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Office of Surface Water Technical Memorandum 2016.07
Office of Water Quality Technical Memorandum 2016.10

Subject: Policy and guidance for approval of surrogate regression models for computation of time series suspended-sediment concentrations and loads

BACKGROUND

The definition of a surrogate measure is a measurement taken with the intent to gain insight into a variable that is either impractical to measure directly, or not possible to measure at the desired continuous time interval. With a direct and uncomplicated causal relation, surrogate measurements can be nearly as useful as direct measurements although uncertainty associated with individual computed values generally is larger than discrete sample data. Increased temporal data richness could compensate for the larger uncertainty associated with computed data compared to laboratory results from actual samples.

In-situ turbidity, acoustic, and streamflow data, combined with discrete sample data, can be used to compute a time series of suspended-sediment concentrations and loads at stream sites. Two standard surrogate methods for computing time-series suspended sediment have been documented in U.S. Geological Survey (USGS) formal series Techniques and Methods reports. Rasmussen and others (2009) describe methods for developing regression models using *in-situ* turbidity and streamflow data, along with discrete samples of suspended-sediment concentrations. Landers and others (2016) describe sediment acoustic index methods for computing suspended-sediment concentrations. Both reports include detailed descriptions of methods for data collection, quality assurance and quality control, and data computation.

This technical memorandum describes reliable methods to develop statistical models specifically for suspended-sediment concentrations and loads based on surrogate measurements. The technical information herein does not apply to surrogate models for concentrations or loads of other water-quality constituents. This policy will facilitate a more consistent and streamlined approach for developing, documenting, and approving surrogate suspended-sediment regression models. Data computed as described in this memorandum meet USGS requirements for non-interpretive information. Users can refer to the Office of Surface Water (OSW) Web site on Sediment for updated model examples, R scripts, and other tools as they become available.

PURPOSE

The purpose of this memorandum is to provide policy and guidance for developing and approving regression models used to compute high temporal frequency time series suspended-sediment concentrations and loads from continuous turbidity or acoustic backscatter data and continuous streamflow data that can be published without the need for documentation in a Bureau-approved interpretive report. As such, computed data from a statistical surrogate model must meet the definition of data rather than interpreted data. This policy applies to surrogate approaches in which continuous (measurement interval every hour or less) *in-situ* turbidity, acoustic, and/or streamflow data are used in combination with discrete suspended-sediment samples to develop regression models for computing similar continuous suspended-sediment concentration or load data.

POLICY

Computed suspended-sediment concentration and load data qualify as "non-interpretive" when the following conditions are met:

(1) Surrogate data and calibration samples are collected and laboratory analyses were performed using consistent sensor technologies (Rasmussen and others, 2009; Landers and others, 2016) and consistent USGS-approved and publicly available field methods for collection of suspended-sediment samples and continuous sensor data including U.S. Geological Survey (2006), Edwards and Glysson (1999), U.S. Geological Survey (2006), and Wagner and others (2006) and are analyzed for suspended-sediment concentration using USGS-approved laboratory methods, such as Guy (1969). Surrogate and calibration data used to develop the model must be available in the National Water Information System (NWIS) database. When guidance provided in this technical memorandum deviates from methods described in the previously-published methods reports, instructions in this memorandum should be followed.

(2) Computed data are derived from linear, log-linear, or log-log statistical models developed according to Ordinary Least Squares (OLS) regression methods described in published techniques and methods reports by Rasmussen and others (2009) and Landers and others (2016).

(3) Each model is documented in an electronic model archive summary (MAS) following guidance in this memorandum. The MAS meets model documentation requirements described in OSW Technical Memorandum (TM) 2015.01 and Office of Water Quality (OWQ) TM 2015.01, and is submitted for technical peer review, verification by the Water Science Field Team (WSFT) Specialist, and approval by the Center Director in lieu of the model archive contents

described in Attachment 2 of TM 2015.01. The MAS is stored in a reliable and publicly available location such as ScienceBase, the National Real-Time Water Quality (NRTWQ) Web site, or a future centralized Water Mission Area archive or repository.

The recommended steps for review and approval of the model and calibration dataset are:

- The MAS, which includes the associated calibration dataset, is tracked in the Information Product Data System (IPDS) as a single information product designated as a data release.
- The MAS is reviewed by two technical peer reviewers at least one of whom is outside the originating Center.
- The reviewed MAS and Model Archive Verification and Approval Form (Attachment 1 of TM 2015.01) are submitted to the WSFT Specialist for verification that models have been adequately reviewed and archiving requirements are met, and the approval form is uploaded to IPDS.
- The MAS is assigned a Digital Object Identifier (DOI) and stored in a reliable and publicly available location.
- The MAS is approved by the Center Director following Fundamental Science Practices and Survey Manual (SM) SM 502.4 and SM 205.18.

(4) Once the MAS has been approved and publicly released, the computed suspended-sediment data may be disseminated to the public along with a link to the MAS in a USGS-approved database such as the NRTWQ Web site and NWIS using appropriate parameter codes as described in the Techniques and Methods reports (Rasmussen and others, 2009; Landers and others, 2016) without need for documentation in a Bureau-approved interpretive report.

(5) Continued sampling is required after model development to validate model performance if models are used to estimate suspended-sediment concentrations or loads on an on-going basis beyond the period of time that the model calibration samples were collected. Model validation is described in Attachment A of this memorandum and by Rasmussen and others (2009). Consistent with OWQ TM 2012.03, suspended-sediment samples must be submitted for laboratory analysis as soon as possible after collection and resulting data should be reviewed and approved promptly for use in model validation.

(6) Data interpolation defined as estimation between measured unit values and extrapolation defined as computation beyond the range of the model calibration dataset are permitted to a limited extent as described for acoustic methods by Landers and others (2016) and as otherwise described in Attachment A of this memorandum.

(7) Surrogate regression models as described in this memorandum are used to compute suspended-sediment concentration or load on the basis of observed explanatory variable(s) and cannot be used alone to predict future suspended-sediment concentration in the absence of a Bureau-approved interpretive report.

(8) Surrogate models and applications of this policy are reviewed during triennial technical reviews.

(9) This policy describes the standard approach for surrogate regression models for suspended sediment, and it must be followed when methods described by Rasmussen and others (2009) and Landers and others (2016) are used. Models documented in interpretive reports published previous to this memorandum may continue to be used if validation sampling and ongoing model evaluation (steps 4-8 in attachment A) are completed as described in this memorandum.

(10) A Bureau-approved interpretive report is required when conditions described in this memorandum are not met. This includes using alternative methods for collection of continuous and discrete data, sensor technologies, laboratory analyses, statistical model-building, and data computation. When alternative methods are used and documented in a separate report, a MAS similar to that described in this memorandum is required to document the model. If the model will be used for ongoing data computation, model validation and ongoing evaluation as described in items 4-8 of Attachment A is required unless circumstances warrant another approach.

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Distribution: All WMA Employees

ATTACHMENTS

A. Policy and Guidance for Surrogate Suspended-Sediment Models

B. Example Model Archive Summary for a Turbidity Suspended-Sediment Model

C. Example Model Archive Summary for an Acoustic Suspended-Sediment Model

REFERENCES

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., accessed March 7, 2016, at https://pubs.er.usgs.gov/publication/twri03C2.

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Attachment A. Requirements and Guidance for Surrogate Suspended-Sediment Models

The following information is provided to supplement methods described by Rasmussen and others (2009) and Landers and others (2016), and to provide additional policy implementation details. It includes a combination of requirements for meeting policy, emphasized using bold font, and guidance for best practices. In addition, the USGS National Training Center class "Environmental Statistics for Data Analysis," QW1075, is recommended for data analysts. Experience or training in the R programming language is recommended. The Surrogate Analysis and Index Developer Tool (SAID) is available for developing surrogate models, particularly using acoustic methods, and SAID produces all of the information needed for the MAS (but not in the same MAS format). The MAS **must** follow the format described in this memorandum. An R script is available for this purpose at http://water.usgs.gov/osw/techniques/sediment.html, or the MAS can be prepared using tools of the user's choice. Additional information may be appended at the end of the MAS if needed.

1. The model development process is documented in a model archive summary (MAS) that includes a written summary of the decisions made during the model-development process, the model form, several diagnostic statistics and graphs that indicate adequate model fit, predictive ability and uncertainty, list and explanation of outliers and how they were handled in model development, and a link to the complete model calibration data set. An example MAS for turbidity and streamflow regression models is provided in Attachment B. An example MAS for acoustic methods is provided in Attachment C.

2. A statistically valid number of samples are **needed** to develop, validate, and verify surrogate regression models over time. Samples **must** be collected over a range of conditions. In the model archive summary, the modeler **must** provide specific, detailed justification as to why the number of samples used for surrogate model development is sufficient to represent the population of data for which predictions are being made. Such justification **must** include the sufficiency of the data to describe seasonal, hydrologic, particle size, or any other factors that could possibly affect the surrogate relation.

   - Model builders **need** to be cognizant of the possibility of overfitting their surrogate model. Overfitted models adhere too closely to the idiosyncrasies of a particular data set that do not actually appear in the population of data being modeled (Babyak, 2004). One way to guard against overfitting is to have an adequate number of sample observations per each explanatory variable in the model. A long used rule of thumb is 10-15 observations per explanatory variable (Babyak, 2004). Harrell (2001, pg. 61) recommends 10-20 observations per explanatory variable. So for a simple linear regression model, 20-40 observations are necessary (10-20 for both the intercept and the single explanatory variable). Green (1991) recommended 50 observations plus 8 additional observations for each explanatory variable. The number of samples also **needs** to sufficiently represent all seasonal, hydrologic, and other conditions potentially affecting the model, and to allow for evaluating the predictive performance of the model. Model fit statistics, such as coefficient of determination (R^2) and mean square error, are not necessarily good measures of how well a model will predict outside the calibration data set. Cross-validation is a good method for measuring this. For example, the cross-validation information in Attachment B indicates that when the model calibration data are randomly divided into subsets, the predictions from each subset regression model are very similar to the final surrogate model. Thus, for surrogate suspended-sediment models, a recommended minimum of 36 suspended-sediment samples is generally considered adequate for developing and validating a model with one explanatory variable, for example, turbidity. This number is based on the mid-range of sample sizes recommended in the literature with an additional 20 percent increase to allow for an adequate cross-validation analysis to assess predictive capability of the model. An additional 12 samples, for a minimum of 48 samples, is recommended for a model with two explanatory variables, for example turbidity and streamflow.

- Samples **must** be representative of the stream cross-section and can be equal width increment (EWI) samples, equal discharge increment (EDI) samples, or fixed-point pump samples that have been adjusted using concurrent cross-section samples (Landers and others, 2016, p. 13; Edwards and Glysson, 1999, p. 31). The relation of fixed-point to EWI/EDI samples **must** be documented in the analysis and model archive summary. Samples also **must** be statistically independent within reason and should be tested for autocorrelation following methods described by Landers and others (2016). If the independence assumption is not met, then appropriate non-OLS statistical methods **must** be used to fit the model and it **must** be documented in a separate Bureau-approved interpretive report (Rasmussen and others, 2009, p. 11; Landers and others, 2016, p. 30). Particle-size analysis for samples is not required, but sand/silt split data often are very helpful when evaluating dataset variability and outliers (Rasmussen and others, 2009).

- The sampling design **must** ensure that samples are representative of the system being modeled. It is recommended that about half of the samples are collected at fixed intervals (monthly), and half of the samples are collected during runoff events or targeting other sources of variability.

- The recommended period to collect data for model development is 3 years, but generally should range from 2-6 years. If data are collected over just 1 year for model development, additional validation samples are **needed** in subsequent years if hydrologic conditions are different. Data collected over more than 6 years should be tested for violation of stationarity assumptions and appropriate actions taken to address it.

3. The data analyst submits the MAS to two qualified technical peer reviewers. Qualified technical reviewers are those with scientific and technical expertise relevant to sound regression model development. The reviewers evaluate the model and recommend the MAS be either approved or rejected. If a model is rejected, the data analyst has the option to redevelop the model and MAS based on the reviewer's suggestions, and then submit it for additional technical review. Before the surrogate regression model is used to compute data to be delivered to the public, the Center Director **must** approve the MAS as described in the Policy section of this technical memorandum.

4. Data to validate model performance are **required** for any model used to estimate constituent values outside of the period of data collection used for model calibration. Validation data must be available in the National Water Information System (NWIS) (http://dx.doi.org/10.5066/F7P55KJN).

- A minimum of 8 validation samples per year on average are **required** to be collected with a minimum of 6 in any given year. This is a larger number than recommended by Rasmussen and others (2009) and Landers and others (2016) to better assess departures from the model and allow sufficient data to refit models if needed. Validation samples are flow-weighted composite samples collected from the channel cross-section (EWI/EDI when possible) using approved field protocols (USGS, 2006; Edward and Glysson, 1999) or fixed-point pump samples as previously described. Four of these samples are to be collected at a quarterly interval, that is, the samples are to be collected about 3 months apart and four samples are to be targeted toward time periods of variability in the system. Exceptions to this guidance may exist, including:
    a. For many situations, variations in streamflow present the greatest source of variability and these four additional samples should be targeted to capture high flows that are often characterized by high suspended-sediment concentrations, and should include rising, peak, and falling limbs of the hydrograph.
    b. Targeted samples should be spread throughout the year unless the variability is limited to shorter periods in which case the targeted samples should be spread throughout the period of variability. For example, for streams affected by storms throughout the year, the samples targeting storm runoff would be spread throughout the year. However, for streams where flow is affected mainly by snowmelt or pronounced wet and dry (or ephemeral) periods, the targeted samples may be spread only throughout the snowmelt or the wet and dry periods.
- Because validation samples are collected at least quarterly, models can be used for data estimation no longer than about 3 months after the last validation sample has been collected.

5. As soon as practicable after each validation sample is collected, performance of the model with respect to that sample should be assessed. The residual from the predicted value

associated with a validation sample should be assessed in the same manner as a residual from the model calibration data set.

- The recommended approach for ongoing model validation is conceptually based on the runs test for randomness in residuals (Hipel and McLeod, 1994, p. 942). A run is a consecutive sequence of positive or negative residuals. The runs test estimates the probability of the number of runs observed happening solely due to chance. For surrogate models, there will be insufficient data available to compute a formal runs test for several years (based on the recommended number of validation samples collected per year). Thus an approach based on consecutive large positive or negative residuals computed from the predicted values and observed concentrations from the validation samples should be used instead. The consecutive occurrence of even a few large residuals with the same sign has a very low probability of occurring due to chance. The presence of one or more of these large residuals is an early warning of possible considerable bias in the values predicted by the surrogate model that warrants investigation.

    a. If the residual from one validation sample has a value of about 2 to 3 standard errors from the predicted value, the operation of sensors and equipment providing input to the surrogate model should be checked to make sure nothing is malfunctioning. Anomalies in the watershed should also be investigated. The probability of a residual falling within this range from a well-fit model is about 0.01 to 0.05.
    b. If there are two consecutive validation samples that have a residual value of about 2 to 3 standard errors from the predicted value with both having the same sign either positive or negative, check equipment again for malfunctions and check for anomalies in the watershed. If all equipment is operating correctly and no anomalies are found, then collect an additional validation sample at the next site visit or within 30 days, if possible during conditions similar to those when samples with large residuals were collected. The probability of two independent consecutive residuals falling within the range of 2 to 3 standard errors from the predicted value from a well-fit model is about 0.0001 to 0.0025.
    c. If there is a third consecutive validation sample that has a residual value of 2 to 3 standard errors from the predicted value (with all three having the same sign, that is all three residuals being either positive or negative), then the model **must** be assumed to be flawed and **must** be refit using all data collected since the release of the previous model including the 3 recent validation samples with large residuals. The probability of three independent consecutive residuals falling within the range of 2 to 3 standard errors from the predicted value from a well-fit model is about 0.000001 to 0.000125.

d. If the residual has a value greater than 3 standard errors from the predicted value and sensors and equipment are not malfunctioning and no watershed anomalies are found, then collect an additional validation sample at the next site visit or within 30 days. The probability of a residual being greater than 3 standard errors from the predicted value from a well-fit model is less than about 0.01.
e. If there are two consecutive validation samples that have a residual value greater than 3 standard errors from the predicted value, regardless of the sign of the residual, then the model **must** be assumed to be flawed and **must** be refit using all data collected since the release of the previous model including the 2 recent validation samples with large residuals. The probability of two independent consecutive residuals both being greater than 3 standard errors from the predicted value from a well-fit model is less than about 0.0001.

- If the refit model is deemed adequate by following the same process used to fit the original model, the refit model will replace the existing model and predicted values from the first validation sample whose residual exceeds the 2 standard error threshold will be re-estimated using the refit model. A new model archive package **must** be prepared and approved following the same process as the original model prior to use of the refit model.

- If the refit model is deemed inadequate, use of the model **must** be discontinued completely or until additional sample data are collected and an adequate model can be developed by making adjustments that are consistent with the Techniques and Methods reports. For example, the original model might use turbidity as a single explanatory variable, and the refit model might use both turbidity and streamflow as explanatory variables, which is consistent with the Techniques and Methods report.

6. Surrogate sediment models **must** be reviewed annually, typically after the continuous data used as a surrogate have been approved and the discrete sample results used in the model have been reviewed and approved. This review occurs even when no validation samples exceed the large residual thresholds discussed in the previous section of this guidance. The annual review should include all of the following:

- Review plots of all validation sample residuals collected during the year against time, predicted values, and explanatory variables. Compare residuals from samples collected during the current year to those collected in previous years. Look for patterns in the current year residuals that might indicate a change or shift in the relation between the response and explanatory variables used in the model.

- Review a boxplot of the validation sample residuals by year. Compare the distribution of residuals from samples collected during the current year to those collected in previous years.

- Review a boxplot of validation sample residuals by seasonal periods. Note this can only be done after several years of additional data collection if just the minimum eight validation samples per year are being collected. Also, fewer than the four seasons per year can be used if necessary to obtain enough data to create boxplots. An example of this might be looking at boxplots for three 4-month periods rather than four 3-month periods. Look for seasonal patterns in the residuals that might indicate a temporal change or shift in the relation between the response and explanatory variables used in the model.

- A narrative describing the annual model review **must** be written describing why the modeler believes there is no problem with the existing surrogate model or if a problem is identified how it was addressed. This narrative is analogous to the annual gaging station analysis that is prepared for each streamgage. Annual model review is documented in the Records Management System (RMS).

- Best practice usually is to start a new model within 6 months of the data collection period. When a revised model is developed, best practice is usually to start applying the model when it is approved; however, users may choose to apply the model beginning at the time that samples indicated deviation from the previous model.

7. Even if no problems are identified during the annual model review, surrogate models **must** still be refit every 3 years with the additional validation samples collected during the ongoing 3-year period and documented in a new MAS. Routine model updates take advantage of additional collected data to ensure models are current and reduce model uncertainty and likelihood of stationarity issues.

   - The initial refitting of the model should use the same form as the model being updated. However, the adequacy of the model form should be examined and if necessary alternative forms of the model should be explored.

   - The data analyst will **need** to pay particular attention to the residual versus time plots for the refit model. If residuals early in the time series show patterns or otherwise depart from random noise about the zero reference line, it is an indication of a shift in the underlying processes driving the model. Sample observations from the earlier period of the sample time series should then be removed from the calibration dataset, removing as few as possible to address the lack of fit in the early periods of the model to see if an adequate model may be obtained. However, if removing sample observations reduces the minimum number of samples for model building below the minimum number recommended or to a time span of less than 2 years, additional data will be **needed** until those criteria are again met. Decisions and reasoning related to sample time series used in model development **must** be documented in the MAS.

- A new model archive summary package is to be prepared and approved following the same process described for the original model including approval in IPDS before the updated model is used.

- Centers **must** use good judgment in deciding when a new model becomes effective. The general recommendation is that the model becomes effective as soon after approval as practical.

8. Extrapolation for acoustic models is allowed as described by Landers and others (2016). Limited extrapolation is allowed as described below for approved models developed following methods described by Rasmussen and others (2009).

- Approved models developed following Rasmussen and others (2009) may be used to extrapolate no more than 10 percent (calculated using retransformed units rather than log units) outside of the range of the sample data used to fit the model *with no additional sample collection required*. For models following Rasmussen and others (2009), extrapolation must not exceed the manufacturer's specifications for the optimal performance range of the turbidity sensor. Approved models following Landers and others (2016) may be used to extrapolate no more than 20 percent outside the range of sample data used to fit the model.

- Approved models may be used to extrapolate more than 10 percent following Rasmussen and others (2009) and more than 20 percent following Landers and others (2016) *if an additional validation sample in that extrapolated range can be collected* during the same season and within about 90 days provided that channel conditions have not changed for either method.
    a. If the validation sample confirms that model predictions are accurate in the extrapolation range with validation data then predicted values may be kept and accepted as final data for display in NWISWeb or NRTWQ
    b. If the validation sample does not confirm that model predictions are accurate in the extrapolation range, then predicted values **must** either be:
        - censored at greater than the predicted value if the validation sample confirms that the direction of the model bias is indeed positive; for example, the model prediction is 100 but the validation sample is 200 then the predicted values may be set to >100, or

- removed or blocked in NWIS using thresholds if the validation sample does not confirm the direction of the model bias; for example, the model prediction is 100 but validation sample is 50.

- Approved models may not be used for extrapolating more than 20 percent outside the range of the sample data used to fit the model until additional data are collected in that range and the model performance and sensor performance are validated or the model is refit using the new data. A minimum of one (but at least two are recommended) independent samples **must** be collected outside the range of the existing data to confirm the model is performing adequately. Model predictions made outside of the two previously mentioned allowable areas of extrapolation may not be served in the real-time water quality system and they **must** be removed or blocked in NWIS until the existing model is validated with the new data or a new model is fit that includes data in the range. Once a new model is approved, it may be used to make predictions for any data previously blocked in NWIS.

- Approved models shall not be used for interpolating between time intervals for which the surrogate data are collected. That is, if surrogate data are collected at 30-minute intervals, the models may not be used to estimate at 15-minute intervals by averaging or otherwise interpolating between values of the surrogates collected at the longer time step.

9. Approved models can be disseminated and archived on the NRTWQ Web site (http://nrtwq.usgs.gov/). These time series are displayed in plots, tables, statistical summaries, and duration curves. Site and model information are also displayed. These computed values also can be displayed using NWIS, or using another approved data release method. As new models are employed, older models are archived along with the computed data. Models are numbered sequentially and include the station number, constituent, year the model was approved, and model version number if needed (for example, 06892350.SSC.WY15.ver1).

10. Surrogate turbidity and streamflow data for computed concentrations and loads are considered category 1 data and are approved by following the Continuous Records Processing (CRP) policy of the Water Mission Area (WRD Policy Numbered Memorandum 2010.02). Methods of collecting the surrogate measurements are documented in formal publications series such as USGS Techniques and Methods or the National Field Manual. Computed concentration and loads are approved following CRP policy under category 3 which indicates approval to be completed within a year in most cases. All surrogate data **must** be stored in NWIS.

11. Circumstances may arise in which historical data need revision. For example, if errors are discovered in explanatory data such as turbidity, then errors also exist in computed

suspended sediment data. Until further guidance is provided, Centers **must** use good judgment in deciding which circumstances justify correction of historical data.

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Attachment B. Example Model Archive Summary for a Turbidity Suspended-Sediment Model

Model Archive Summary for Suspended-Sediment Concentration at Station 07144100; Little Arkansas River near Sedgwick, Kansas

This model archive summary summarizes the suspended-sediment concentration (SSC) model developed to compute hourly SSC from January 1, 2007 onward. This model supersedes all models used from 2007 onward. The methods used follow USGS guidance as referenced in relevant Office of Surface Water/Office of Water Quality Technical Memoranda and USGS Techniques and Methods, book 3, chap. C4 (Rasmussen and others, 2009).

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 ¼ NW ¼ NW ¼ sec. 15, T. 25 S., R. 1 W., Sedgwick County, Kansas, Hydrologic Unit 11030012, on left bank at downstream side from county highway bridge, 2.1 miles (mi) south of Sedgwick, and at mile marker 23.7.

Equipment: A YSI 6600 water-quality monitor equipped with sensors for water temperature, specific conductance (SC), dissolved oxygen, and pH, and a YSI Model 6136 turbidity sensor. The monitor is housed in a 4-inch plastic pipe and typically is placed in the deepest section of the river that has velocity similar to rest of the stream. Readings from the YSI 6600 are recorded every 30 minutes and transmitted by way of satellite, hourly. A YSI Model 6136 turbidity sensor started operation July 27, 2004.

Model number: 07144100.SSC.WY07.1

Date model was created: December 26, 2014

Model calibration data period: July, 27 2004 to August 4, 2014

Model application date: January 1, 2007 onward

Computed by: Patrick Eslick, KS WSC, June 21, 2016

Reviewed by: Patrick Rasmussen, KS WSC and Brian Kelly, KS WSC, July 8, 2016

Approved by: Andy Ziegler, KS WSC Director, July 20, 2016

Model Data

All data were collected using U.S. Geological Survey (USGS) protocols and are stored in the National Water Information System (NWIS) database (http://dx.doi.org/10.5066/F7P55KJN). The regression model is based on 120 concurrent measurements of suspended-sediment concentration, streamflow, and turbidity samples collected from July 27, 2004 through August 4, 2014. Samples were collected throughout the range of continuously observed hydrologic and turbidity conditions. Summary statistics and the complete model-calibration data are provided in the dataset. Studentized residuals from the final model were inspected for values greater than 3 or less than negative 3. Values outside of the 3 to -3 range are considered potential outliers and were investigated. Samples collected May 29, 2008; December 1, 2009; December 17, 2009; and December 11, 2013; June 13, 2010; July 6, 2010; and August 15, 2013 were deemed outliers and were removed from the dataset.

Sediment Data

Cross-section samples are collected either from the downstream side of the bridge or instream upstream near the bridge. The equal-width-increment or multi-vertical method is used, and samples typically are composited for analysis. Cross-section samples are obtained during all discrete sample collections every month and during selected runoff events. A FISP US D-95 with a Teflon bottle, cap, and nozzle depth-integrating sampler is used from the bridge; and a DH-81with a Teflon bottle, cap, and nozzle hand sampler or a grab sample with a Teflon bottle is used for wading samples. Samples are analyzed for SSC and/ or LOI and 5-point grain size in the USGS Sediment Laboratory in Iowa City, Iowa.

Surrogate Data

The turbidity data used in this analysis were measured using a YSI model 6136 installed and in use from 2007 onward. The 6136 replaced the old YSI model 6026 sensor. Data from the YSI 6026 and 6136 sensors are not equivalent and therefore cannot be used interchangeably with this new SSC model.

See the Station Analysis for the streamflow and turbidity records for more information (available upon request).

Model Development

Regression analysis was done using R by examining turbidity and other continuously measured data as explanatory variables for estimating suspended-sediment concentration. A variety of models that predict SSC and models that predict $\log_{10}$(SSC) were evaluated. The distribution of residuals was 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 of several models led to the conclusion that the most appropriate and reliable model would be one that estimated $\log_{10}$(SSC).
Turbidity and streamflow were selected as the best predictors 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 for all 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 07144100.
Suspended-sediment concentration-based model:

$$\log_{10}(SSC) = 0.933 \times \log_{10}(TURB) + 0.0431 \times \log_{10}(Q) + 0.262 ,$$

where

SSC = suspended-sediment concentration, in milligrams per liter (mg/L);
Q = streamflow in cubic feet per second (ft^3/s); and,
$TURB$ = Turbidity, YSI model 6136, in formazin nephelometric units (FNU).

The use of turbidity and streamflow as explanatory variables is appropriate physically and statistically. Turbidity makes sense physically because suspended sediment is composed of particles that scatter light in water. Suspended sediment correlates well with streamflow because high streamflow values tend to increase concentrations of SSC. The relation between turbidity and SSC can vary given varying concentrations of organic suspended particles that increase turbidity, but are 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). For this model, the calculated BCF is 1.02. The retransformed model, accounting for BCF is:

$$SS = 1.865 \times TURB^{0.933} \times Q^{0.0431}.$$

Previous models

<u>Model</u> <u>Start year</u> <u>End year</u> <u>Model</u>

1.0	1999	2006	$\log_{10}(SS) = 0.715 \times \log_{10}(TURB) + 0.188 \times \log_{10}(Q) + 0.185$
1.1	2007	--	$\log_{10}(SS) = 0.933 \times \log_{10}(TURB) + 0.0431 \times \log_{10}(Q) + 0.262$

Suspended-Sediment Concentration Record

The SSC record is computed using this regression model in the National Real-Time Water Quality (NRTWQ) Web site from 2015 onward. Data are computed at hourly intervals. The complete water quality record can be found at http://nrtwq.usgs.gov/ks.

Model Statistics, Data, and Plots

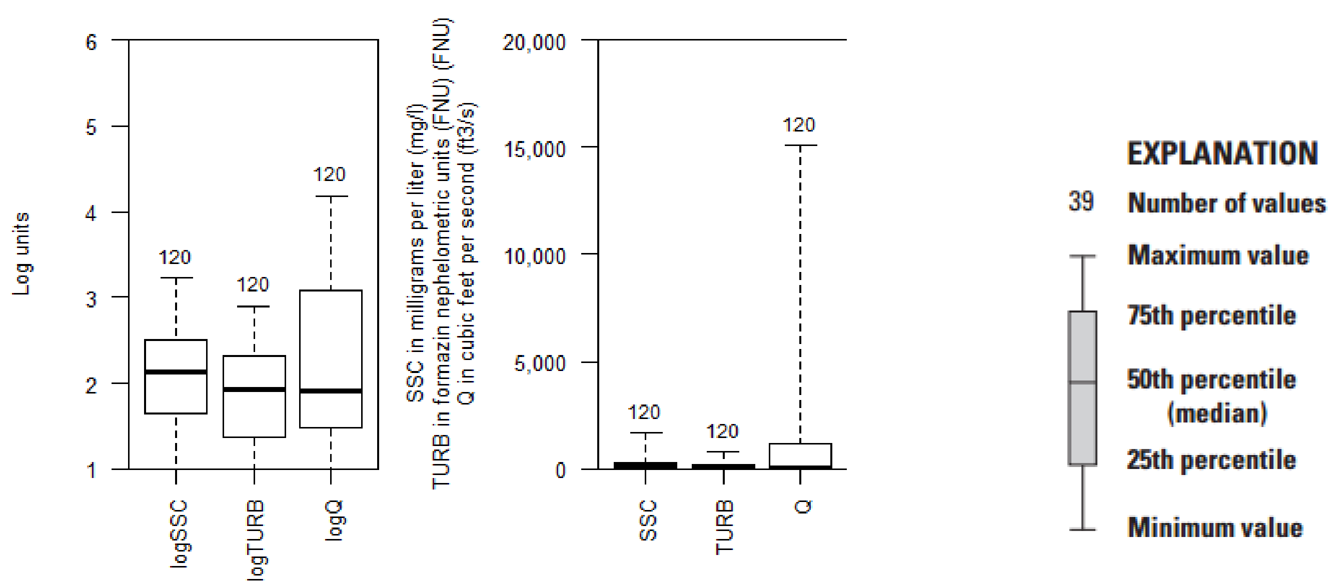
Model

logSSC = + 0.933 * logTURB + 0.0431 * logQ + 0.262

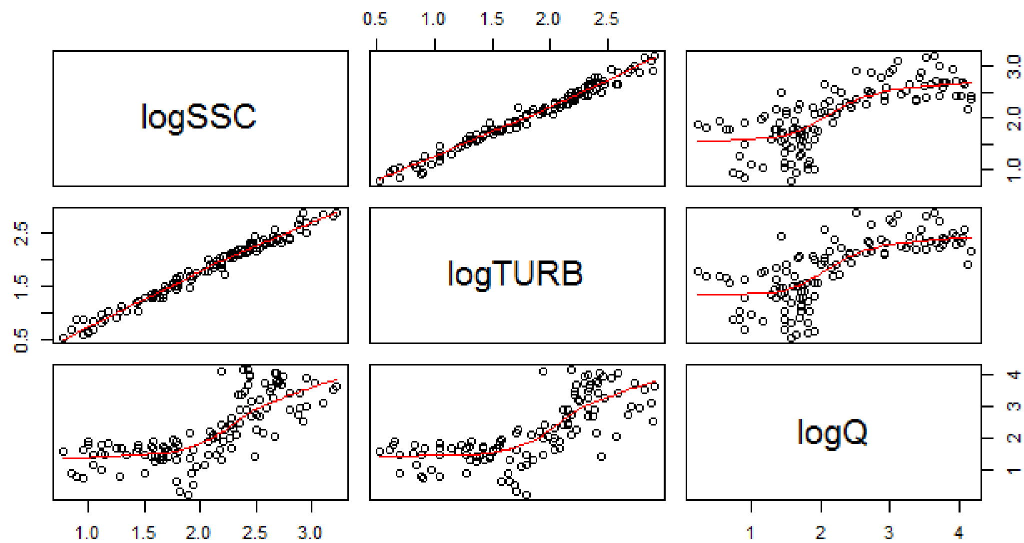
Variable Summary Statistics

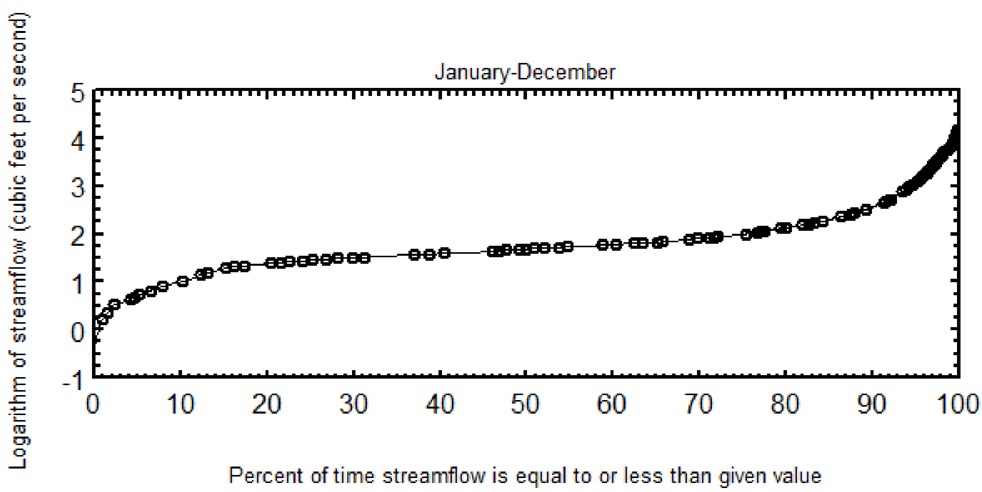
	logSSC	SSC	logTURB	logQ	TURB	Q
Minimum	0.778	6	0.531	0.204	3.4	1.6
1st Quartile	1.650	45	1.360	1.490	23.0	30.6
Median	2.130	136	1.920	1.920	83.0	82.4
Mean	2.050	243	1.820	2.230	138.0	1630.0
3rd Quartile	2.500	318	2.310	3.080	204.0	1200.0
Maximum	3.230	1680	2.890	4.180	784.0	15100.0

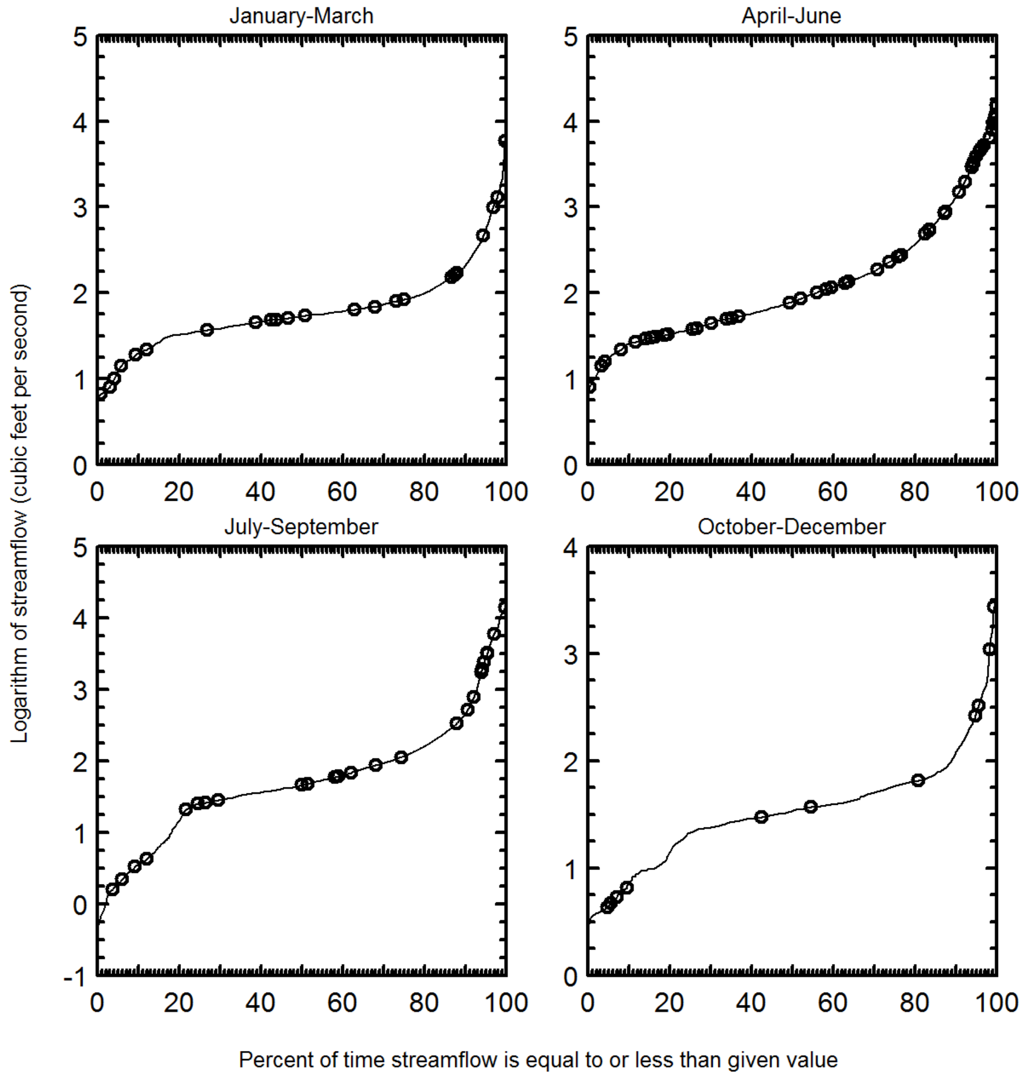
Box Plots



Exploratory Plots







Basic Model Statistics

Number of Observations	120
Standard error (RMSE)	0.0848
Average Model standard percentage error (MSPE)	19.7
Coefficient of determination (R^2)	0.98
Adjusted Coefficient of Determination (Adj. R^2)	0.979
Bias Correction Factor (BCF)	1.02

Variance Inflation Factors (VIF)

logTURB	logQ
2.04	2.04

Explanatory Variables

	Coefficients	Standard Error	t value	Pr(>|t|)
(Intercept)	0.2620	0.0250	10.50	1.60e-18

logTURB	0.9330	0.0187	49.80	1.27e-80
logQ	0.0431	0.0110	3.93	1.45e-04

Correlation Matrix

	Intercept	logTURB	logQ
Intercept	1.0000	-0.660	-0.0075
logTURB	-0.6600	1.000	-0.7150
logQ	-0.0075	-0.715	1.0000

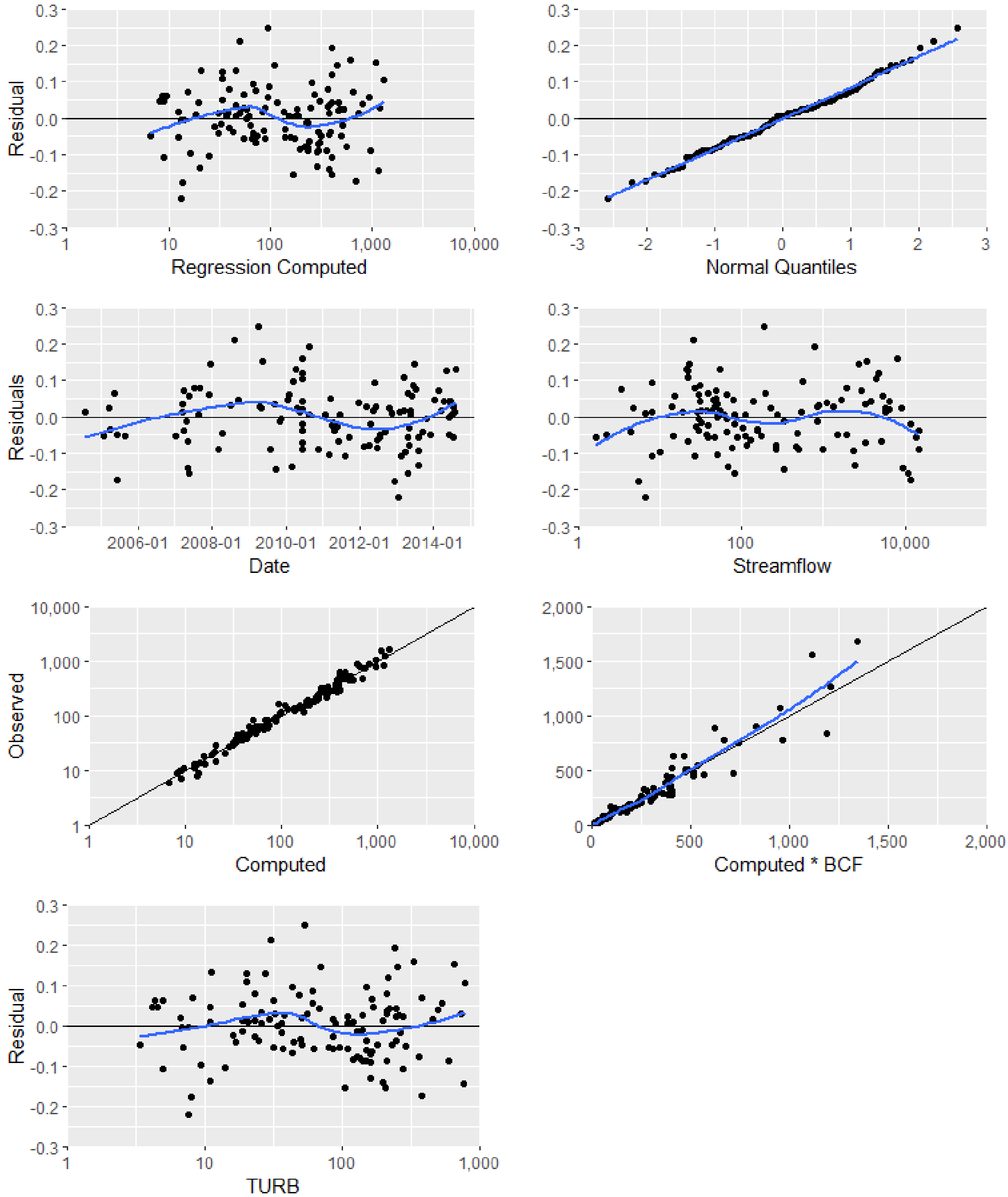
Outlier Test Criteria

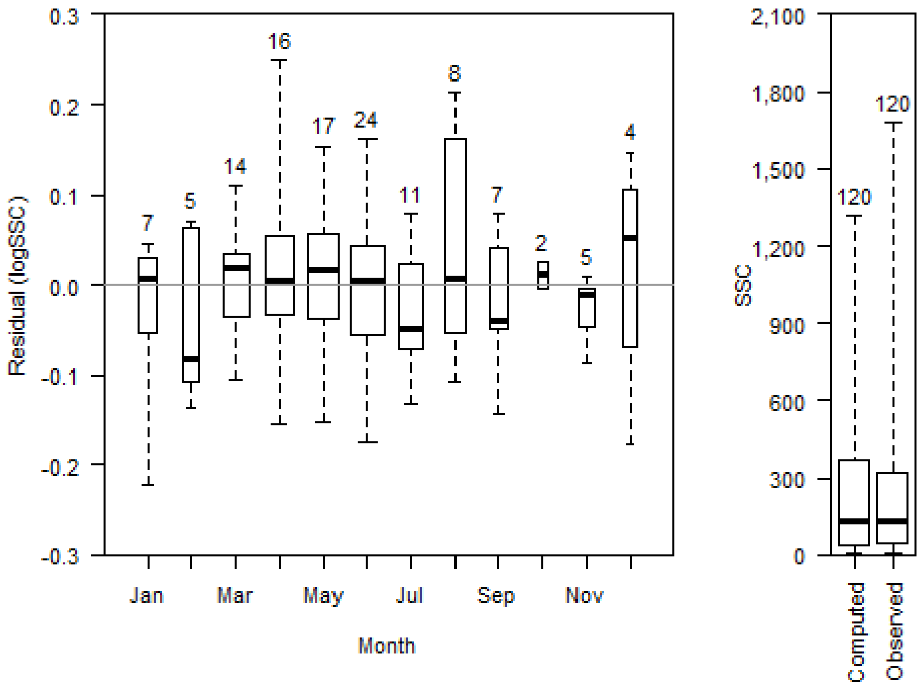
Leverage	Cook's D	DFFITS
0.050	0.194	0.258

Flagged Observations

	logSSC	Estimate	Residual	Standard Residual	Studentized Residual	Leverage	Cook's D	DFFITS
6/9/2005 10:55	2.670	2.840	-0.1740	-2.090	-2.120	0.03630	0.05470	-0.411
5/8/2007 11:30	2.440	2.580	-0.1410	-1.690	-1.710	0.03600	0.03560	-0.329
5/25/2007 13:10	2.450	2.600	-0.1530	-1.830	-1.850	0.03820	0.04460	-0.369
8/5/2008 9:30	1.910	1.700	0.2130	2.530	2.590	0.01390	0.03000	0.307
4/6/2009 13:05	2.220	1.970	0.2490	2.940	3.050	0.00893	0.02600	0.289
5/8/2009 12:55	3.190	3.040	0.1540	1.850	1.860	0.03220	0.03770	0.340
9/24/2009 11:20	2.930	3.070	-0.1420	-1.730	-1.740	0.05320	0.05580	-0.413
1/19/2010 10:00	1.000	0.954	0.0463	0.563	0.561	0.06050	0.00680	0.142
2/4/2010 10:40	1.000	0.937	0.0626	0.761	0.760	0.05840	0.01200	0.189
2/23/2010 12:55	1.180	1.310	-0.1370	-1.640	-1.650	0.02770	0.02540	-0.278
4/14/2010 9:05	1.450	1.310	0.1330	1.590	1.600	0.02550	0.02200	0.259
6/13/2010 15:20	2.950	2.780	0.1610	1.930	1.950	0.03160	0.04050	0.353
8/25/2010 11:00	2.800	2.610	0.1940	2.310	2.350	0.01590	0.02870	0.299
8/15/2011 10:45	2.500	2.600	-0.1070	-1.300	-1.310	0.05960	0.03600	-0.329
7/12/2012 10:15	1.820	1.870	-0.0486	-0.592	-0.590	0.06020	0.00747	-0.149
7/19/2012 10:15	1.890	1.940	-0.0569	-0.697	-0.696	0.07530	0.01320	-0.198
12/12/2012 10:00	0.954	1.130	-0.1770	-2.120	-2.150	0.03090	0.04780	-0.384
1/16/2013 9:30	0.903	1.120	-0.2220	-2.650	-2.730	0.03030	0.07320	-0.481
2/13/2013 9:30	0.845	0.953	-0.1080	-1.300	-1.300	0.03810	0.02230	-0.259
6/24/2013 9:40	2.190	2.040	0.1470	1.760	1.770	0.02220	0.02330	0.267
8/7/2013 9:45	2.190	2.240	-0.0558	-0.679	-0.678	0.06110	0.01000	-0.173
11/25/2013 9:10	0.778	0.826	-0.0477	-0.581	-0.579	0.06150	0.00738	-0.148
1/14/2014 10:20	0.954	0.909	0.0457	0.555	0.553	0.05580	0.00607	0.135

Statistical Plots




Residual (logSSC)
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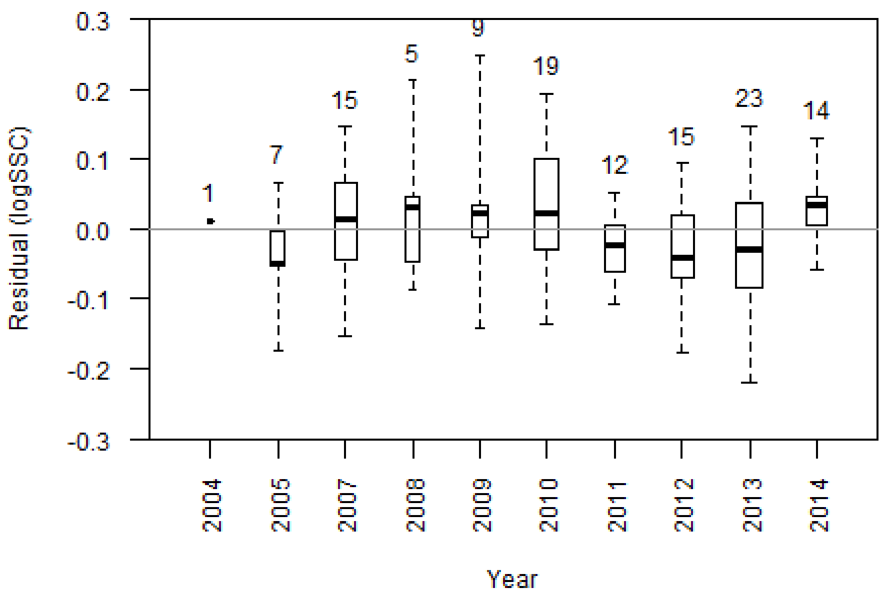
0.2
0.1
0.0
-0.1
-0.2
-0.3
7
5
14
16
17
24
11
8
7
2
5
4
Jan
Mar
May
Jul
Sep
Nov
Month
SSC
2,100
1,800
1,500
1,200
900
600
300
0
120
120
Computed
Observed


Residual (logSSC)
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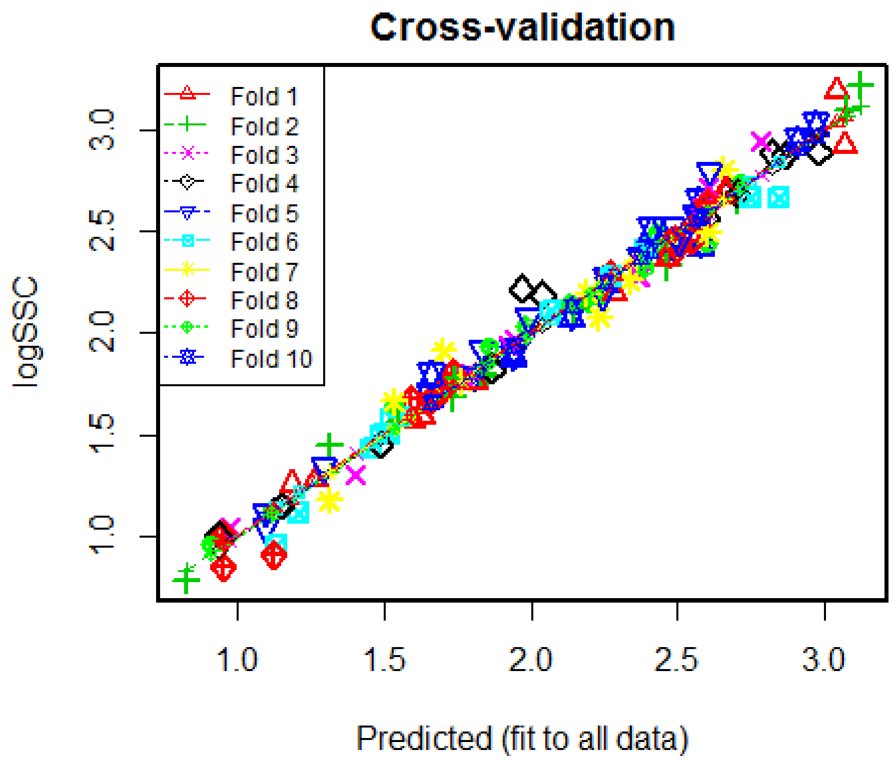
0.2
0.1
0.0
-0.1
-0.2
-0.3
1
7
15
5
9
19
12
15
23
14
2004
2005
2007
2008
2009
2010
2011
2012
2013
2014
Year

Cross Validation




```
          Minimum MSE of folds:  0.00526
             Mean MSE of folds:  0.00727
           Median MSE of folds:  0.00644
          Maximum MSE of folds:  0.01250
 (Mean MSE of folds) / (Model MSE):  1.01000
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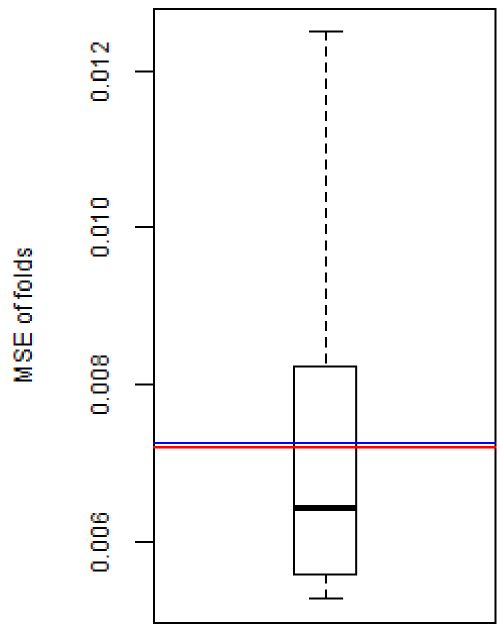


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Red line - Model MSE
Blue line - Mean MSE of folds
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Model-Calibration Data Set

0	Date	logSSC	logTURB	logQ	SSC	TURB	Q	Computed logSSC	Computed SSC	Residual	Normal Quantiles	Censored Values
1	2004-07-27	2.58	2.3	3.77	384	200	5850	2.57	380	0.0127	0.0731	--
2	2005-01-27	2.09	1.91	2.23	122	81	171	2.14	140	-0.0529	-0.584	--
3	2005-03-23	2.7	2.41	3.77	506	260	5840	2.68	485	0.0263	0.351	--
4	2005-03-31	1.91	1.7	2.18	81	50	153	1.94	89.1	-0.0331	-0.329	--
5	2005-05-10	2.5	2.22	2.29	314	165	196	2.43	274	0.0669	0.917	--
6	2005-06-06	2.65	2.46	3.29	449	290	1940	2.7	512	-0.0493	-0.56	--
7	2005-06-09	2.67	2.58	4.08	469	380	11900	2.84	713	-0.174	-2.02	--
8	2005-08-31	2.15	1.98	2.05	141	96.5	111	2.2	162	-0.0529	-0.609	--
9	2007-01-10	1.04	0.839	1.16	11	6.9	14.5	1.09	12.7	-0.0536	-0.634	--
10	2007-03-12	1.6	1.36	1.28	40	23	19	1.59	39.4	0.0142	0.115	--
11	2007-03-21	1.69	1.41	1.71	49	26	51	1.66	46.2	0.0341	0.488	--
12	2007-03-27	2.56	2.4	2.2	362	250	158	2.59	400	-0.0357	-0.351	--
13	2007-04-02	2.89	2.58	3.46	775	380	2880	2.82	671	0.0709	0.982	--
14	2007-04-18	2.35	2.11	2.94	223	130	861	2.36	234	-0.0128	-0.178	--
15	2007-05-08	2.44	2.3	3.97	275	200	9280	2.58	388	-0.141	-1.6	--
16	2007-05-10	2.43	2.22	3.71	267	165	5170	2.49	316	-0.0648	-0.825	--
17	2007-05-24	3.03	2.73	3.73	1070	540	5390	2.97	957	0.0568	0.796	--
18	2007-05-25	2.45	2.32	4.04	280	208	10900	2.6	405	-0.153	-1.77	--
19	2007-07-11	2.65	2.32	3.28	446	210	1920	2.57	379	0.0788	1.09	--
20	2007-08-16	1.66	1.41	1.77	46	25.8	59	1.66	46.1	0.0071	-0.0104	--
21	2007-09-06	1.67	1.36	1.41	47	23	26	1.59	40	0.0783	1.05	--
22	2007-12-06	1.04	0.699	1.48	11	5	30	0.978	9.69	0.0633	0.855	--
23	2007-12-13	2.8	2.41	3.44	638	256	2740	2.66	464	0.147	1.6	--
24	2008-03-06	2.89	2.77	2.99	779	593	966	2.98	970	-0.087	-1.05	--
25	2008-04-14	2.54	2.36	2.68	343	230	484	2.58	389	-0.0463	-0.465	--
26	2008-06-30	2.59	2.33	2.94	389	212	872	2.56	369	0.0307	0.465	--
27	2008-08-05	1.91	1.48	1.41	82	30	25.5	1.7	51.2	0.213	2.22	--
28	2008-09-16	2.53	2.23	3.23	337	170	1690	2.48	309	0.0452	0.66	--
29	2009-04-06	2.22	1.72	2.27	165	53	187	1.97	94.9	0.249	2.58	--
30	2009-04-13	2.42	2.15	2.93	262	140	856	2.39	251	0.0272	0.373	--
31	2009-04-28	2.74	2.45	3.96	549	280	9190	2.72	530	0.0232	0.285	--
32	2009-05-08	3.19	2.81	3.54	1560	650	3430	3.04	1120	0.154	1.77	--
33	2009-07-30	2.46	2.32	2.71	287	210	507	2.55	358	-0.0877	-1.09	--
34	2009-09-09	2.62	2.32	3.51	413	210	3230	2.58	388	0.0357	0.512	--
35	2009-09-24	2.93	2.89	2.52	842	777	333	3.07	1190	-0.142	-1.68	--
36	2009-11-03	2.36	2.15	2.52	230	140	328	2.37	241	-0.0114	-0.157	--
37	2009-11-19	1.11	0.835	1.81	13	6.83	65	1.12	13.4	-0.00518	-0.136	--
38	2010-01-19	1	0.653	1.9	10	4.5	80	0.954	9.16	0.0463	0.713	--
39	2010-02-04	1	0.64	1.81	10	4.37	64	0.937	8.82	0.0626	0.825	--
40	2010-02-23	1.18	1.04	1.83	15	11	68.2	1.31	20.9	-0.137	-1.53	--
41	2010-03-10	2.51	2.18	2.74	322	150	549	2.41	262	0.0971	1.21	--
42	2010-04-14	1.45	1.05	1.72	28	11.2	53	1.31	21	0.133	1.53	--
43	2010-04-23	2.29	2.04	2.36	196	110	228	2.27	189	0.0237	0.307	--
44	2010-05-13	2.88	2.66	2.73	758	460	541	2.86	746	0.0152	0.136	--
45	2010-06-09	3.23	2.89	3.65	1680	784	4460	3.12	1340	0.105	1.25	--
46	2010-06-10	2.4	2.2	3.52	251	160	3290	2.47	301	-0.0707	-0.885	--
47	2010-06-13	2.95	2.52	3.92	883	333	8220	2.78	621	0.161	1.88	--
48	2010-06-14	2.68	2.43	4.07	484	267	11600	2.7	513	-0.0175	-0.242	--
49	2010-06-14	2.43	2.18	4.18	272	150	15100	2.47	303	-0.0382	-0.396	--
50	2010-06-14	2.38	2.18	4.17	242	150	14900	2.47	302	-0.0887	-1.17	--
51	2010-06-15	2.71	2.4	3.81	510	250	6440	2.66	470	0.0438	0.609	--
52	2010-06-15	2.69	2.4	3.8	486	250	6380	2.66	470	0.023	0.264	--
53	2010-06-16	2.72	2.34	3.68	525	217	4810	2.6	407	0.119	1.35	--
54	2010-08-19	1.8	1.56	1.79	63	36.3	61	1.79	63.4	0.00526	-0.0313	--
55	2010-08-25	2.8	2.38	2.89	633	240	770	2.61	413	0.194	2.02	--
56	2010-11-16	2.28	2.15	2.42	191	140	262	2.37	238	-0.0879	-1.13	--
57	2011-01-19	1.58	1.32	1.91	38	20.7	81	1.57	38	0.00809	0.0313	--
58	2011-03-07	1.3	1.15	1.71	20	14	51	1.41	25.9	-0.104	-1.3	--
59	2011-03-16	1.58	1.28	1.68	38	19	48	1.53	34.4	0.052	0.74	--

60	2011-04-06	1.43	1.2	1.58	27	16	38	1.45	29	-0.0224	-0.264	--
61	2011-04-18	1.51	1.28	1.51	32	19	32	1.52	33.8	-0.0151	-0.199	--
62	2011-05-02	1.59	1.4	1.46	39	24.9	29	1.63	43.3	-0.0372	-0.373	--
63	2011-05-16	1.57	1.36	1.43	37	23	27	1.59	40.1	-0.0263	-0.285	--
64	2011-06-07	1.79	1.64	1.34	61	44	22	1.85	72.7	-0.0682	-0.855	--
65	2011-06-21	2.26	2.04	2.04	182	110	110	2.25	183	0.00516	-0.0522	--
66	2011-08-15	2.5	2.44	1.41	313	277	26	2.6	408	-0.107	-1.35	--
67	2011-09-22	2.18	2.04	1.66	152	110	45.7	2.24	176	-0.0566	-0.713	--
68	2011-12-20	2.95	2.7	3.04	895	500	1090	2.91	831	0.0404	0.535	--
69	2012-02-06	2.28	2.13	2.67	192	135	464	2.36	236	-0.0816	-0.982	--
70	2012-03-01	3.1	2.87	3.12	1270	740	1310	3.07	1210	0.0301	0.419	--
71	2012-04-07	2.26	2.11	2.41	182	130	259	2.34	222	-0.0786	-0.917	--
72	2012-04-17	1.79	1.56	1.92	61	36.5	82.7	1.8	64.7	-0.0172	-0.221	--
73	2012-05-09	1.94	1.7	1.63	87	50.5	42.5	1.92	85.1	0.0179	0.221	--
74	2012-05-30	1.92	1.64	0.898	84	43.5	7.9	1.83	68.8	0.0946	1.17	--
75	2012-06-12	1.97	1.75	1.15	94	56	14	1.94	89.3	0.0304	0.441	--
76	2012-06-18	2.32	2.18	2.11	210	150	130	2.38	247	-0.0615	-0.796	--
77	2012-06-19	2.2	2.08	1.89	158	120	77	2.28	196	-0.0848	-1.02	--
78	2012-07-12	1.82	1.71	0.342	66	50.8	2.2	1.87	75.2	-0.0486	-0.535	--
79	2012-07-19	1.89	1.79	0.204	77	62	1.6	1.94	89.4	-0.0569	-0.74	--
80	2012-09-11	1.79	1.65	0.633	62	45	4.3	1.83	69.2	-0.0396	-0.419	--
81	2012-10-24	1.79	1.58	0.672	62	38.2	4.7	1.77	59.7	0.0246	0.329	--
82	2012-11-14	1.28	1.04	0.82	19	11	6.6	1.27	18.9	0.00956	0.0522	--
83	2012-12-12	0.954	0.898	0.732	9	7.9	5.4	1.13	13.8	-0.177	-2.22	--
84	2013-01-16	0.903	0.886	0.82	8	7.7	6.6	1.12	13.6	-0.222	-2.58	--
85	2013-01-29	1.51	1.28	0.898	32	18.9	7.9	1.49	31.7	0.0129	0.094	--
86	2013-02-13	0.845	0.699	0.898	7	5	7.9	0.953	9.15	-0.108	-1.41	--
87	2013-03-12	1.64	1.3	1.34	44	20	22	1.53	34.8	0.109	1.3	--
88	2013-03-13	1.57	1.3	1.73	37	20	53.8	1.55	36.2	0.0175	0.199	--
89	2013-03-27	1.11	0.97	1	13	9.32	10	1.21	16.5	-0.0961	-1.25	--
90	2013-04-15	1.68	1.51	1.59	48	32	39	1.74	55.4	-0.0539	-0.66	--
91	2013-04-15	1.8	1.51	1.59	63	32	39	1.74	55.4	0.0642	0.885	--
92	2013-04-24	2.08	2.02	1.91	119	105	82	2.23	173	-0.155	-1.88	--
93	2013-05-06	2.12	1.93	2	132	85	101	2.15	144	-0.0283	-0.307	--
94	2013-05-09	2.67	2.57	2.05	463	367	114	2.74	566	-0.0787	-0.949	--
95	2013-05-15	2.15	1.93	1.51	140	85.5	32	2.13	137	0.0164	0.178	--
96	2013-05-21	2.28	2.08	1.7	192	120	50	2.28	192	0.0079	0.0104	--
97	2013-05-28	2.04	1.79	1.18	109	61.3	15.2	1.98	97.6	0.0563	0.768	--
98	2013-06-13	2.08	1.79	1.49	120	61	30.7	1.99	100	0.0871	1.13	--
99	2013-06-24	2.19	1.84	1.36	154	69.7	22.7	2.04	112	0.147	1.68	--
100	2013-07-09	1.93	1.69	0.519	86	48.4	3.3	1.86	73.3	0.0775	1.02	--
101	2013-07-29	2.33	2.2	3.38	215	160	2390	2.46	297	-0.132	-1.46	--
102	2013-07-29	2.37	2.2	3.37	236	160	2370	2.46	297	-0.0913	-1.21	--
103	2013-08-07	2.19	1.93	4.14	154	85.5	13800	2.24	178	-0.0558	-0.686	--
104	2013-09-12	1.45	1.23	1.82	28	17	65.3	1.49	31.4	-0.0414	-0.441	--
105	2013-10-24	1.15	0.883	1.48	14	7.63	30	1.15	14.4	-0.00338	-0.115	--
106	2013-11-25	0.778	0.531	1.57	6	3.4	37.3	0.826	6.82	-0.0477	-0.488	--
107	2014-01-14	0.954	0.616	1.65	9	4.13	45	0.909	8.25	0.0457	0.686	--
108	2014-02-20	1.26	0.91	1.69	18	8.13	49	1.18	15.6	0.0709	0.949	--
109	2014-03-17	1.11	0.82	1.57	13	6.6	37	1.09	12.7	0.0194	0.242	--
110	2014-04-09	1.34	1.04	1.48	22	11	30.5	1.3	20.2	0.0446	0.634	--
111	2014-05-08	1.66	1.3	1.34	46	20	22	1.53	34.8	0.129	1.41	--
112	2014-06-03	1.76	1.53	1.71	58	34	50.8	1.76	59.3	-0.00127	-0.094	--
113	2014-06-05	2.11	1.84	2.15	130	69	141	2.07	120	0.0434	0.584	--
114	2014-06-09	2.45	2.26	3.17	285	180	1470	2.5	325	-0.0483	-0.512	--
115	2014-06-12	2.64	2.34	3.59	441	220	3880	2.6	408	0.0419	0.56	--
116	2014-06-24	2.2	1.95	2.44	157	90	278	2.19	158	0.00493	-0.0731	--
117	2014-07-10	1.76	1.57	1.95	57	37.3	88.3	1.81	66.2	-0.0571	-0.768	--
118	2014-07-15	1.77	1.51	1.66	59	32.3	46	1.74	56.3	0.0284	0.396	--
119	2014-07-24	1.72	1.47	1.45	52	29.8	28	1.7	51.1	0.0155	0.157	--
120	2014-08-04	1.79	1.44	1.33	62	27.5	21.2	1.66	46.8	0.13	1.46	--

Definitions

SSC: Suspended-sediment concentration (SSC) in mg/L (80154)
TURB: Turbidity in FNU (63680)
Q: Streamflow, in ft^3/s (00060)

Model Archive Summary for Suspended-Sediment Concentration at Station 01648010; Rock Creek at Joyce Road at Washington, DC

This model archive summary documents the suspended-sediment concentration (SSC) model developed to compute 15-minute SSC for the U.S. Geological Survey (USGS) station, Rock Creek at Joyce Road (USGS ID: 01648010) from October 1, 2014 onward. This is the first model developed for the site to compute continuous SSC. The methods used follow USGS guidance as referenced in relevant Office of Surface Water/Office of Water Quality Technical Memoranda and USGS Techniques and Methods, book 3, chap. C5 (Landers and others, 2016).

Site and Model Information

Site number: 01648010

Site name: Rock Creek at Joyce Rd, Washington, DC

Location: Lat 38°57'36.6", long 77°02'31.4" (NAD 1927), Washington, DC, Hydrologic Unit: 02070010, on right bank at downstream side of bridge on Joyce Road.

Drainage area: 62.7 mi^2

Model number: 01648010.SSC.WY15.1

Date model was created: September 9, 2016
Model calibration data period: October 8, 2014 to May 03, 2016
Model application date: October 8, 2014 onwards
Computed by: Joseph Bell, USGS, MD.DE.DC WSC (jmbell@usgs.gov)
Reviewed by: Timothy Straub, USGS, IL-IA WSC (tdstraub@usgs.gov), and Mark Landers, USGS, OSW (landers@usgs.gov)
Approved by: USGS, Center Director, MD.DE.DC Water Science Center

Model Data

All model data were collected using USGS protocols described in Edwards and Glysson (1999), Landers and others (2016), and the USGS National Field Manual. All data are stored in the National Water Information System (NWIS) database (http://dx.doi.org/10.5066/F7P55KJN).

Suspended sediment characteristics at this site are computed from a regression model based on measured suspended sediment characteristics and sediment-corrected backscatter ($\overline{SCB}$). The regression model is based on 41 concurrent measurements of SSC and $\overline{SCB}$ collected from October 8, 2014, through May 3, 2016. An additional 51 concurrent data sets collected during this period were evaluated and excluded from the regression because of potential serial correlation of auto sampler results, and are flagged as excluded in the model calibration dataset. Samples represent the range of observed hydrologic, sediment, and acoustic conditions.

Rock Creek at Joyce Road is a Piedmont valley stream that bisects Rock Creek Park from the border of Washington D.C. south to the Potomac River and ultimately into the Chesapeake Bay, draining a heavily urbanized watershed. The median and maximum SSC in the calibration data set is 84 and 2,900 mg/L, respectively. The system is dominated by fine size material. The average and standard deviation of the percent of fine sized material is 83% and 12%, respectively from 98 samples. Summary statistics and complete model-calibration dataset are provided in the model statistics.

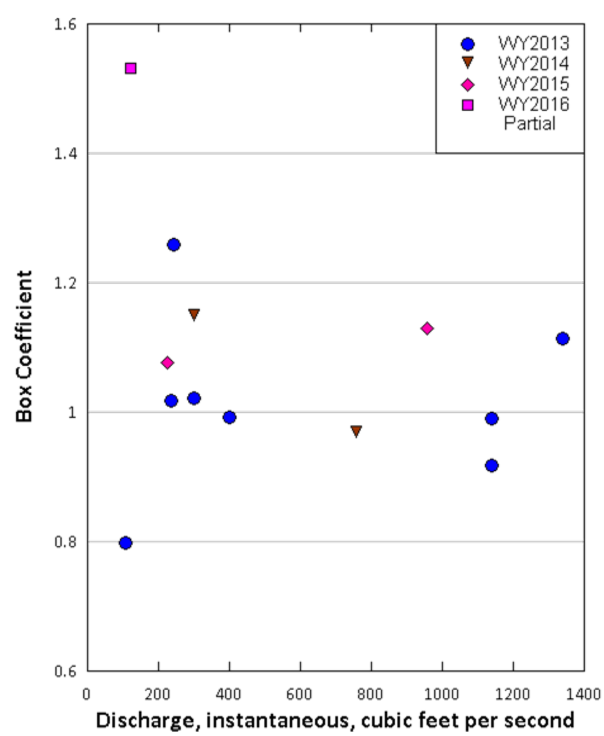
Sediment Data

Discrete, manual sample collection for SSC monitoring takes place on a 4-week, fixed-frequency (FF) interval and targets 10–12 unique storm events throughout the year. These samples are collected by trained USGS personnel using DH-81, DH-95, or D-95 suspended-sediment samplers as dictated by in-stream conditions. When conditions are safe for wading, the equal-width-increment (EWI) method is used to collect a sample from a cross-section approximately 75ft downstream of the Joyce Rd Bridge; these samples typically are composited for analysis. When conditions are not safe for wading, the EWI method is used to collect a sample from the downstream side of the Joyce Rd Bridge. There are no appreciable inputs between the Joyce Rd Bridge and wading cross section.

Discrete monitoring is augmented by the use of an automatic sampler to facilitate sampling during 8-12 storm events throughout the year. The automatic sampler is configured to trigger when empirically-determined threshold(s) are exceeded and paced to collect 4 samples across a given storm hydrograph. Storm-sampling efforts target rising, peak, and falling stream conditions throughout the year to capture the range of sediment, flow, and seasonal conditions. To avoid imparting a negative bias on SSC results, SSC samples are not drawn from a churn splitter. All samples are analyzed for SSC in the USGS Sediment Laboratory in Louisville, Kentucky.

Fixed-Point and Cross Section Samples

The relation between SSC from EWI cross-section samples and from a fixed-point automatic sampler is evaluated using concurrent samples. This evaluation used 15 concurrent samples (from WY2013 to WY2016-partial) of which 9 were collected in Water Year 2013 (WY2013); three were collected in Water Year 2014 (WY2014); two were collected in Water Year 2015 (WY2015); and 1 was collected thus far in Water Year 2016 (WY2016 Partial). The statistics of the ratio of EWI-sample SSC to automatic-sample SSC are: mean 1.11, median 1.05, maximum 1.57, and minimum 0.80. One sample out of the 15 samples was removed from the mean and maximum computation.



Additionally, results from a replicate sample were used for ratio analysis on April 20, 2013. This replicate was ordered based on field-crew concerns about digging the sampler into the bed during collection; the ratio affiliated with the environmental sample is 2.12, and the ratio for the replicate sample is 1.02. Seventy-one percent of the ratios are within 0.9 and 1.1, and 79 percent are within 0.8 and 1.2. A plot of box coefficients versus streamflow indicates scatter about the 1.0 axis (see adjacent plot). A constant ratio of EWI cross-section to automatic-sampler SSC appears reasonable for this site for WY2013−2015. All single-station samples were multiplied by a coefficient (box coefficient) of 1.00 to adjust to cross-section concentration.

Surrogate Data

At the Joyce Rd Bridge, a SonTek Argonaut SL ADVM (for sediment-acoustic index method) and automatic-sampler intake are installed. The ADVM is mounted on the face of the right bridge abutment, near the middle of the bridge. The beams are horizontal and perpendicular to the flow. The gage house is located downstream of the bridge and on the right bank. Power from the gage house is regulated and fused to provide a constant, fixed 13.5 volts to the ADVM. Backup power (also regulated) is provided by a regulated 40-watt solar panel charging a 12-volt deep-cycle battery.

For the period 08/01/2015-08/06/2015 ADVM data were degraded due to an atypical, large sandbar migrating through the cross section. This bar was the result of accelerated bank erosion associated with the large root-ball failure of a ~75ft oak tree located along the left bank, approximate 1/4 mi upstream of the Joyce Rd Bridge.

Surrogate data including mean $\overline{SCB}$, sediment attenuation coefficient (*SAC*), Turbidity, Q, and other continuously measured data were evaluated as explanatory variables for SSC. The $\overline{SCB}$ and *SAC* were determined from the measured backscatter following methods described in Landers and others (2016) using the Surrogate Analysis and Index Developer (SAID) tool (Domanski and others, 2015). The tables below show the ADVM instrument characteristics, deployment configuration, and SAID processing settings.

ADVM Manufactured Characteristics						
Make	**Model**	**Frequency (in kilohertz)**	**Serial number**	**Effective transducer diameter (in meters, m)**	**Slant beam angle (in degrees)**	**Echo intensity factor**
SonTek	Argonaut SL	1,500	E2064	0.03	25	0.43

ADVM Configuration					
Blanking Distance (m)	Number of cells	Cell size (m)	Measurement Averaging period (sec)	Measurement Interval (sec)	Date installed
1.0	10	1.00	120	900	10/08/2014

ADVM Processing						
Beam used (1, 2, or average)	Moving average span[1]	Backscatter values (SNR, amp, RSSI)	Intensity scale factor (if using amp or RSSI)	Cells used	Near field correction[2]	WCB profile adjustment
Average	1	SNR	N/A	1-10	Yes	Yes

[1]The span, in number of observations, used in a centered, moving, averaging of the backscatter time series. The span must be an odd integer.
[2]The near field correction was activated in the analysis, but was not used because cell 1 is beyond the near field distance.

Model Development

Ordinary least squares regression analysis was done using the SAID tool to examine Q, $\overline{SCB}$, and several other explanatory variables for estimating *SSC*. Several untransformed and log10-transformed data were evaluated. The distribution of residuals was examined for normality and plots of residuals (the difference between the measured and predicted values) as compared to predicted SS were examined for homoscedasticity (meaning that their departures from zero did not change substantially over the range of predicted values).

The $\overline{SCB}$ was selected as the best explanatory variables of $\log_{10}$(SSC) based on residual plots, relatively high adjusted coefficient of determination (adjusted R^2), relatively low model standard percentage error (*MSPE*), significance tests (p-values), and cross validation. Values for all of the aforementioned statistics and metrics were computed for this model 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 01648010.

Logarithmic suspended-sediment concentration-based model:

$$\log_{10}(SSC) = 0.0674 \times \overline{SCB} - 3.48$$

where

SSC = suspended-sediment concentration, in milligrams per liter (mg/L); and

$\overline{SCB}$ = sediment corrected backscatter in decibels.

The use of $\overline{SCB}$ as an explanatory variable for SSC is appropriate physically and statistically. Physically, $\overline{SCB}$ varies linearly with $\log_{10}$(SSC) following basic principles of acoustic scattering. Changing sediment particle sizes for a given concentration can produce additional variance in $\overline{SCB}$, but those changes are negligible at this site.

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). For this model, the calculated BCF is 1.22. The retransformed model, accounting for BCF is:

Model	Start date	End date	Linear Regression Model
1	10/08/2014	Current	$SSC = \overline{SCB}^{0.0674} \times 10^{-3.48} \times 1.22$

Model Statistics, Data, and Plots

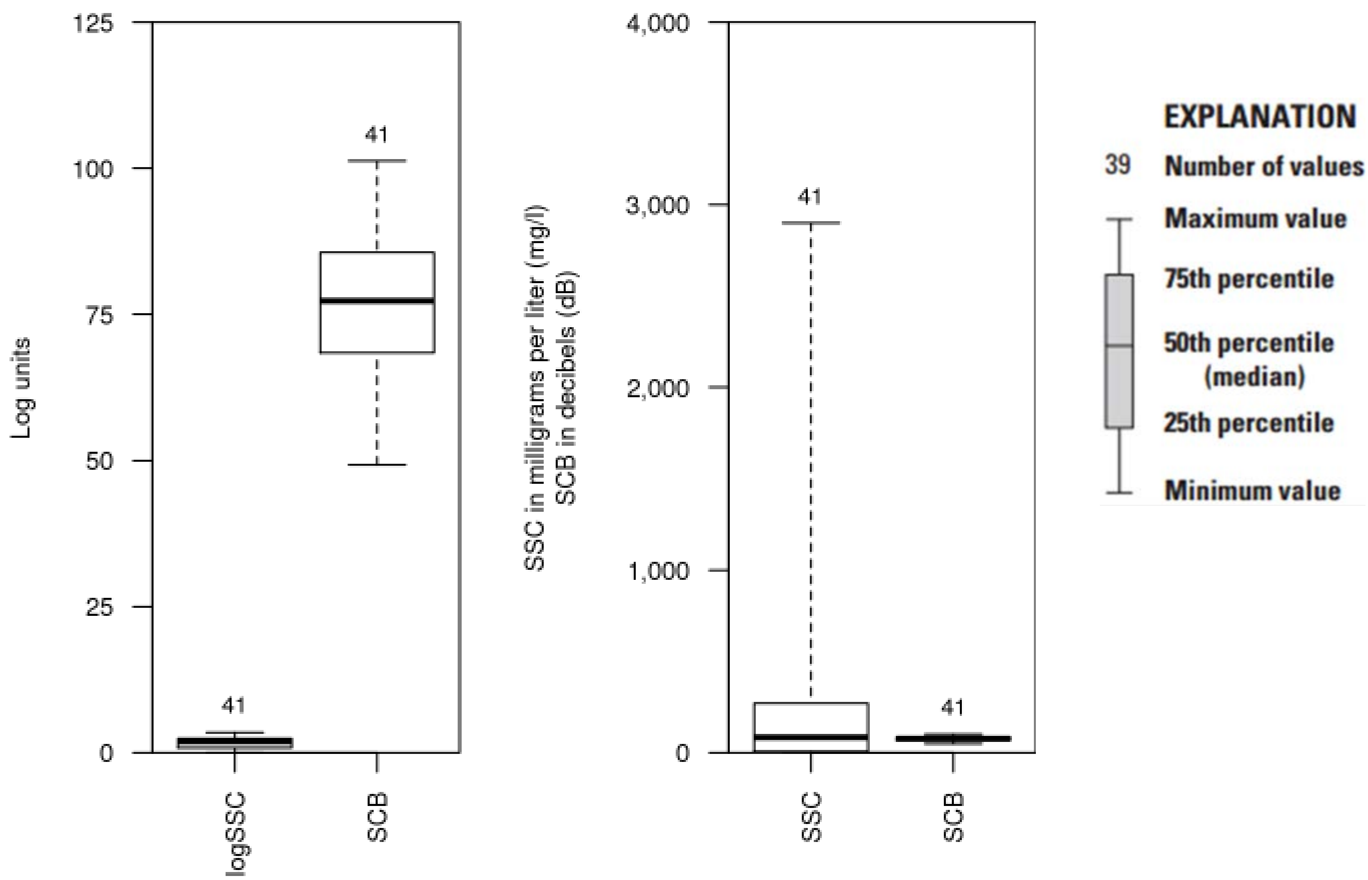
Model

logSSC = + 0.0674 * SCB - 3.48

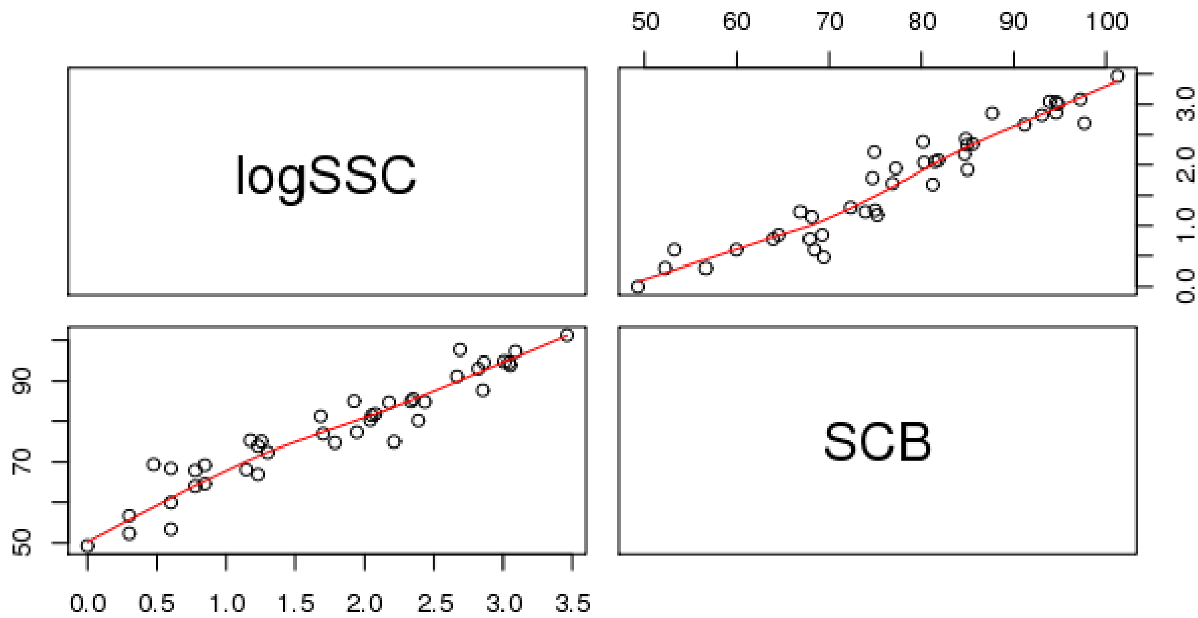
Variable Summary Statistics

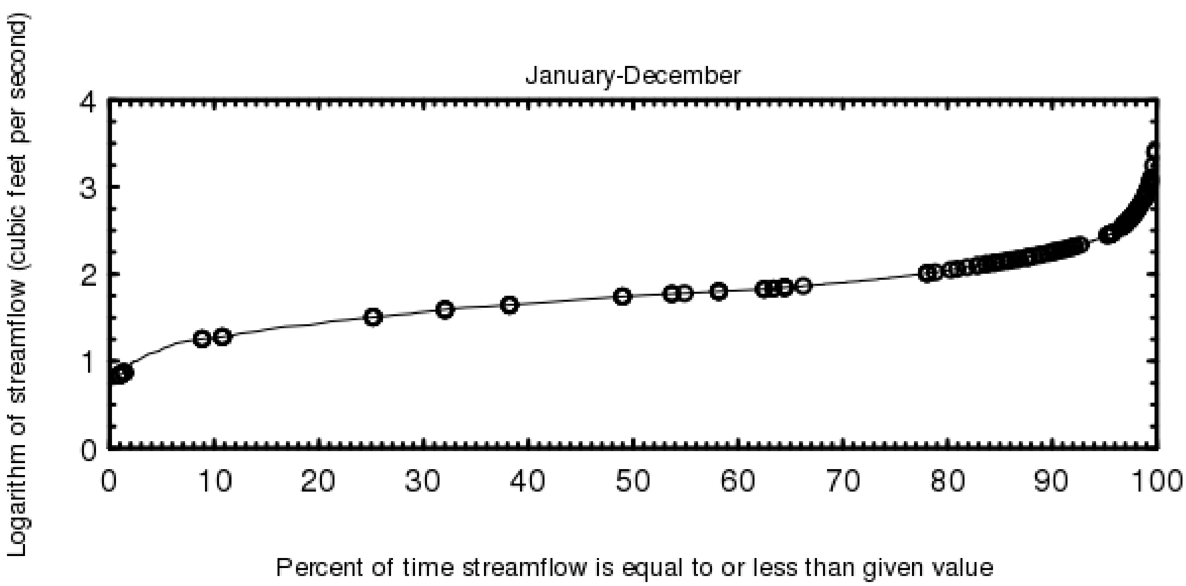
```
              logSSC  SSC   SCB
Minimum        0.000    1  49.3
1st Quartile   0.845    7  68.4
Median         1.920   84  77.3
Mean           1.760  305  77.7
3rd Quartile   2.430  271  85.6
Maximum        3.460 2900 101.0
```

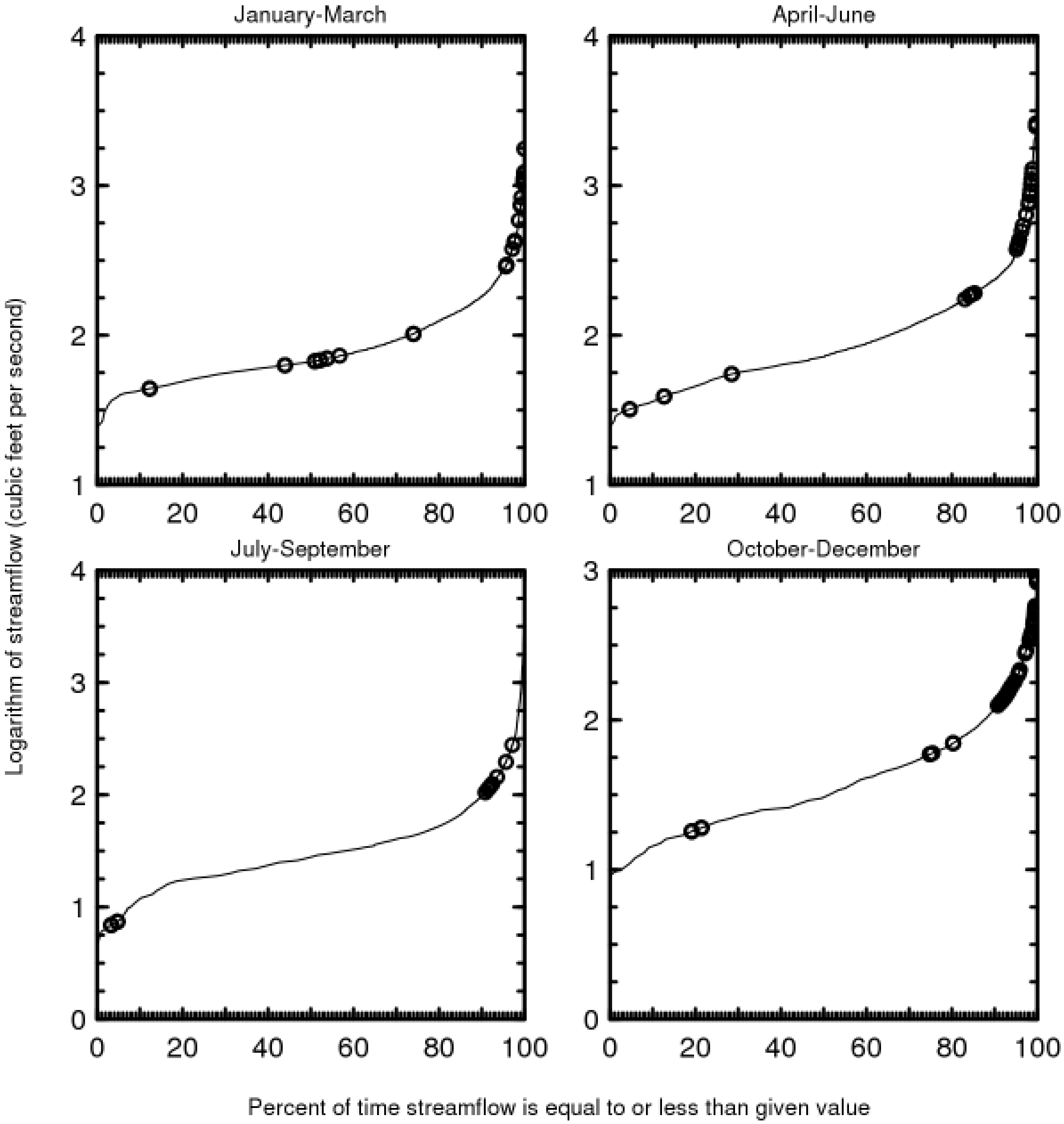
Box Plots


125
100
75
50
25
0
Log units
41
41
logSSC
SCB
4,000
3,000
2,000
1,000
0
SSC in milligrams per liter (mg/l)
SCB in decibels (dB)
41
41
SSC
SCB
EXPLANATION
39 Number of values
Maximum value
75th percentile
50th percentile (median)
25th percentile
Minimum value

Exploratory Plots







Basic Model Statistics

Number of Observations	41
Standard error (RMSE)	0.286
Average Model standard percentage error (MSPE)	70.8
Coefficient of determination (R^2)	0.91
Adjusted Coefficient of Determination (Adj. R^2)	0.907
Bias Correction Factor (BCF)	1.22

Explanatory Variables

	Coefficients	Standard Error	t value	Pr(>|t|)
(Intercept)	-3.4800	0.2680	-13.0	9.97e-16
SCB	0.0674	0.0034	19.8	5.85e-22

Correlation Matrix

	Intercept	E.vars
Intercept	1.000	-0.986
E.vars	-0.986	1.000

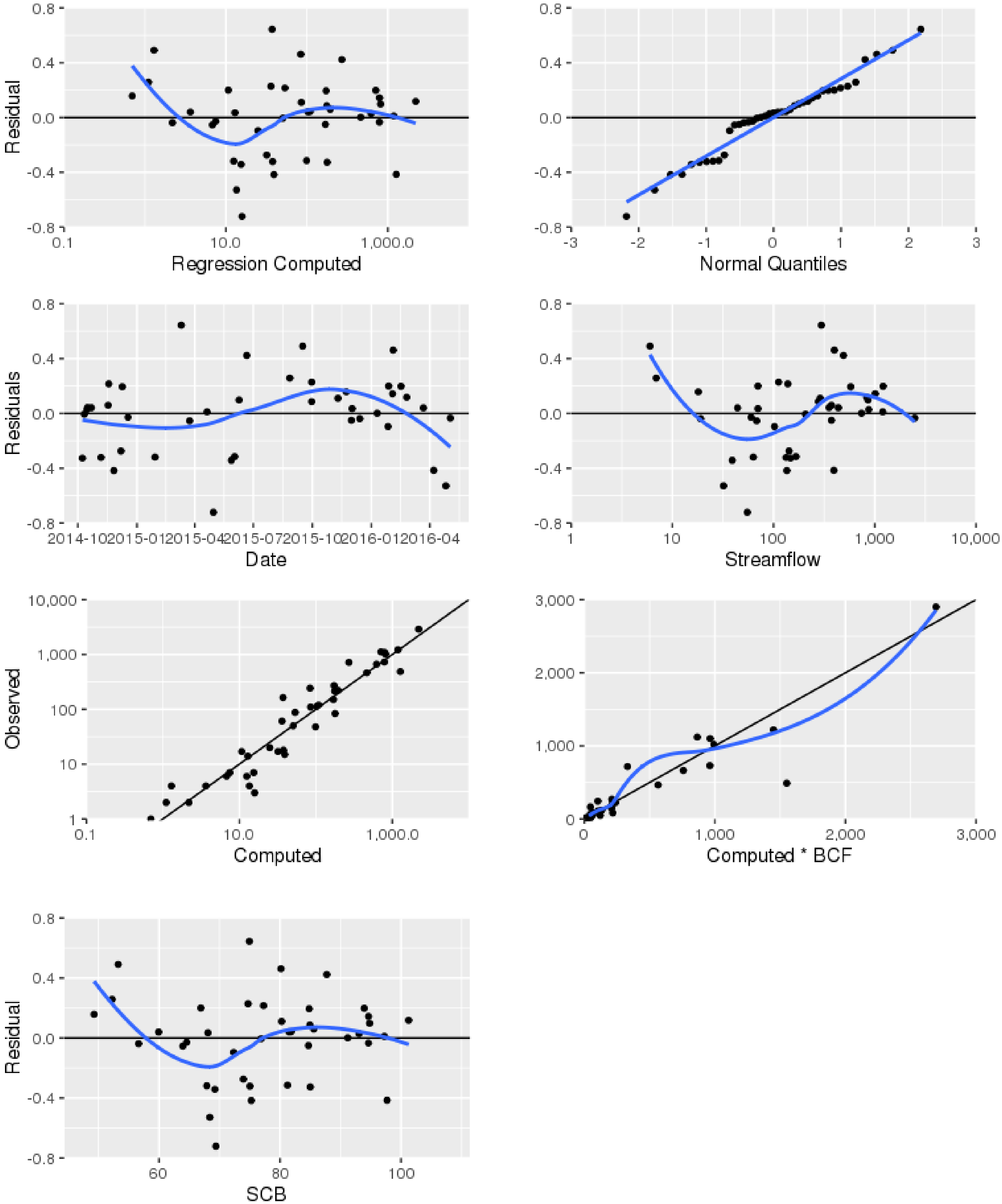
Outlier Test Criteria

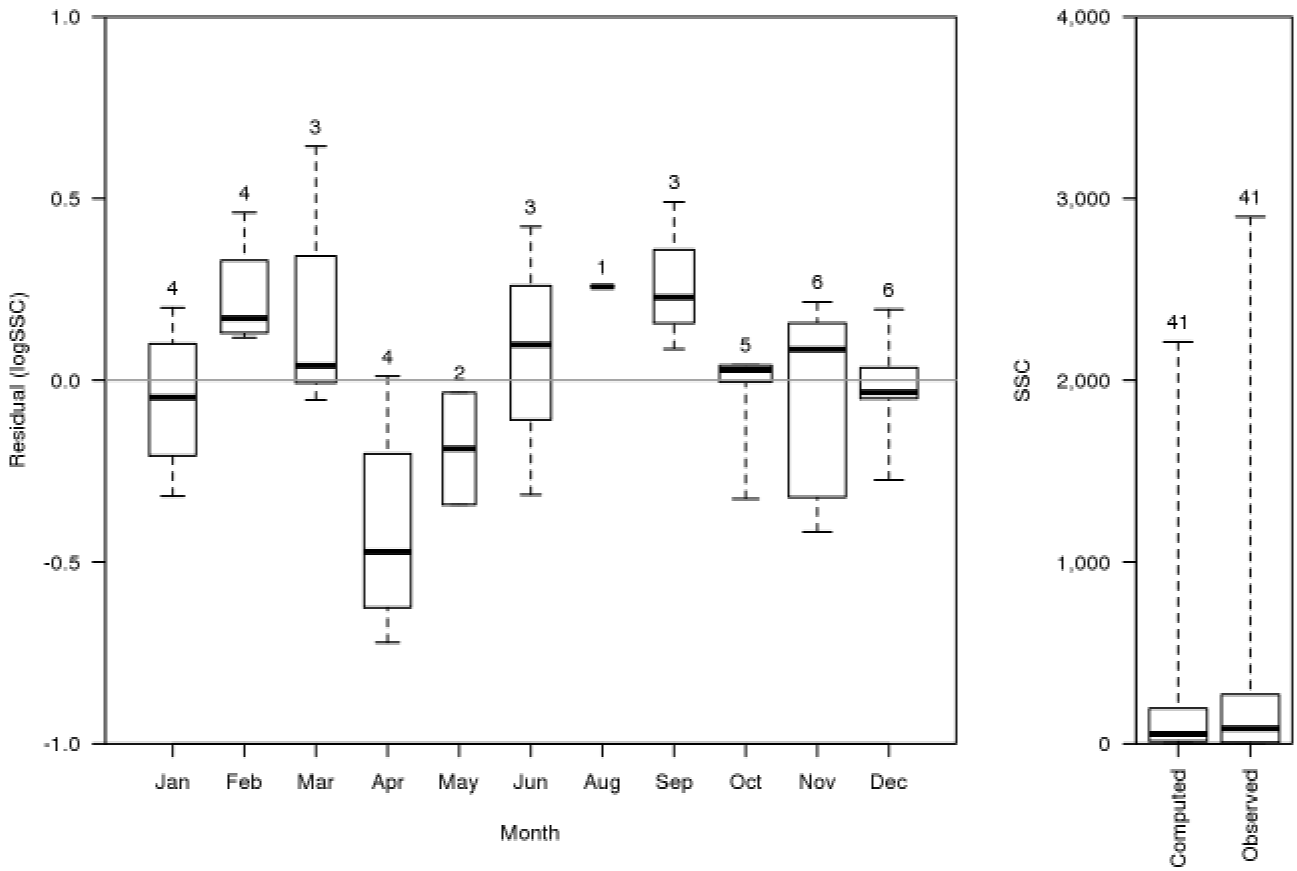
Leverage	Cook's D	DFFITS
0.0732	0.1056	0.3123

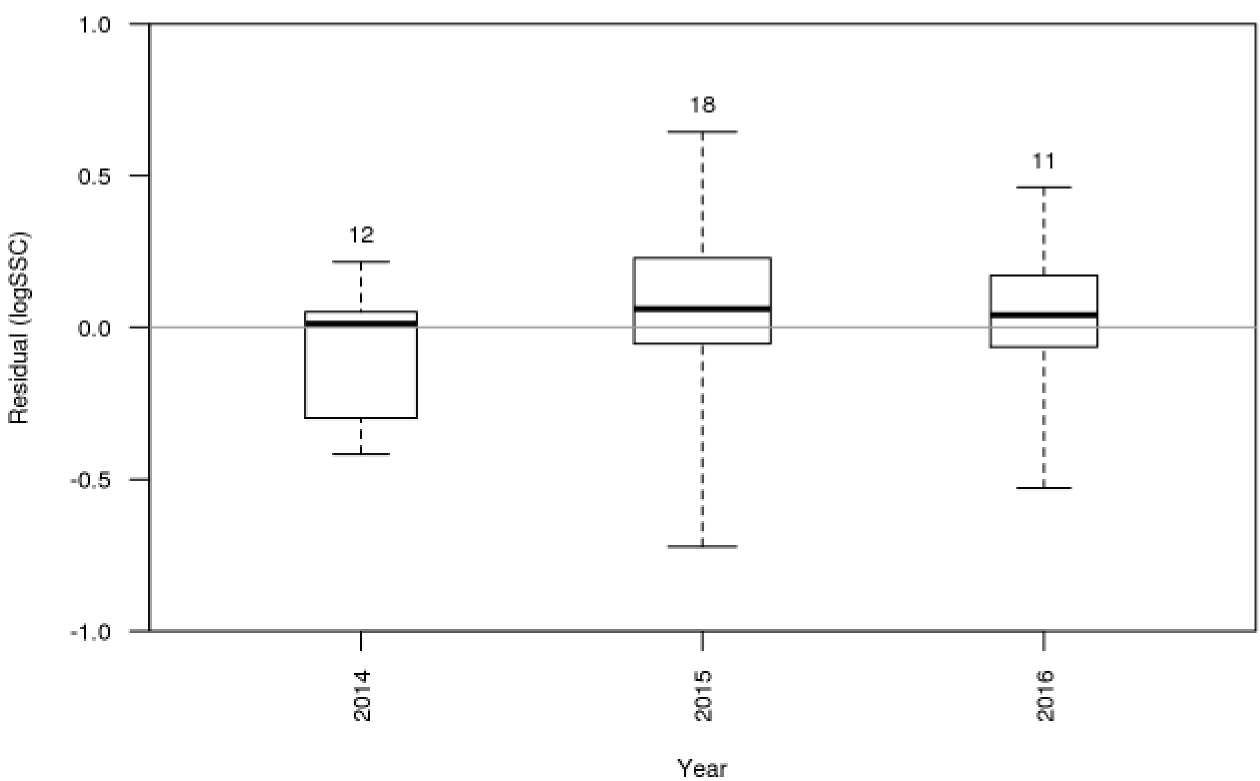
Flagged Observations

	logSSC	Estimate	Residual	Standard Residual	Studentized Residual	Leverage	Cook's D	DFFITS
3/11/2015 10:00	2.210	1.5700	0.6440	2.280	2.4200	0.0255	6.79e-02	0.3910
4/20/2015 3:30	3.090	3.0800	0.0113	0.041	0.0405	0.0782	7.13e-05	0.0118
4/30/2015 8:15	0.477	1.2000	-0.7220	-2.570	-2.7800	0.0341	1.16e-01	-0.5220
8/27/2015 13:45	0.301	0.0432	0.2580	0.958	0.9570	0.1160	6.01e-02	0.3460
9/16/2015 11:45	0.602	0.1110	0.4910	1.820	1.8700	0.1090	2.01e-01	0.6540
11/23/2015 11:00	0.000	-0.1570	0.1570	0.593	0.5880	0.1390	2.82e-02	0.2360
12/14/2015 10:00	0.301	0.3390	-0.0380	-0.139	-0.1370	0.0871	9.22e-04	-0.0424
2/24/2016 18:30	3.460	3.3400	0.1180	0.434	0.4290	0.1030	1.08e-02	0.1450
4/7/2016 17:30	2.690	3.1000	-0.4150	-1.510	-1.5400	0.0807	1.00e-01	-0.4560
4/26/2016 9:00	0.602	1.1300	-0.5290	-1.880	-1.9500	0.0367	6.73e-02	-0.3800

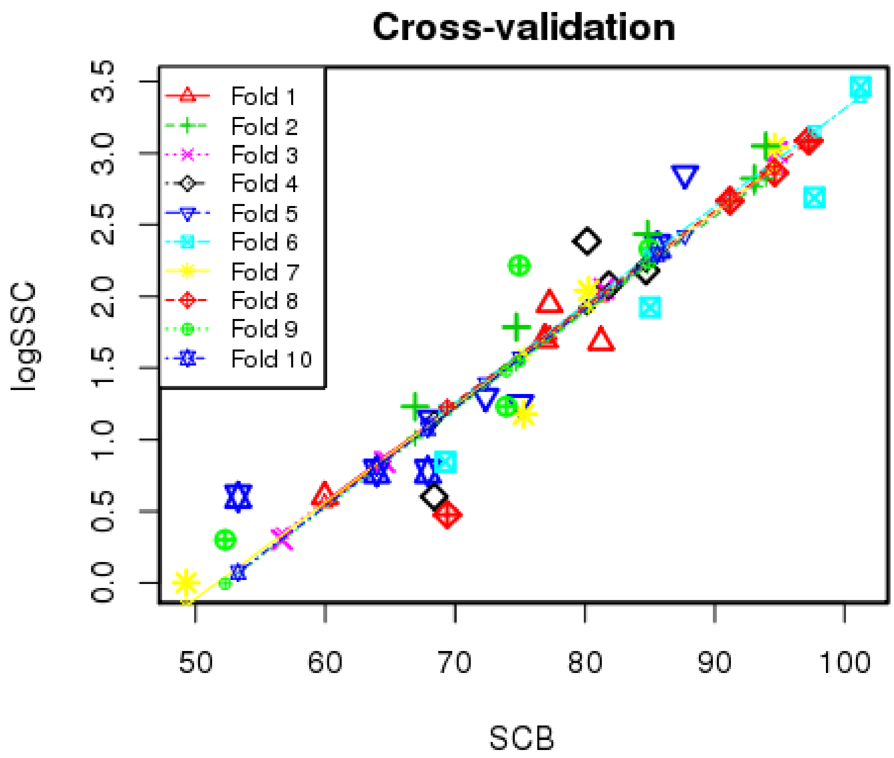
Statistical Plots



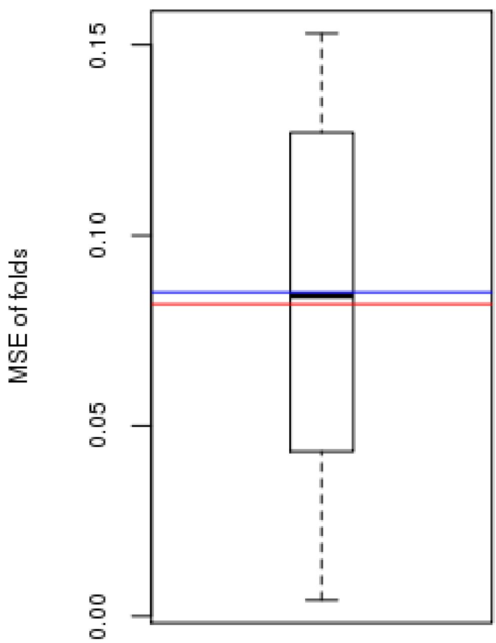

Residual (logSSC)
1.0
0.5
0.0
-0.5
-1.0
4
4
3
4
2
3
1
3
5
6
6
Jan
Feb
Mar
Apr
May
Jun
Aug
Sep
Oct
Nov
Dec
Month
SSC
4,000
3,000
2,000
1,000
0
41
41
Computed
Observed


Residual (logSSC)
1.0
0.5
0.0
-0.5
-1.0
12
18
11
2014
2015
2016
Year

Cross Validation




```
              Minimum MSE of folds:  0.00423
                 Mean MSE of folds:  0.08510
               Median MSE of folds:  0.08420
              Maximum MSE of folds:  0.15300
(Mean MSE of folds) / (Model MSE):  1.04000
```




```
Red line - Model MSE

Blue line - Mean MSE of folds
```

Model-Calibration Data Set

0	Date	logSSC	SCB	SSC	Computed logSSC	Computed SSC	Residual	Normal Quantiles	Censored Values
1	2014-10-08	1.92	85	84	2.25	217	-0.326	-1.1	--
2	2014-10-11	1.7	76.9	50	1.7	61.6	-0.00494	-0.246	--
3	2014-10-15	2.82	93.1	664	2.79	758	0.0284	-0.0609	--
4	2014-10-16	2.08	81.8	120	2.04	133	0.0424	0.184	--
5	2014-10-22	2.05	81.5	113	2.01	125	0.0413	0.122	--
6	2014-11-06	1.26	75	18	1.58	46	-0.322	-0.994	--
7	2014-11-17	2.35	85.6	223	2.29	237	0.0596	0.246	--
8	2014-11-18	1.94	77.3	88	1.73	65.3	0.215	0.994	--
9	2014-11-26	1.18	75.3	15	1.59	47.7	-0.417	-1.53	--
10	2014-12-07	1.23	73.9	17	1.5	38.9	-0.274	-0.729	--
11	2014-12-09	2.43	84.8	271	2.24	211	0.195	0.729	--
12	2014-12-18	0.845	64.6	7	0.873	9.1	-0.0281	-0.309	--
13	2015-01-29	0.778	67.9	6	1.1	15.2	-0.319	-0.898	--
14	2015-03-11	2.21	74.9	164	1.57	45.4	0.644	2.18	--
15	2015-03-24	0.778	64	6	0.832	8.28	-0.054	-0.578	--
16	2015-04-20	3.09	97.2	1220	3.08	1450	0.0113	-0.122	--

17	2015-04-30	0.477	69.4	3	1.2	19.3	-0.722	-2.18	--
18	2015-05-28	0.845	69.2	7	1.19	18.8	-0.342	-1.22	--
19	2015-06-02	1.68	81.2	48	2	121	-0.315	-0.811	--
20	2015-06-09	3.01	94.8	1020	2.91	991	0.098	0.374	--
21	2015-06-21	2.86	87.7	717	2.43	330	0.423	1.36	--
22	2015-08-27	0.301	52.3	2	0.0432	1.35	0.258	1.22	--
23	2015-09-16	0.602	53.3	4	0.111	1.57	0.491	1.76	--
24	2015-09-30	2.33	85	215	2.25	215	0.086	0.309	--
25	2015-09-30	1.79	74.7	61	1.56	43.9	0.228	1.1	--
26	2015-11-10	2.04	80.3	110	1.93	104	0.11	0.44	--
27	2015-11-23	0	49.3	1	-0.157	0.848	0.157	0.652	--
28	2015-12-01	2.18	84.7	151	2.23	206	-0.0502	-0.508	--
29	2015-12-02	1.15	68.1	14	1.11	15.7	0.035	0	--
30	2015-12-14	0.301	56.6	2	0.339	2.66	-0.038	-0.44	--
31	2016-01-10	2.67	91.2	465	2.67	565	0.00137	-0.184	--
32	2016-01-27	1.3	72.3	20	1.4	30.4	-0.0958	-0.652	--
33	2016-01-28	1.23	66.9	17	1.03	13.1	0.2	0.898	--
34	2016-02-03	3.04	94.6	1100	2.9	963	0.143	0.578	--
35	2016-02-04	2.39	80.2	243	1.92	102	0.461	1.53	--
36	2016-02-16	3.05	93.9	1120	2.85	864	0.198	0.811	--
37	2016-02-25	3.46	101	2900	3.34	2690	0.118	0.508	--
38	2016-03-22	0.602	60	4	0.562	4.44	0.0401	0.0609	--
39	2016-04-07	2.69	97.7	489	3.1	1550	-0.415	-1.36	--
40	2016-04-26	0.602	68.4	4	1.13	16.5	-0.529	-1.76	--
41	2016-05-03	2.86	94.6	730	2.9	961	-0.0339	-0.374	--

Definitions

SSC: Suspended sediment concentration (SSC) in mg/L (80154)
$\overline{SCB}$: in decibels (72238)