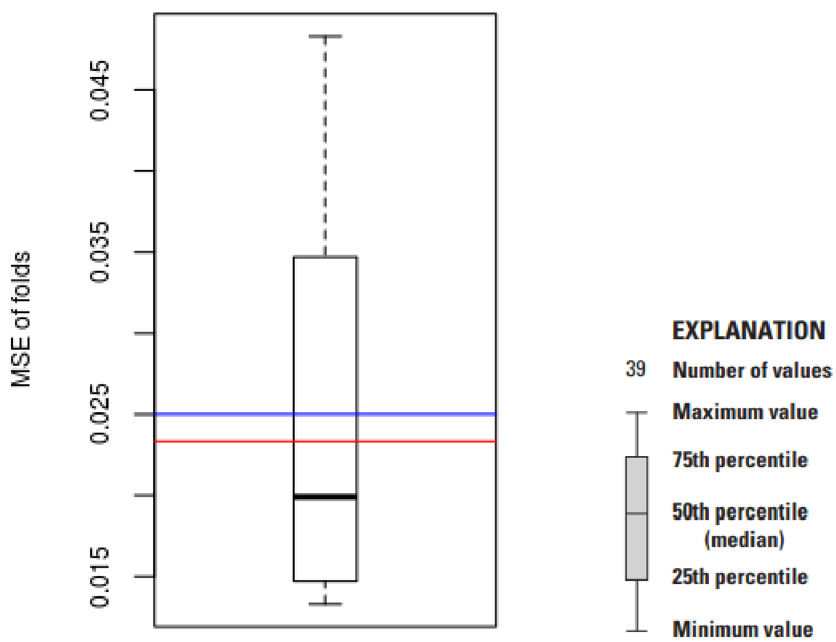

```
Fold – equal partition of the data (10 percent of the data)

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:  0.0133
                Mean MSE of folds:  0.0250
              Median MSE of folds:  0.0199
             Maximum MSE of folds:  0.0483
 (Mean MSE of folds) / (Model MSE):  1.0700
```



Red line - Model MSE

Blue line - Mean MSE of folds

Model-Calibration Data Set

0	Date	logTSS	logTBY6026	sin2piD	cos2piD	TSS	TBY6026	Computed logTSS	Computed TSS	Residual	Normal Quantiles	Censored Values
1	1999-01-26	1.23	1.29	0.433	0.902	16.8	19.6	1.47	30.9	-0.241	-1.83	--
2	1999-01-31	2.37	2.22	0.523	0.852	232	167	2.23	180	0.134	0.93	--
3	1999-02-03	1.8	1.78	0.552	0.834	62.4	60.4	1.88	80.2	-0.0843	-0.583	--
4	1999-03-17	2.21	1.95	0.966	0.26	162	90.1	2.1	134	0.108	0.789	--
5	1999-04-06	2.29	2.17	0.995	-0.0988	194	147	2.29	208	-0.00525	0	--
6	1999-04-16	2.49	2.11	0.963	-0.268	309	130	2.25	190	0.236	1.68	--
7	1999-05-13	1.74	1.18	0.753	-0.658	54.8	15.1	1.49	32.7	0.249	1.83	--
8	1999-05-24	2.08	2.13	0.615	-0.788	119	134	2.24	185	-0.167	-1.37	--
9	1999-06-10	1.78	1.5	0.346	-0.938	60.7	31.6	1.71	53.9	0.0765	0.435	--
10	1999-06-25	2.17	2.09	0.112	-0.994	148	122	2.15	149	0.0205	0.0976	--
11	1999-07-02	2.43	2.42	-0.00861	-1	272	266	2.41	270	0.0273	0.163	--
12	1999-07-14	1.62	1.44	-0.214	-0.977	42	27.7	1.59	40.9	0.0362	0.263	--
13	1999-07-29	1.68	1.8	-0.456	-0.89	48	63.4	1.84	73.3	-0.159	-1.09	--
14	1999-08-12	1.55	1.69	-0.655	-0.755	35.4	48.5	1.71	54.7	-0.165	-1.29	--
15	1999-08-26	1.32	1.44	-0.817	-0.577	21	27.4	1.48	32.2	-0.161	-1.22	--
16	1999-09-22	1.48	1.36	-0.989	-0.15	30.5	22.8	1.38	25.2	0.108	0.746	--
17	1999-12-02	1.4	1.29	-0.479	0.878	25.2	19.4	1.34	23.2	0.06	0.331	--

18	2000-02-25	2.63	2.67	0.821	0.57	422	467	2.64	466	-0.0186	-0.0976	--
19	2000-03-24	2.47	2.51	0.994	0.107	292	327	2.56	388	-0.0987	-0.789	--
20	2000-04-27	1.44	1.11	0.896	-0.444	27.3	12.8	1.44	29.3	-0.00598	-0.0325	--
21	2000-05-25	1.59	1.44	0.588	-0.809	38.5	27.5	1.68	51.2	-0.0992	-0.834	--
22	2000-06-21	1.74	1.62	0.146	-0.989	55.3	41.3	1.78	63.2	-0.0331	-0.263	--
23	2000-07-26	2.15	2.07	-0.425	-0.905	142	119	2.07	123	0.0871	0.508	--
24	2000-08-29	1.17	1.2	-0.854	-0.52	14.8	15.8	1.28	20.3	-0.113	-0.881	--
25	2000-09-28	0.924	1.43	-1	-0.0301	8.4	27.1	1.43	28.5	-0.505	-2.42	--
26	2000-10-26	2.21	2.5	-0.9	0.437	162	316	2.28	203	-0.0725	-0.4	--
27	2001-06-06	2.33	2.4	0.425	-0.905	212	253	2.44	294	-0.118	-0.981	--
28	2001-09-04	1.66	1.59	-0.896	-0.444	45.6	39	1.59	41.2	0.0687	0.4	--
29	2002-06-12	2.76	2.98	0.329	-0.944	582	960	2.9	841	-0.135	-1.04	--
30	2002-08-14	2.42	2.64	-0.681	-0.732	264	434	2.48	317	-0.0548	-0.365	--
31	2003-03-18	2.84	2.7	0.974	0.226	696	500	2.7	536	0.138	0.981	--
32	2003-03-19	2.68	2.76	0.978	0.209	476	580	2.76	605	-0.0799	-0.471	--
33	2003-04-21	2.09	2.11	0.943	-0.333	124	130	2.25	190	-0.161	-1.15	--
34	2004-03-05	2.57	2.7	0.907	0.421	375	504	2.69	517	-0.115	-0.93	--
35	2004-05-14	2	2.32	0.73	-0.684	100	208	2.41	270	-0.407	-2.04	--
36	2004-06-14	2.21	2.08	0.28	-0.96	162	120	2.17	155	0.0434	0.297	--
37	2004-06-14	2.2	2.08	0.28	-0.96	159	120	2.17	155	0.0353	0.229	--
38	2004-09-08	1.11	1.09	-0.931	-0.366	12.8	12.4	1.18	16	-0.0734	-0.435	--
39	2005-03-24	2.08	2.02	0.99	0.142	120	104	2.16	153	-0.0805	-0.508	--
40	2005-05-16	2.11	2.05	0.718	-0.696	128	113	2.19	165	-0.0856	-0.622	--
41	2005-06-10	2.4	2.38	0.362	-0.932	250	242	2.42	279	-0.023	-0.196	--
42	2005-06-13	2.16	2.09	0.313	-0.95	145	124	2.18	161	-0.0206	-0.163	--
43	2005-08-29	2.24	2.15	-0.845	-0.534	172	140	2.05	118	0.187	1.37	--
44	2006-03-02	1.33	1.14	0.867	0.498	21.2	13.8	1.42	27.9	-0.0948	-0.746	--
45	2006-03-22	1.94	1.85	0.984	0.176	87.2	70.5	2.02	111	-0.0816	-0.545	--
46	2006-05-01	1.74	1.37	0.872	-0.49	55.2	23.6	1.65	47.8	0.0874	0.583	--
47	2006-05-12	2.06	1.65	0.764	-0.645	114	45.1	1.87	79.2	0.183	1.29	--
48	2006-06-05	1.88	1.48	0.441	-0.898	75	30.3	1.7	53.4	0.172	1.22	--
49	2006-07-31	1.38	1.09	-0.486	-0.874	24	12.4	1.26	19.4	0.116	0.834	--
50	2006-09-07	1.46	1.4	-0.918	-0.398	29	25	1.43	28.4	0.033	0.196	--
51	2006-09-21	1.18	1.11	-0.986	-0.167	15	13	1.18	16	-0.00446	0.0325	--
52	2006-09-21	1.15	1.11	-0.986	-0.167	14	12.9	1.18	16	-0.0322	-0.229	--
53	2007-01-09	1.48	1.34	0.154	0.988	30	22	1.46	30.9	0.0123	0.065	--
54	2007-03-14	1.36	1.16	0.951	0.309	23	14.3	1.45	30.1	-0.0919	-0.662	--
55	2007-03-22	1.87	1.58	0.984	0.176	74	38	1.81	67.6	0.0636	0.365	--
56	2007-03-26	2.5	2.28	0.994	0.107	316	190	2.37	250	0.126	0.881	--
57	2007-03-31	2.66	2.35	1	0.0043	459	222	2.43	288	0.227	1.56	--
58	2007-04-16	1.97	1.81	0.963	-0.268	94	65	2.01	109	-0.0382	-0.297	--
59	2007-05-07	2.32	2.23	0.817	-0.577	211	170	2.34	233	-0.0183	-0.065	--
60	2007-06-29	1.96	1.83	0.043	-0.999	92	68	1.94	91.5	0.0267	0.13	--
61	2007-09-04	1.35	1.17	-0.896	-0.444	22.4	14.8	1.25	18.9	0.0985	0.622	--
62	2008-04-24	2.13	2.08	0.918	-0.398	136	120	2.23	178	-0.0923	-0.703	--
63	2008-05-09	2.45	2.39	0.786	-0.619	283	247	2.47	314	-0.02	-0.13	--
64	2008-06-19	1.82	1.96	0.197	-0.98	66.8	92.3	2.06	123	-0.239	-1.68	--
65	2008-09-15	2.16	1.86	-0.968	-0.251	146	72.6	1.79	65.1	0.375	2.42	--
66	2008-10-16	2.05	2.03	-0.961	0.276	112	107	1.9	84.1	0.149	1.15	--
67	2009-03-31	2.56	2.33	1	0.0215	364	213	2.42	278	0.142	1.09	--
68	2009-04-27	2.5	2.3	0.896	-0.444	318	198	2.4	266	0.102	0.703	--
69	2009-06-17	2.3	2.15	0.247	-0.969	201	140	2.22	174	0.0872	0.545	--
70	2009-08-20	2.44	2.34	-0.753	-0.658	278	220	2.23	178	0.219	1.46	--
71	2009-09-10	2.41	2.45	-0.937	-0.35	258	280	2.27	197	0.141	1.04	--
72	2010-04-23	2.29	2.04	0.931	-0.366	197	110	2.2	166	0.0988	0.662	--
73	2010-05-27	2.58	2.18	0.574	-0.819	381	150	2.28	200	0.304	2.04	--
74	2010-06-14	1.96	2.06	0.297	-0.955	92	115	2.15	151	-0.189	-1.46	--
75	2010-06-16	2.06	1.85	0.264	-0.965	115	70	1.98	100	0.0854	0.471	--
76	2010-07-06	2.11	2.36	-0.0774	-0.997	130	230	2.35	235	-0.233	-1.56	--
77	2010-08-25	2.31	2.52	-0.806	-0.591	204	330	2.36	241	-0.0472	-0.331	--

Definitions

TSS: total suspended solids in milligrams per liter (00530)
TBY6026: turbidity, YSI model 6026, in formazin nephelometric units (63680)
D: date, in decimal years

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

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