Prepared in cooperation with the Kansas Water Office

# Relations Between Continuous Real-Time Turbidity Data and Discrete Suspended-Sediment Concentration Samples in the Neosho and Cottonwood Rivers, East-Central Kansas, 2009–2012

Open-File Report 2014–1171

U.S. Department of the Interior
U.S. Geological Survey

**Cover.** Neosho River, November 2009. All photographs by Guy M. Foster, U.S. Geological Survey.

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SALLY JEWELL, Secretary

**U.S. Geological Survey**
Suzette M. Kimball, Acting Director

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# Conversion Factors

Inch/Pound to SI

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| foot (ft) | 0.3048 | meter (m) |
| micrometer (µm) | 0.00003937 | inch (in.) |
| mile (mi) | 1.609 | kilometer (km) |
| | Area | |
| acre | 4,047 | square meter ($m^2$) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |
| | Volume | |
| acre-foot (acre-ft) | 1,233 | cubic meter ($m^3$) |
| | Flow | |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second ($m^3/s$) |
| cubic foot per second ($ft^3/s$) | 1.9835 | acre-feet per day (acre-ft/d) |

Suspended-sediment concentrations are reported in milligrams per liter (mg/L).

# Relations Between Continuous Real-Time Turbidity Data and Discrete Suspended-Sediment Concentration Samples in the Neosho and Cottonwood Rivers, East-Central Kansas, 2009–2012

By Guy M. Foster

## Abstract

The Neosho River and its primary tributary, the Cottonwood River, are the primary sources of inflow to the John Redmond Reservoir in east-central Kansas. Sedimentation rate in the John Redmond Reservoir was estimated as 743 acre-feet per year for 1964–2006. This estimated sedimentation rate is more than 80 percent larger than the projected design sedimentation rate of 404 acre-feet per year, and resulted in a loss of 40 percent of the conservation pool since its construction in 1964. To reduce sediment input into the reservoir, the Kansas Water Office implemented stream bank stabilization techniques along an 8.3 mile reach of the Neosho River during 2010 through 2011. The U.S. Geological Survey, in cooperation with the Kansas Water Office and funded in part through the Kansas State Water Plan Fund, operated continuous real-time water-quality monitors upstream and downstream from stream bank stabilization efforts before, during, and after construction. Continuously measured water-quality properties include streamflow, specific conductance, water temperature, and turbidity. Discrete sediment samples were collected from June 2009 through September 2012 and analyzed for suspended-sediment concentration (SSC), percentage of sediments less than 63 micrometers (sand-fine break), and loss of material on ignition (analogous to amount of organic matter). Regression models were developed to establish relations between discretely measured SSC samples, and turbidity or streamflow to estimate continuously SSC. Continuous water-quality monitors represented between 96 and 99 percent of the cross-sectional variability for turbidity, and had slopes between 0.91 and 0.98. Because consistent bias was not observed, values from continuous water-quality monitors were considered representative of stream conditions. On average, turbidity-based SSC models explained 96 percent of the variance in SSC. Streamflow-based regressions explained 53 to 60 percent of the variance. Mean squared prediction error for turbidity-based regression relations ranged from -32 to 48 percent, whereas mean square prediction error for streamflow-based regressions ranged from -69 to 218 percent. These models are useful for evaluating the variability of SSC during rapidly changing conditions, computing loads and yields to assess SSC transport through the watershed, and for providing more accurate load estimates compared to streamflow-only based estimation methods used in the past. These models can be used to evaluate the efficacy of streambank stabilization efforts.

## Introduction

The Upper Neosho and Cottonwood River watersheds, located in east-central Kansas, drain about 3,015 square miles ($mi^2$) and are the primary inflows to the John Redmond Reservoir (Lee and others, 2008; fig. 1*A*). Sedimentation rate in the John Redmond Reservoir was estimated as 743 acre-feet per year for 1964–2006. This is over 80 percent larger than the projected design sedimentation rate of 404 acre-feet per year, and resulted in a loss of 40 percent of the conservation pool (Kansas Water Office, 2012). Based on data from the Kansas Department of Health and Environment and the U.S. Geological Survey (USGS), the Kansas Water Office (the state agency responsible for water policy and planning) determined that the greatest sediment yield occurred along an 8.3 mile reach of the main stem of the Neosho River located downstream of the confluence with the Cottonwood River (fig. 1*A*; Kansas Water Office, 2009). In order to reduce sediment yields along this reach, engineered stabilization features including grading, adding riprap, rock vanes, and vegetation were constructed and installed at 12 sites (fig. 1*B*) from late summer 2010 through spring 2011 (Kansas Water Office, 2010).

The USGS, in cooperation with the Kansas Water Office and funded in part through the Kansas State Water Plan Fund, continuously monitored water-quality on the Neosho and Cottonwood Rivers before, during, and after construction of stabilization features to assess the efficacy of stream bank stabilization efforts. USGS study sites were located upstream

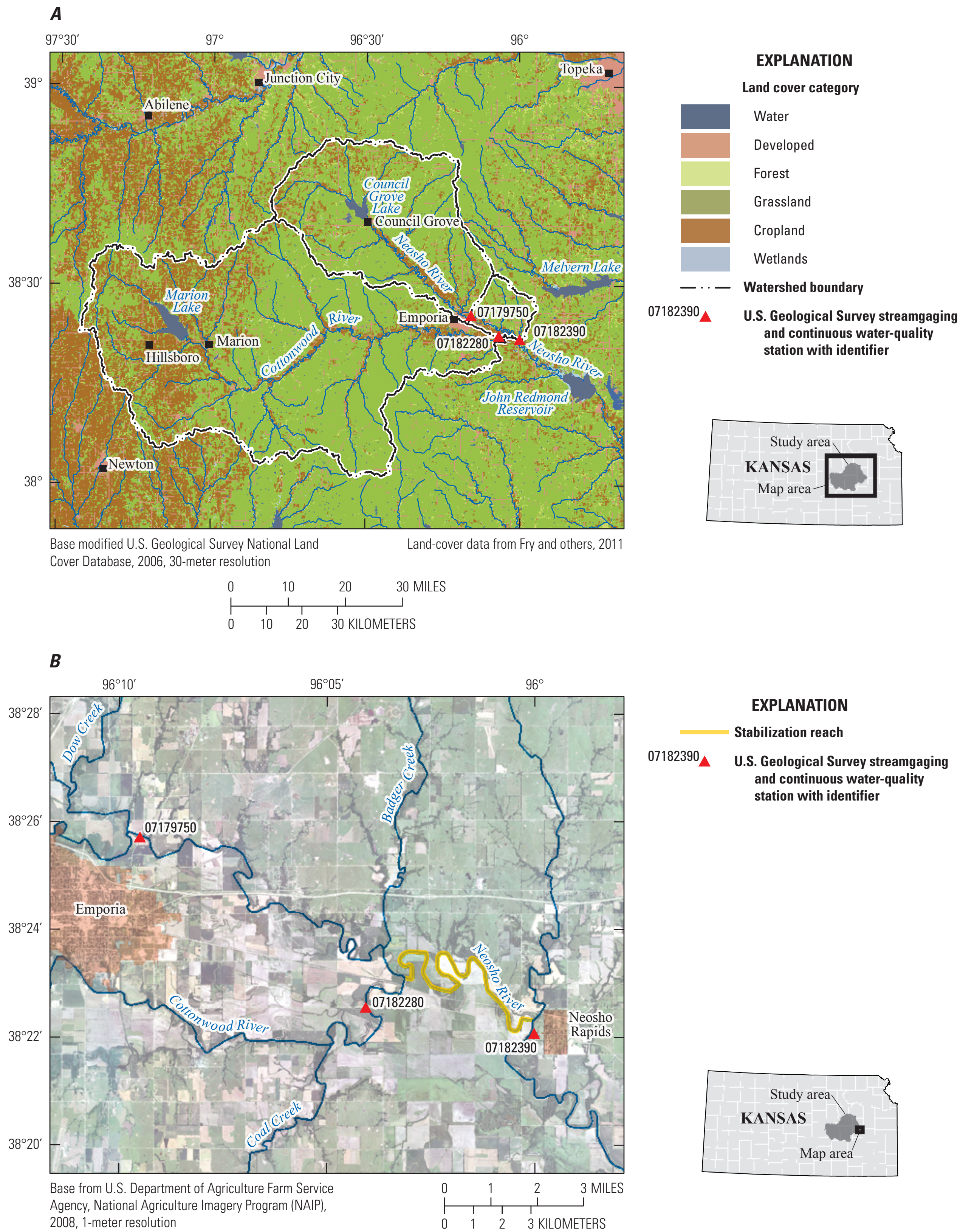


**Figure 1.** Neosho and Cottonwood River watersheds, landuse, and U.S. Geological Survey (USGS) streamgages and water-quality monitoring stations.

from stream stabilization at the Neosho River at Burlingame Road near Emporia, Kansas (USGS station number 07179750; fig. 1*B*; hereafter referred to as Burlingame) and at the Cottonwood River near Neosho Rapids, Kansas (USGS station number 07182280; fig. 1*B*; hereafter referred to as Cottonwood). The downstream site was located at the Neosho River at Neosho Rapids, Kansas (USGS station number 07182390; fig. 1*B*; hereafter referred to as Neosho Rapids).

## Purpose and Scope

The purpose of this report is to document regression models that establish relations between continuously measured turbidity, streamflow, and discretely collected suspended-sediment concentration (SSC) data at the Burlingame, Cottonwood, and Neosho Rapids sites (fig. 1*A* and 1*B*). The regression models were developed using data collected from June 2009 through September 2012. These models are useful for evaluating the variability of SSC concentrations during rapidly changing conditions, computing loads and yields to assess SSC transport through the watershed, and for providing more accurate load estimates compared to streamflow-only based estimation methods used in the past (Rasmussen and others, 2009). Models may be used to calculate concentrations, loads, and yields to assess the efficacy of streambank stabilization efforts. The water-quality information in this report allows SSC to be estimated in real time, and characterized over conditions and time scales that would not otherwise be possible.

## Description of Study Area

The Upper Neosho and Cottonwood River watersheds (fig. 1*A*), located in east-central Kansas, drain about 3,015 $mi^2$ upstream from the John Redmond Reservoir (Lee and others, 2008; fig. 1*A*). The contributing drainage areas at Burlingame, Cottonwood, and Neosho Rapids are 757; 1,912; and 2,753 $mi^2$. The Neosho and Cottonwood Rivers have upstream reservoirs that regulate part of their drainage areas. Council Grove Lake regulates 246 $mi^2$ of the Neosho River headwaters, and Marion Lake regulates 200 $mi^2$ of the Cottonwood River headwaters (fig. 1*A*).

Land use in the Upper Neosho River and Cottonwood River basins is mostly grassland, but there are some areas of cultivated cropland in the upper Cottonwood River watershed and along the Neosho River main stem corridor (fig. 1*A*). Upstream from the Neosho Rapids site (including the Neosho and Cottonwood watersheds), 21 percent of land use is cropland, 69 percent is grassland and pasture, 4 percent is urban, and the remaining is a combination of forest, wetlands, or water (fig. 1*A*; Fry and others, 2011).

# Methods

Turbidity, streamflow, and SSC data were collected at three sites in the Neosho and Cottonwood basins; two sites were located on the Neosho River and one was located on the Cottonwood River. Data collected by the USGS during June 2009 through December 2012 were used to evaluate the relations between continuous real-time turbidity data and discrete SSC samples in the Neosho and Cottonwood Rivers.

## Continuous Water-Quality Monitoring

Streamgages and water-quality monitors were installed in August 2009 and operated through December 2012 at the Burlingame and Cottonwood sites. The Neosho Rapids site was installed in August 2009 and is still in operation (as of 2014). Sites were equipped with YSI (Yellow Springs International Inc., 2010) water-quality monitors that measured specific conductance, water temperature, and turbidity (YSI model 6136). Monitors were housed in 4-inch polyvinyl chloride (PVC) pipes with holes drilled to facilitate flow through the installation and were suspended from bridges approximately 1 to 2 feet (ft) below the water surface. Suitable locations were selected to represent sediment transport upstream and downstream from streambank stabilization sites, and were located far enough upstream from the John Redmond Reservoir (fig. 1*A*) to avoid backwater conditions. During winter months, monitors were moved to nearby deep pools and set to log internally to prevent ice damage. During these winter periods, monitors were serviced, and data were downloaded monthly or as conditions allowed.

Data were collected every 15 minutes at Burlingame and Neosho Rapids, and every 30 minutes at Cottonwood because of data storage limitations imposed by the acoustic velocity and stage sensors installed at the site; these data are available on the USGS website at *http://waterdata.usgs.gov/ks/nwis*. Monitor maintenance and data reporting generally followed procedures described in Wagner and others (2006) with the exception of increased length between calibration checks (approximately 2–3 months) because of minimal calibration drift experienced with these sensors. Monitor cleanings were completed approximately every 6 weeks or as needed. Turbidity records generally were rated good (error of 5–10 percent) and occasionally fair (10–15 percent) on the basis of guidelines developed by Wagner and others (2006).

Stage sensors approved by the USGS were installed to measure water levels using methods described in Sauer and Turnipseed (2010). Streamflow was measured and calculated using methods described in Kennedy (1983), Lavesque and Oberg (2012), Oberg and others (2005), Rantz (1982), and Turnipseed and Sauer (2010). Ratings comparing gage height and streamflow were developed using streamflow measurements and methods described in Kennedy (1984).

## Suspended-Sediment Concentration Samples

SSC samples were collected using methods described in Gray and others (2008), Nolan and others (2005), and Wilde (variously dated), from June 2009 through December 2012. Samples were analyzed for SSC, percentage of sediments less than 63 micrometers (µm; sand-fine break), and loss of material on ignition (analogous to amount of organic matter). Selected samples also were analyzed for grain-size distribution (percent of sediment less than 2, 4, 8, 16, and 31 µm in diameter). Samples were analyzed at the USGS Sediment Laboratory in Iowa City, Iowa, using methods described by Guy (1969). Discrete sample data for SSC, turbidity, and streamflow at the three study sites are contained in appendix tables 1–1, 2–1, and 3–1.

## Quality Assurance and Quality Control

Turbidity values were measured across the width of the stream during the collection of SSC samples. Mean values of cross-sectional turbidity measurements were compared with fixed continuous turbidity sensors to confirm the ability of the continuous turbidity sensor to accurately represent turbidity throughout the stream cross-section (fig. 2). Fixed continuous turbidity sensors represented between 96 and 99 percent of the cross-sectional variability of turbidity (computed by plotting cross-sectional mean as compared with continuous turbidity sensor value at time of sample), and linear relations had slopes between 0.91 and 0.98 (fig. 2). There was more variability between the continuous turbidity sensor and the cross-sectional measurements of turbidity at higher flows, which was likely caused by rapidly changing conditions. Measurements that plotted outside of a 1:1 fit likely were caused by localized differences in turbidity or instrument error. Because consistent bias was not observed, values from continuous water-quality monitors were considered representative of stream water-quality conditions.

No other quality-assurance samples were collected because of the large number of samples collected over the study period, and the lack of variability typically seen in turbidity as compared to SSC regressions in Kansas studies (Foster and others, 2012; Juracek, 2011; Lee and Ziegler, 2010). Numerous samples were collected at similar turbidity values and flows (fig. 2).

## Development of Regression Models to Compute Suspended-Sediment Concentrations

Ordinary-least squares regression equations were developed to compute continuous, 15-minute estimates of SSC from streamflow and in-stream turbidity measurements using methods described in Rasmussen and others (2009). SSC, turbidity, and streamflow relations were evaluated at each site using single linear regressions (SLR) for normal and log-transformed data using the USGS Sediment Spreadsheet (Rasmussen, 2010). Regression models were evaluated based on diagnostic statistics ($R^2$, coefficient of determination; $R^2_a$, adjusted coefficient of determination; $C_p$, Mallow's; *RMSE*, root mean square error; MSPE, model standard percentage error; and *PRESS*, prediction error sum of squares), and the range and distribution of discrete SSC and continuous turbidity data (Helsel and Hirsch, 2002). Regression relations using log-transformed data were transformed back to original units, which results in a low-biased estimate (Helsel and Hirsch, 2002). Therefore, a bias-correction factor (Duan, 1983) was calculated. Uncertainty of regression estimates were determined by calculating 90-percent prediction intervals (Rasmussen and others, 2009).

# Regression Model Results for Suspended-Sediment Concentration

Regression models for SSC using turbidity as the explanatory variable were developed using data collected during June 2009 through December 2012 (fig. 3; table 1). Additional streamflow-based models to estimate SSC using streamflow as the independent variable were developed to allow computation of SSC when turbidity data were unavailable because of fouling or sensor malfunction (fig. 4; table 1). Turbidity-based SSC models explained between 95 and 97 percent of the variance in SSC (fig. 3; table 1). Similarities in slope between turbidity-based regressions at all three sites (fig. 3) indicate similarities in sediment grain-size and color. Streamflow-based regressions explained 53 to 60 percent of the variance; the lower explanatory power compared with turbidity-based models is expected from streamflow-based regression relations with SSC (fig. 4; table 1; Rasmussen and others, 2009). As described in Rasmussen and others (2009) MSPE is the RMSE expressed as a percent and represents model uncertainty associated with regression-computed values. The lower a MSPE value, the lower the uncertainty in regression computed values. MSPE for turbidity-based regression relations ranged from -32 to 48 percent, while MSPE for discharge-based regression relations ranged from -69 to 218 percent. A measure of the quality of a regression relation is the PRESS statistic, which when minimized, indicates the relation with the least amount of error when making new predictions (Helsel and Hirsch, 2002). The PRESS statistic for turbidity-based regressions ranged from 0.30 to 0.83; streamflow-based regression PRESS statistics ranged from 5.14 to 7.41 (table 1).

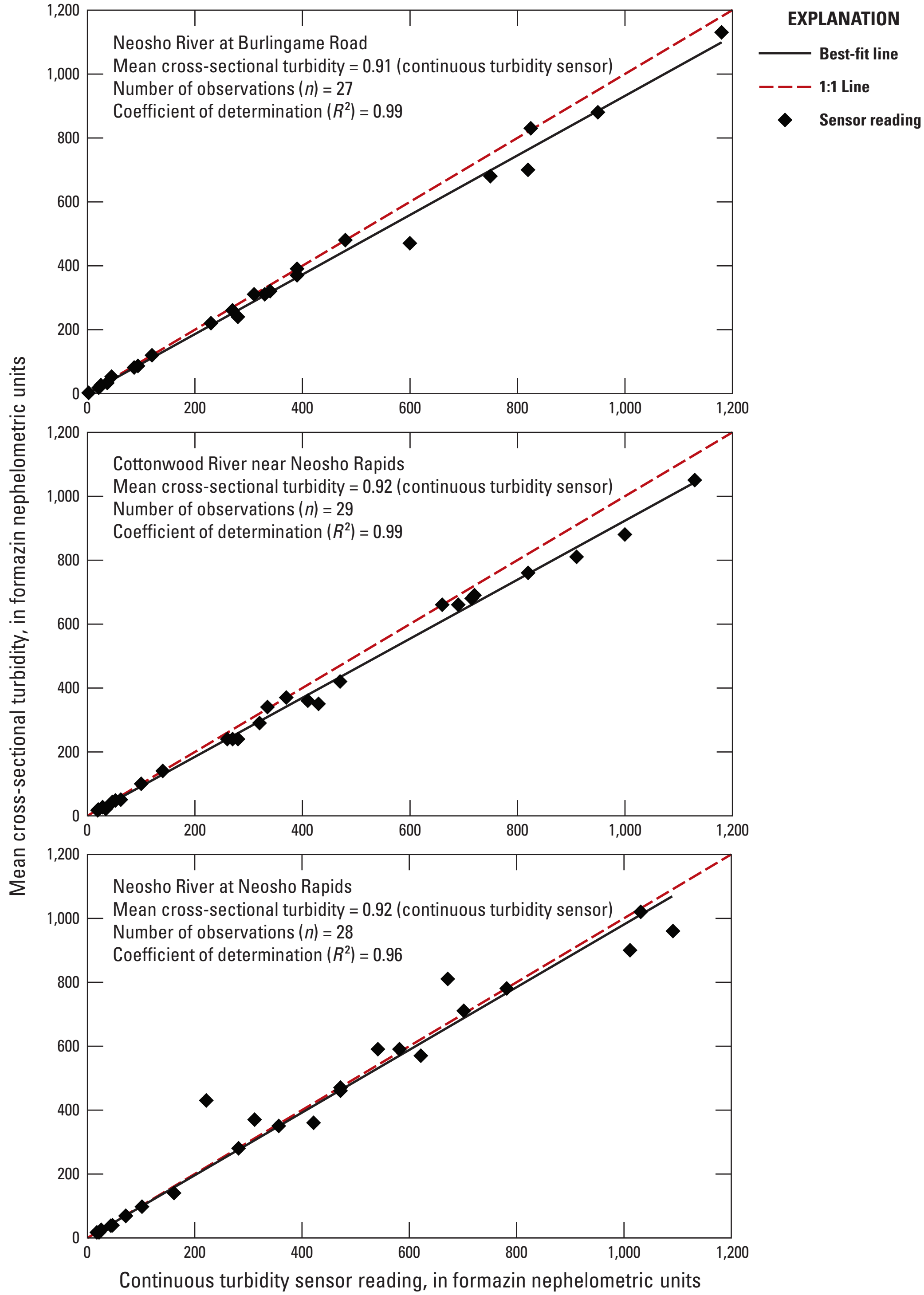


**Figure 2.** Relation between cross-sectional mean and continuous turbidity sensor readings at study sites in the Neosho and Cottonwood River watersheds during August 2009 through September 2012.

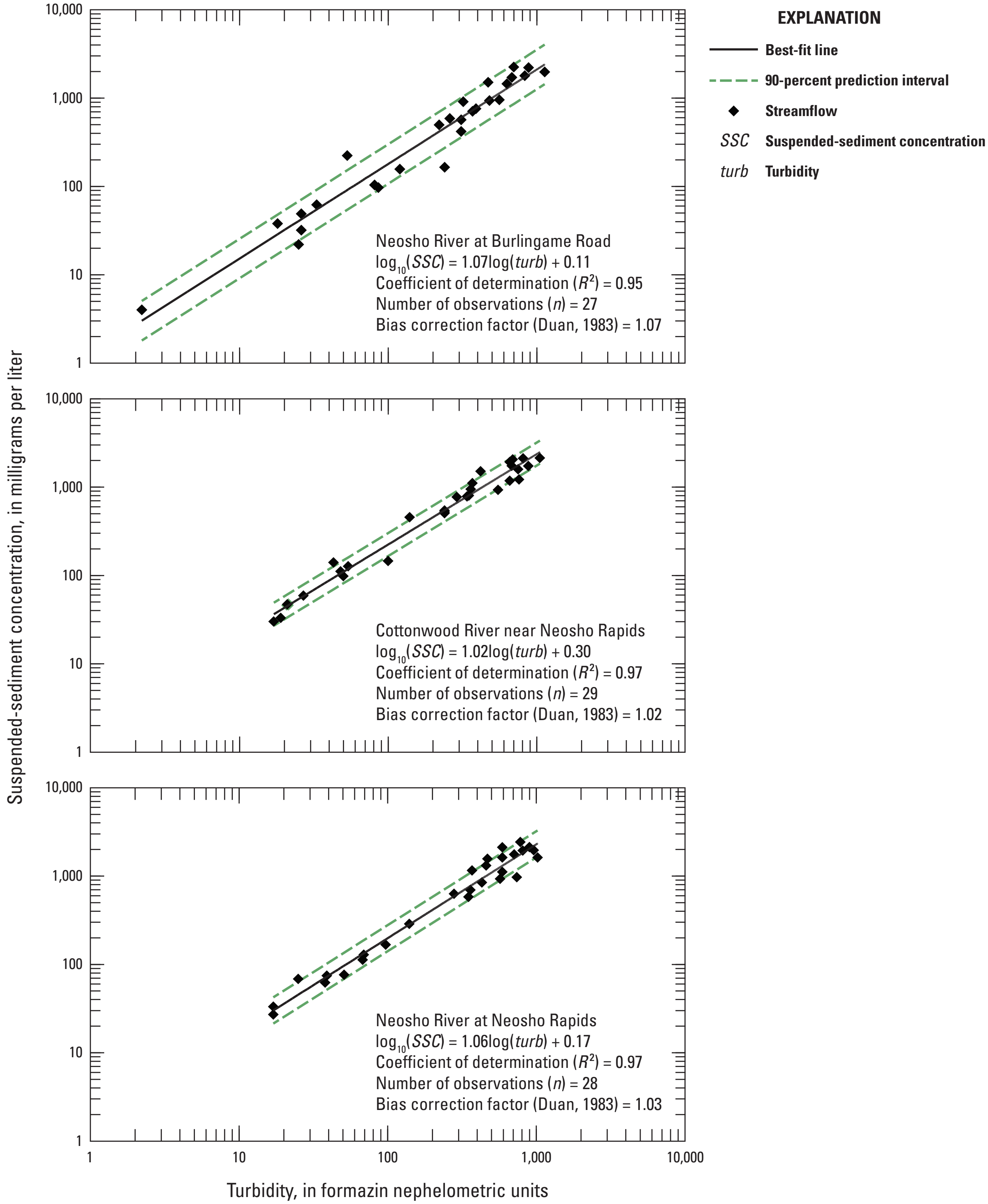


**Figure 3.** Regression relations between turbidity and suspended-sediment concentrations for study sites in the Neosho and Cottonwood River watersheds during June 2009 through September 2012.

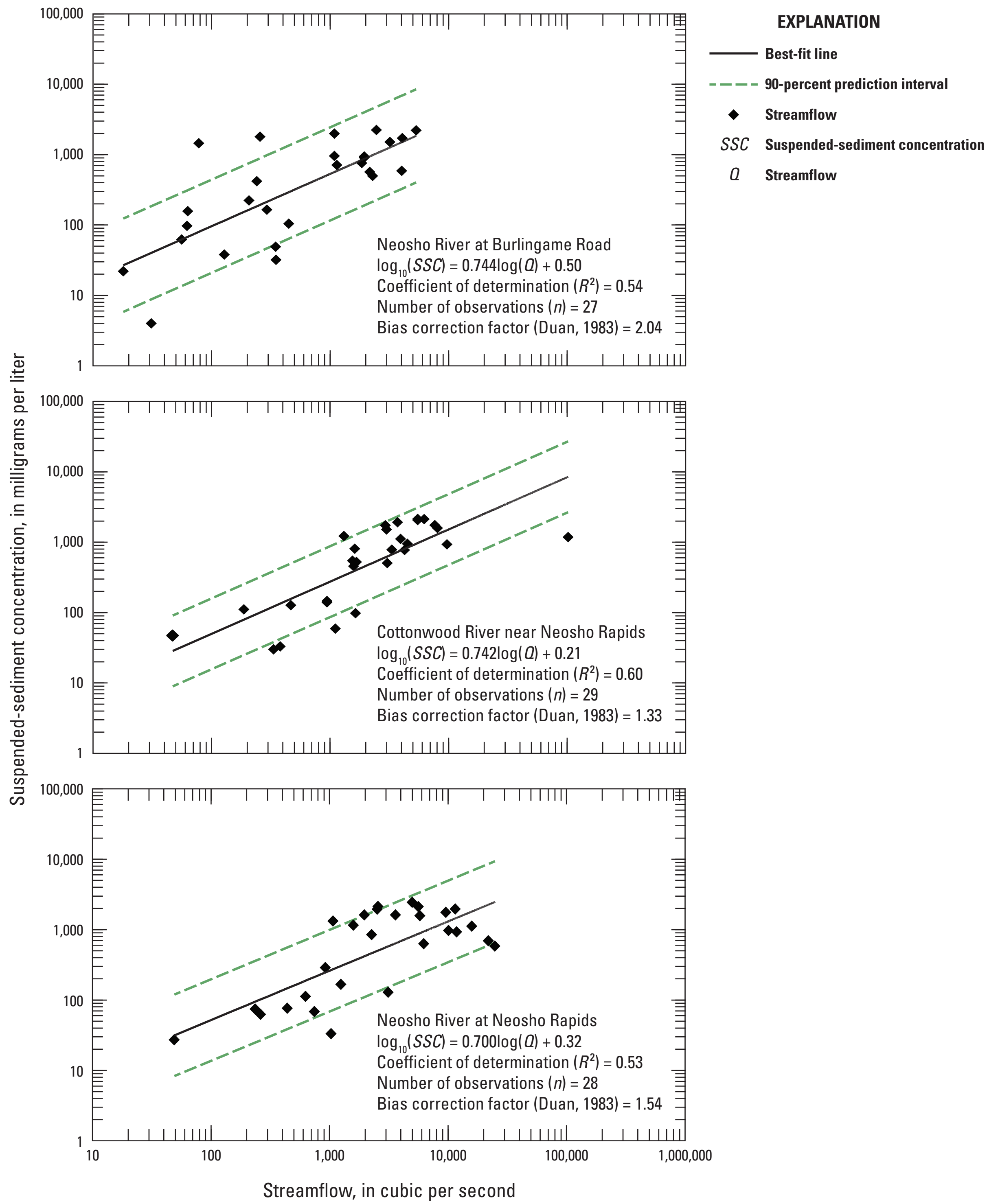


**Figure 4.** Regression relations between streamflow and suspended-sediment concentrations for study sites in the Neosho and Cottonwood River watersheds during June 2009 through September 2012.

**Table 1.** Regression models and summary statistics for suspended-sediment concentration computations at study sites in the Neosho and Cottonwood River watersheds during June 2009 through September 2012.

[$R^2$, square of coefficient of determination; $R^2_a$, adjusted square of coefficient of determination; RMSE, root mean square error; MSPE, model standard percentage error; PRESS, prediction error sum of squares; ±, plus or minus; %, percent; *n*, number of discrete samples; log, $\log_{10}$; *SSC*, suspended-sediment concentration; *turb*, turbidity, in formazin nephelometric units; *Q*, streamflow in cubic feet per second]

| Regression model | $R^2$ | $R^2_a$ Adjusted | Mallow's $C_p$ | RMSE | MSPE (upper) | MSPE (lower) | Bias correction factor (Duan, 1983) | PRESS | 90 percent prediction interval, in ±% | Discrete data: *n* | Discrete data: Range of values in variable measurements | Discrete data: Mean | Discrete data: Median | Discrete data: Standard deviation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Burlingame** | | | | | | | | | | | | | | |
| log(*SSC*) = 1.07log(*turb*) + 0.11 | 0.95 | 0.95 | 6.40 | 0.17 | 47.9 | -32.4 | 1.07 | 0.83 | 75 | 27 | *turb*: 2.2–1,130 | 343 | 310 | 309 |
| | | | | | | | | | | | *SSC*: 4.0–2,240 | 747 | 567 | 738 |
| log(*SSC*) = 0.744log(*Q*) + 0.50 | 0.54 | 0.52 | 234 | 0.50 | 218 | -68.6 | 2.04 | 7.41 | 695 | 27 | *Q*: 18–5,320 | 1,302 | 448 | 1,478 |
| **Cottonwood** | | | | | | | | | | | | | | |
| log(*SSC*) = 1.02log(*turb*) + 0.30 | 0.97 | 0.97 | 1.10 | 0.10 | 25.6 | -20.4 | 1.02 | 0.30 | 40 | 29 | *turb*: 17–1,050 | 374 | 340 | 310 |
| | | | | | | | | | | | *SSC*: 30–2,140 | 875 | 784 | 719 |
| log(*SSC*) = 0.742log(*Q*) + 0.21 | 0.60 | 0.59 | 367 | 0.38 | 142 | -58.6 | 1.33 | 5.14 | 276 | 29 | *Q*: 47–102,000 | 6,454 | 2,935 | 18,552 |
| **Neosho Rapids** | | | | | | | | | | | | | | |
| log(*SSC*) = 1.06log(*turb*) + 0.17 | 0.97 | 0.97 | 1.35 | 0.11 | 29.6 | -22.8 | 1.03 | 0.38 | 46 | 28 | *turb*: 17–1,020 | 412 | 400 | 324 |
| | | | | | | | | | | | *SSC*: 27–2,420 | 939 | 883 | 781 |
| log(*SSC*) = 0.700log(*Q*) + 0.32 | 0.53 | 0.51 | 365 | 0.44 | 176 | -63.8 | 1.54 | 5.69 | 407 | 28 | *Q*: 49–24,900 | 5,452 | 2,550 | 6,578 |

## Summary

The Neosho River and its primary tributary, the Cottonwood River, are the primary sources of inflow to the John Redmond Reservoir. The John Redmond Reservoir has lost more than 40 percent of its conservation pool storage since its construction in 1964 because of a sedimentation rate nearly 80 percent larger than the original rate projected during construction planning. In order to reduce sediment input into the reservoir, the Kansas Water Office implemented stream bank stabilization techniques along an 8.3 mile reach of the Neosho River during August 2010 through March 2011.

The U.S. Geological Survey, in cooperation with the Kansas Water Office and funded in part through the Kansas State Water Plan Fund, collected discrete suspended-sediment concentration samples and operated continuous real-time water-quality monitors with turbidity sensors upstream and downstream from stream bank stabilization efforts before, during, and after construction from June 2009 through December 2012.

Discrete water-quality samples were collected from June 2009 through September 2012 and analyzed for suspended-sediment concentration (SSC), percentage of sediments less than 63 micrometers (µm; sand-fine break), and loss of material on ignition (analogous to amount of organic matter). Regression models were developed to establish relations between discretely sampled SSC samples, and turbidity or streamflow that can be used to estimate continuously SSC.

Continuous turbidity sensors represented between 96 and 99 percent of the variability in cross-sectional turbidity SSC, and had slopes between 0.91 and 0.98 when plotted against cross-sectional means. Because consistent bias was not observed, values from continuous water-quality monitors were considered representative of stream conditions. On average, the turbidity-based SSC models explained 96 percent of the variance in SSC. Similarities between turbidity-based regressions at all three sites indicate similarities in sediment grain-size and color. streamflow-based regressions explained 53 to 60 percent of the variance in SSC. MSPE for turbidity based regression relations ranged from -32 to 48 percent, whereas MSPE for streamflow-based regressions ranged from -69 to 218 percent.

These models can be useful for evaluating variability of SSC during rapidly changing conditions, computing loads and yields to assess SSC transport through the watershed, and for providing more accurate load estimates compared to streamflow-only based methods used in the past. The water-quality information in this report is important to the Kansas Water Office because it allows SSC to be estimated in real time and characterized over conditions and time scales that would not otherwise be possible.

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# Appendixes

# Appendix 1. Complete Review Package for Neosho River at Burlingame Road near Emporia, Kansas

**SITE NUMBER**—07179750

**SITE NAME**—Neosho River at Burlingame Road near Emporia, Kansas

**DATE CREATED**—October 31, 2013

**MODEL-CALIBRATION DATASET**—All data were collected using U.S. Geological Survey (USGS) protocols (Wagner 2006) and are stored in USGS databases. The regression model is based on 27 concurrent measurements of turbidity and streamflow, and suspended-sediment samples collected from June 17, 2009, through September 27, 2012. Samples were collected throughout the range of continuously observed hydrologic and turbidity conditions. Turbidity and streamflow values are time-averaged approved unit values corresponding with the duration of sample collection. Water-quality data were collected using a YSI 6600 monitor with a 6136 turbidity sensor (FNU). No outliers were removed, as analysis of their removal did not result in substantial improvements to the model, and no obvious errors were indicated in the field or lab sheets. Summary statistics and complete model-calibration data are included.

**MODEL DEVELOPMENT**—The use of turbidity or streamflow as explanatory variables has been documented in several USGS publications, and the procedure has been documented by Rasmussen and others (2009). Regression analysis was done using the Sediment Spreadsheet (Rasmussen, 2010), which examined both turbidity and streamflow as possible explanatory variables for estimating suspended-sediment concentration. Different combinations of untransformed and $\log_{10}$-transformed data were evaluated. The model incorporating suspended-sediment concentration and $\log_{10}$-transformed turbidity data were selected as the best model on the basis of comparisons of residual plots, coefficient of determination ($R^2$), Adjusted coefficient of determination ($R^2_a$), Mallow's $C_p$, root mean square error (RMSE), model standard percentage error (MSPE), and prediction error sum of squares (*PRESS*). The best streamflow-based model was selected using the same statistical parameters for use in periods when turbidity data are not available.

**MODEL SUMMARY**—Summary of final regression analysis for suspended-sediment concentration at 07179750 Neosho River at Burlingame Road near Emporia, Kansas.

Primary turbidity-based model:

$$\log_{10}(SSC) = 1.07\log_{10}(turb) + 0.11,\ BCF = 1.07 \qquad (1)$$

where

- $SSC$ = Suspended-sediment concentration, in mg/L;
- $turb$ = turbidity in formazin nephelometric units (FNU); and
- $BCF$ = Bias correction factor (Duan 1983).

Model information—
Number of measurements ($n$) = 27
Root-mean-squared error (RMSE) = 0.17
Mallow's $C_p$ = 6.40
Model standard percentage error (MSPE) = +47.9 and -32.4 percent
90-percent prediction intervals = ± 75 percent
Adjusted coefficient of determination ($R^2_a$) = 0.95
Prediction error sum of squares (*PRESS*) = 0.83

Secondary streamflow-based model:

$$\log_{10}(SSC) = 0.744\log_{10}(Q) + 0.50,\ BCF = 2.04 \qquad (2)$$

where

- $SSC$ = Suspended-sediment concentration, in mg/L;
- $Q$ = streamflow in cubic feet per second; and
- $BCF$ = Bias correction factor (Duan 1983).

Model information.—
Number of measurements ($n$) = 27
Root-mean-squared error (RMSE) = 0.50
Mallow's $C_p$ = 234
Model standard percentage error (MSPE) = +218 and -68.6 percent
90-percent prediction intervals = ± 695 percent
Adjusted coefficient of determination ($R^2_a$) = 0.52
Prediction error sum of squares (*PRESS*) = 7.41

**REMARKS**—Site location, equipment, and other gage information are documented on the USGS website, *http://waterdata.usgs.gov/ks/nwis*.

**Sediment Spreadsheet (Rasmussen, 2010) Outputs**—

**Table 1–1.** Suspended-sediment concentration linear regression dataset for Neosho River at Burlingame Road near Emporia, Kansas (site 07179750), east-central Kansas, June 2009 through September 2012.

[mg/L, milligrams per liter; FNU, formazin nephelometric units; <, less than; µm, micrometers; log, $\log_{10}$; *SSC*, suspended-sediment concentration; *turb*, turbidity, in formazin nephelometric units; *Q*, streamflow in cubic feet per second]

| Sample date | Suspended-sediment concentration (mg/L) | In-place turbidity (FNU) | Streamflow ($ft^3/s$) | Percent < 63 µm | log(*SSC*) | log(*turb*) | Turbidity model regression computed *SSC* | Turbidity model residual log(*SSC*) | Turbidity model normal quantiles | log(*Q*) | Streamflow model regression computed *SSC* | Streamflow model residual log(*SSC*) | Streamflow model normal quantiles |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Sample statistic | | | | | | |
| 6/17/2009 | 956 | 560 | 1,090 | 100 | 2.98 | 2.75 | 1,135 | -0.07 | -0.48 | 3.04 | 567 | 0.23 | 0.70 |
| 7/22/2009 | 1,450 | 630 | 78 | 100 | 3.16 | 2.80 | 1,288 | 0.05 | 0.09 | 1.80 | 79.8 | 1.26 | 2.01 |
| 8/4/2009 | 32 | 26 | 350 | 99 | 1.51 | 1.41 | 42.5 | -0.12 | -0.70 | 3.04 | 244 | -0.88 | -1.57 |
| 8/12/2009 | 38 | 18 | 128 | 89 | 1.58 | 1.26 | 28.7 | 0.12 | 0.96 | 1.89 | 115 | -0.48 | -1.12 |
| 8/27/2009 | 97 | 86 | 62 | 100 | 1.99 | 1.93 | 153 | -0.20 | -1.31 | 2.54 | 67.3 | 0.16 | 0.58 |
| 9/9/2009 | 2,240 | 700 | 2,460 | 91 | 3.35 | 2.85 | 1,442 | 0.19 | 1.31 | 2.11 | 1,039 | 0.33 | 0.82 |
| 10/29/2009 | 223 | 53 | 207 | 94 | 2.35 | 1.72 | 458 | -0.44 | -2.01 | 1.79 | 165 | 0.13 | 0.48 |
| 10/30/2009 | 497 | 220 | 2,290 | 98 | 2.70 | 2.34 | 418 | 0.08 | 0.48 | 3.39 | 985 | -0.30 | -0.70 |
| 11/19/2009 | 104 | 81 | 448 | 99 | 2.02 | 1.91 | 143.3 | -0.14 | -0.82 | 2.32 | 293 | -0.45 | -0.96 |
| 3/9/2010 | 1,510 | 470 | 3,200 | 97 | 3.18 | 2.67 | 941 | 0.21 | 1.57 | 3.36 | 1,263 | 0.08 | 0.19 |
| 3/11/2010 | 1,710 | 680 | 4,070 | 97 | 3.23 | 2.83 | 1,398 | 0.09 | 0.70 | 2.65 | 1,510 | 0.05 | 0.09 |
| 4/7/2010 | 708 | 370 | 1,140 | 96 | 2.85 | 2.57 | 729 | -0.01 | -0.28 | 3.51 | 586 | 0.08 | 0.38 |
| 5/13/2010 | 1,790 | 830 | 257 | 99 | 3.25 | 2.92 | 1,730 | 0.01 | 0.00 | 3.33 | 194 | 0.97 | 1.57 |
| 5/20/2010 | 587 | 260 | 4,020 | 98 | 2.77 | 2.41 | 499 | 0.07 | 0.38 | 3.61 | 1,497 | -0.41 | -0.82 |
| 6/16/2010 | 907 | 320 | 1,940 | 94 | 2.96 | 2.51 | 624 | 0.16 | 1.12 | 3.06 | 871 | 0.02 | -0.09 |
| 7/6/2010 | 2,210 | 880 | 5,320 | 98 | 3.34 | 2.94 | 1,842 | 0.08 | 0.58 | 2.41 | 1,843 | 0.08 | 0.28 |
| 9/16/2010 | 165 | 240 | 293 | 98 | 2.22 | 2.38 | 91.0 | 0.39 | 2.01 | 3.60 | 214 | -0.11 | -0.48 |
| 12/7/2010 | 4 | 2 | 31 | 97 | 0.60 | 0.34 | 3.02 | 0.12 | 0.82 | 3.29 | 40.2 | -1.00 | -2.01 |
| 3/28/2011 | 49 | 26 | 348 | 99 | 1.69 | 1.41 | 42.5 | 0.06 | 0.28 | 3.27 | 243 | -0.69 | -1.31 |
| 4/11/2011 | 418 | 310 | 241 | 100 | 2.62 | 2.49 | 603 | -0.16 | -1.12 | 3.29 | 185 | 0.35 | 0.96 |
| 6/9/2011 | 62 | 33 | 56 | 99 | 1.79 | 1.52 | 54.8 | 0.05 | 0.19 | 3.73 | 62.4 | -0.00 | -0.19 |
| 10/24/2011 | 22 | 25 | 18 | 98 | 1.34 | 1.40 | 40.7 | -0.27 | -1.57 | 2.47 | 26.8 | -0.09 | -0.38 |
| 12/20/2011 | 938 | 480 | 1,940 | 97 | 2.97 | 2.68 | 963 | -0.01 | -0.19 | 1.49 | 871 | 0.03 | 0.00 |
| 3/1/2012 | 1,980 | 1,130 | 1,090 | 99 | 3.30 | 3.05 | 2,407 | -0.08 | -0.58 | 2.54 | 567 | 0.54 | 1.31 |
| 3/22/2012 | 760 | 390 | 1,850 | 98 | 2.88 | 2.59 | 771 | -0.01 | -0.09 | 2.38 | 840 | -0.04 | -0.28 |
| 3/23/2012 | 567 | 310 | 2,160 | 97 | 2.75 | 2.49 | 603 | -0.03 | -0.38 | 1.75 | 943 | -0.22 | -0.58 |
| 9/27/2012 | 157 | 120 | 63 | 100 | 2.20 | 2.08 | 218 | -0.14 | -0.96 | 1.26 | 68.1 | 0.36 | 1.12 |
| | | | | | | | Summary statistics | | | | | | |
| Minimum | 4 | 2 | 18 | 89 | 0.60 | 0.34 | 3.0 | -0.44 | -2.01 | 1.26 | 27 | -1.00 | -2.01 |
| 1st quartile | 101 | 67 | 168 | 97 | 2.00 | 1.82 | 117 | -0.10 | -0.64 | 2.21 | 140 | -0.26 | -0.64 |
| Median | 567 | 310 | 448 | 98 | 2.75 | 2.49 | 603 | 0.01 | 0.00 | 2.65 | 293 | 0.03 | 0.00 |
| Mean | 747 | 343 | 1,302 | 97 | 2.50 | 2.23 | 691 | -0.00 | 0.00 | 2.70 | 570 | -0.00 | 0.00 |
| 3d quartile | 1,203 | 520 | 2,050 | 99 | 3.07 | 2.71 | 1,049 | 0.08 | 0.64 | 3.31 | 907 | 0.19 | 0.64 |
| Maximum | 2,240 | 1,130 | 5,320 | 100 | 3.35 | 3.05 | 2,407 | 0.39 | 2.01 | 3.73 | 1,843 | 1.26 | 2.01 |
| Standard deviation | 738 | 309 | 1,478 | 2.7 | 0.73 | 0.66 | 652 | 0.17 | 0.98 | 0.72 | 529 | 0.49 | 0.98 |

**Covariance matrix**

| | Intercept | log(*turb*) |
|---|---|---|
| Intercept | 1 | -0.96 |
| log(*turb*) | -0.96 | 1 |
| | Intercept | log(*Q*) |
| Intercept | 1 | -0.967 |
| log(*Q*) | -0.967 | 1 |

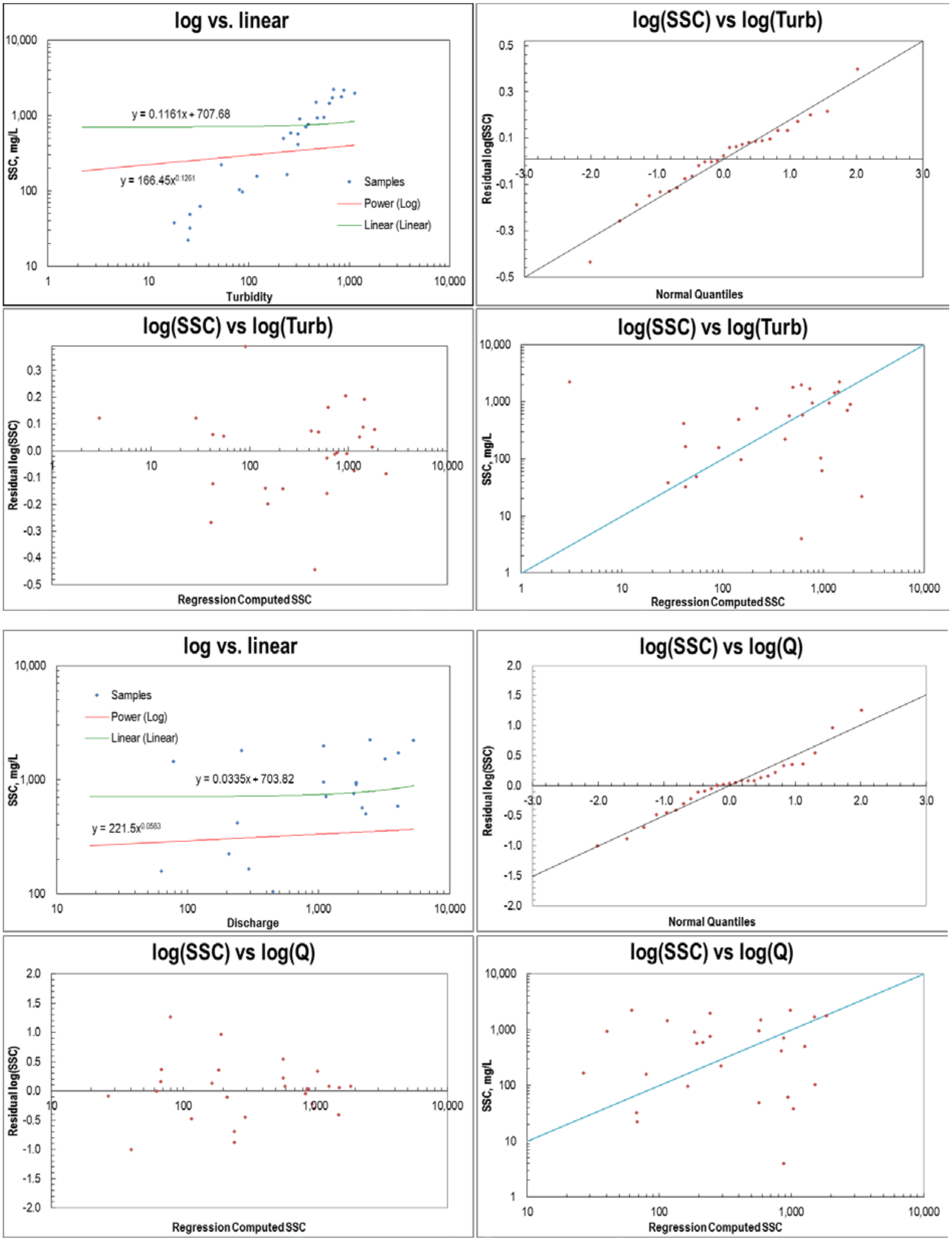


**Figure 1–1.** Sediment Spreadsheet (Rasmussen, 2010) output plots for Neosho River at Burlingame Road near Emporia, Kansas (site 07179750), east-central Kansas. [SSC, suspended-sediment concentration; Turb, turbidity, in formazin nephelometric units; Q, streamflow, in cubic feet per second]

# Appendix 2. Complete Review Package for Cottonwood River near Neosho Rapids, Kansas

**SITE NUMBER**—07182280

**SITE NAME**—Cottonwood River near Neosho Rapids, Kansas

**DATE CREATED**—October 31, 2013

**MODEL-CALIBRATION DATA SET**—All data were collected using U.S. Geological Survey (USGS) protocols (Wagner 2006) and are stored in USGS databases. The regression model is based on 29 concurrent measurements of turbidity and streamflow, and suspended-sediment samples collected from June 17, 2009, through March 23, 2012. Samples were collected throughout the range of continuously observed hydrologic and turbidity conditions. Turbidity and streamflow values are time-averaged approved unit values corresponding with the duration of sample collection. Water-quality data were collected using a YSI 6600 monitor with a 6136 turbidity sensor (FNU). No outliers were removed, as analysis of their removal did not result in substantial improvements to the model, and no obvious errors were indicated in the field or lab sheets. Summary statistics and complete model-calibration data are included.

**MODEL DEVELOPMENT**—The use of turbidity or streamflow as explanatory variables has been documented in several USGS publications and the procedure has been documented by Rasmussen and others (2009). Regression analysis was done using the Sediment Spreadsheet (Rasmussen, 2010), which examined both turbidity and streamflow as possible explanatory variables for estimating suspended-sediment concentration. Different combinations of untransformed and $\log_{10}$-transformed data were evaluated. The model incorporating suspended-sediment concentration and $\log_{10}$-transformed turbidity data were selected as the best model on the basis of comparisons of residual plots, coefficient of determination ($R^2$), Adjusted coefficient of determination ($R^2_a$), Mallow's $C_p$, root mean square error (RMSE), model standard percentage error (MSPE), and prediction error sum of squares (*PRESS*). The best flow-based model was selected using the same statistical parameters for use in periods when turbidity data are not available.

**MODEL SUMMARY**—Summary of final regression analysis for suspended-sediment concentration at 07182280 Cottonwood River near Neosho Rapids, Kansas.

Primary turbidity-based model:

$$\text{Log}_{10}(SSC) = 1.02\log_{10}(turb) + 0.30,\ BCF = 1.02 \quad (3)$$

where

$SSC$ = Suspended-sediment concentration, in mg/L;
$turb$ = turbidity in formazin nephelometric units (FNU); and
$BCF$ = Bias correction factor (Duan 1983).

Model information.—
Number of measurements ($n$) = 29
Root-mean-squared error (RMSE) = 0.10
Mallow's $C_p$ = 1.10
Model standard percentage error (MSPE) = +25.6 and -20.4 percent
90-percent prediction intervals = ± 40 percent
Adjusted coefficient of determination ($R^2_a$) = 0.97
Prediction error sum of squares (*PRESS*) = 0.30

Secondary flow-based model:

$$\text{Log}_{10}(SSC) = 0.742\log_{10}(Q) + 0.21,\ BCF = 1.33 \quad (4)$$

where

$SSC$ = Suspended-sediment concentration, in mg/L;
$Q$ = streamflow in cubic feet per second; and
$BCF$ = Bias correction factor (Duan 1983).

Model information.—
Number of measurements ($n$) = 29
Root-mean-squared error (RMSE) = 0.38
Mallow's $C_p$ = 367
Model standard percentage error (MSPE) = +142 and -58.6 percent
90-percent prediction intervals = ± 276 percent
Adjusted coefficient of determination ($R^2_a$) = 0.59
Prediction error sum of squares (*PRESS*) = 5.14

**REMARKS**— Site location, equipment, and other gage information are documented on the USGS website, *http://waterdata.usgs.gov/ks/nwis*.

**Sediment Spreadsheet (Rasmussen, 2010) Outputs**—

**Table 2–1.** Suspended-sediment concentration linear regression dataset for Cottonwood River near Neosho Rapids, Kansas (site 07182280), east-central Kansas, June 2009 through March 2012.

[mg/L, milligrams per liter; FNU, formazin nephelometric units; ft³/s, cubic feet per second; <, less than; µm, micrometers; log, $\log_{10}$; *SSC*, suspended-sediment concentration; *turb*, turbidity, in formazin nephelometric units; *Q*, streamflow in cubic feet per second]

| Sample date | Suspended-sediment concentration (mg/L) | In-place turbidity (FNU) | Streamflow (ft³/s) | Percent < 63 µm | log(*SSC*) | log(*turb*) | Turbidity model regression computed *SSC* | Turbidity model residual log(*SSC*) | Turbidity model normal quantiles | log(*Q*) | Streamflow model regression computed *SSC* | Streamflow model residual log(*SSC*) | Streamflow model normal quantiles |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample statistics | | | | | | | | | | | | | |
| 6/17/2009 | 931 | 550 | 9,720 | 95 | 2.97 | 2.74 | 1,286 | -0.14 | -1.35 | 3.99 | 1,485 | -0.20 | -0.64 |
| 7/22/2009 | 1,590 | 750 | 8,060 | 96 | 3.20 | 2.88 | 1,767 | -0.05 | -0.44 | 3.91 | 1,292 | 0.09 | 0.00 |
| 8/12/2009 | 127 | 54 | 468 | 94 | 2.10 | 1.73 | 119 | 0.03 | 0.35 | 2.67 | 157 | -0.09 | -0.44 |
| 8/27/2009 | 804 | 350 | 1,620 | 99 | 2.91 | 2.54 | 809 | -0.00 | -0.09 | 3.21 | 393 | 0.31 | 0.75 |
| 9/9/2009 | 948 | 360 | 4,500 | 98 | 2.98 | 2.56 | 833 | 0.06 | 0.64 | 3.65 | 839 | 0.05 | -0.26 |
| 10/9/2009 | 146 | 100 | 942 | 99 | 2.16 | 2.00 | 224 | -0.19 | -2.04 | 2.97 | 263 | -0.26 | -0.75 |
| 10/20/2009 | 33 | 19 | 380 | 97 | 1.52 | 1.28 | 40.9 | -0.09 | -1.01 | 2.58 | 134 | -0.61 | -1.35 |
| 10/29/2009 | 140 | 43 | 942 | 98 | 2.15 | 1.63 | 94.4 | 0.17 | 1.60 | 2.97 | 263 | -0.27 | -0.87 |
| 10/30/2009 | 505 | 240 | 3,040 | 98 | 2.70 | 2.38 | 550 | -0.04 | -0.35 | 3.48 | 627 | -0.09 | -0.54 |
| 11/19/2009 | 98 | 50 | 1,640 | 99 | 1.99 | 1.70 | 110 | -0.05 | -0.54 | 3.22 | 397 | -0.61 | -1.01 |
| 3/11/2010 | 773 | 290 | 4,260 | 97 | 2.89 | 2.46 | 667 | 0.06 | 0.75 | 3.63 | 805 | -0.02 | -0.35 |
| 4/8/2010 | 1,110 | 370 | 3,940 | 97 | 3.05 | 2.57 | 857 | 0.11 | 1.16 | 3.60 | 760 | 0.16 | 0.44 |
| 5/20/2010 | 784 | 340 | 3,320 | 98 | 2.89 | 2.53 | 785 | -0.00 | 0.00 | 3.52 | 669 | 0.07 | -0.17 |
| 6/10/2010 | 1,180 | 660 | 102,000 | 93 | 3.07 | 2.82 | 1,550 | -0.12 | -1.16 | 5.01 | 8,489 | -0.86 | -2.04 |
| 7/6/2010 | 2,120 | 810 | 6,240 | 97 | 3.33 | 2.91 | 1,912 | 0.04 | 0.54 | 3.80 | 1,069 | 0.30 | 0.64 |
| 7/15/2010 | 1,510 | 420 | 3,000 | 97 | 3.18 | 2.62 | 975 | 0.19 | 2.04 | 3.48 | 621 | 0.39 | 1.16 |
| 9/16/2010 | 543 | 240 | 1,550 | 99 | 2.74 | 2.38 | 550 | -0.01 | -0.17 | 3.19 | 381 | 0.15 | 0.35 |
| 9/17/2010 | 1,920 | 660 | 3,720 | 97 | 3.28 | 2.82 | 1,550 | 0.09 | 0.87 | 3.57 | 728 | 0.42 | 1.35 |
| 12/7/2010 | 59 | 27 | 1,110 | 97 | 1.77 | 1.43 | 58.6 | 0.00 | 0.09 | 3.05 | 297 | -0.70 | -1.60 |
| 3/28/2011 | 30 | 17 | 334 | 96 | 1.48 | 1.23 | 36.5 | -0.08 | -0.87 | 2.52 | 122 | -0.61 | -1.16 |
| 4/11/2011 | 1,220 | 760 | 1,310 | 99 | 3.09 | 2.88 | 1,791 | -0.17 | -1.60 | 3.12 | 336 | 0.56 | 2.04 |
| 6/9/2011 | 111 | 48 | 188 | 97 | 2.05 | 1.68 | 106 | 0.02 | 0.26 | 2.27 | 79.6 | 0.14 | 0.17 |
| 10/24/2011 | 47 | 21 | 47 | 97 | 1.67 | 1.32 | 45.3 | 0.02 | 0.17 | 1.67 | 28.5 | 0.22 | 0.54 |
| 12/20/2011 | 522 | 240 | 1,670 | 98 | 2.72 | 2.38 | 550 | -0.02 | -0.26 | 3.22 | 402 | 0.11 | 0.09 |
| 12/22/2011 | 2,140 | 1,050 | 5,490 | 98 | 3.33 | 3.02 | 2,495 | -0.07 | -0.64 | 3.74 | 972 | 0.34 | 1.01 |
| 3/1/2012 | 456 | 140 | 1,580 | 97 | 2.66 | 2.15 | 316 | 0.16 | 1.35 | 3.20 | 386 | 0.07 | -0.09 |
| 3/2/2012 | 1,730 | 880 | 2,935 | 98 | 3.24 | 2.94 | 2,082 | -0.08 | -0.75 | 3.47 | 611 | 0.45 | 1.60 |
| 3/22/2012 | 2,060 | 690 | 5,500 | 97 | 3.31 | 2.84 | 1,622 | 0.10 | 1.01 | 3.74 | 973 | 0.33 | 0.87 |
| 3/23/2012 | 1,740 | 680 | 7,670 | 96 | 3.24 | 2.83 | 1,598 | 0.04 | 0.44 | 3.89 | 1,246 | 0.15 | 0.26 |
| Summary statistics | | | | | | | | | | | | | |
| Minimum | 30 | 17 | 47 | 93 | 1.48 | 1.23 | 36 | -0.19 | -2.04 | 1.67 | 28.47 | -0.86 | -2.04 |
| 1st quartile | 140 | 54 | 1,110 | 97 | 2.15 | 1.73 | 119 | -0.07 | -0.64 | 3.05 | 297 | -0.20 | -0.64 |
| Median | 784 | 340 | 2,935 | 97 | 2.89 | 2.53 | 785 | -0.00 | 0.00 | 3.47 | 611 | 0.09 | 0.00 |
| Mean | 875 | 374 | 6,454 | 97 | 2.68 | 2.32 | 875 | -0.00 | 0.00 | 3.32 | 856 | -0.00 | 0.00 |
| 3d quartile | 1,510 | 660 | 4,500 | 98 | 3.18 | 2.82 | 1,550 | 0.06 | 0.64 | 3.65 | 839 | 0.30 | 0.64 |
| Maximum | 2,140 | 1,050 | 102,000 | 99 | 3.33 | 3.02 | 2,495 | 0.19 | 2.04 | 5.01 | 8,489 | 0.56 | 2.04 |
| Standard deviation | 719 | 310 | 18552 | 1.4 | 0.60 | 0.57 | 736 | 0.10 | 0.98 | 0.62 | 1,518 | 0.38 | 0.98 |

**Covariance matrix**

| | Intercept | log(*turb*) |
|---|---|---|
| Intercept | 1 | -0.972 |
| log(*turb*) | -0.972 | 1 |
| | Intercept | log(*Q*) |
| Intercept | 1 | -0.983 |
| log(*Q*) | -0.983 | 1 |

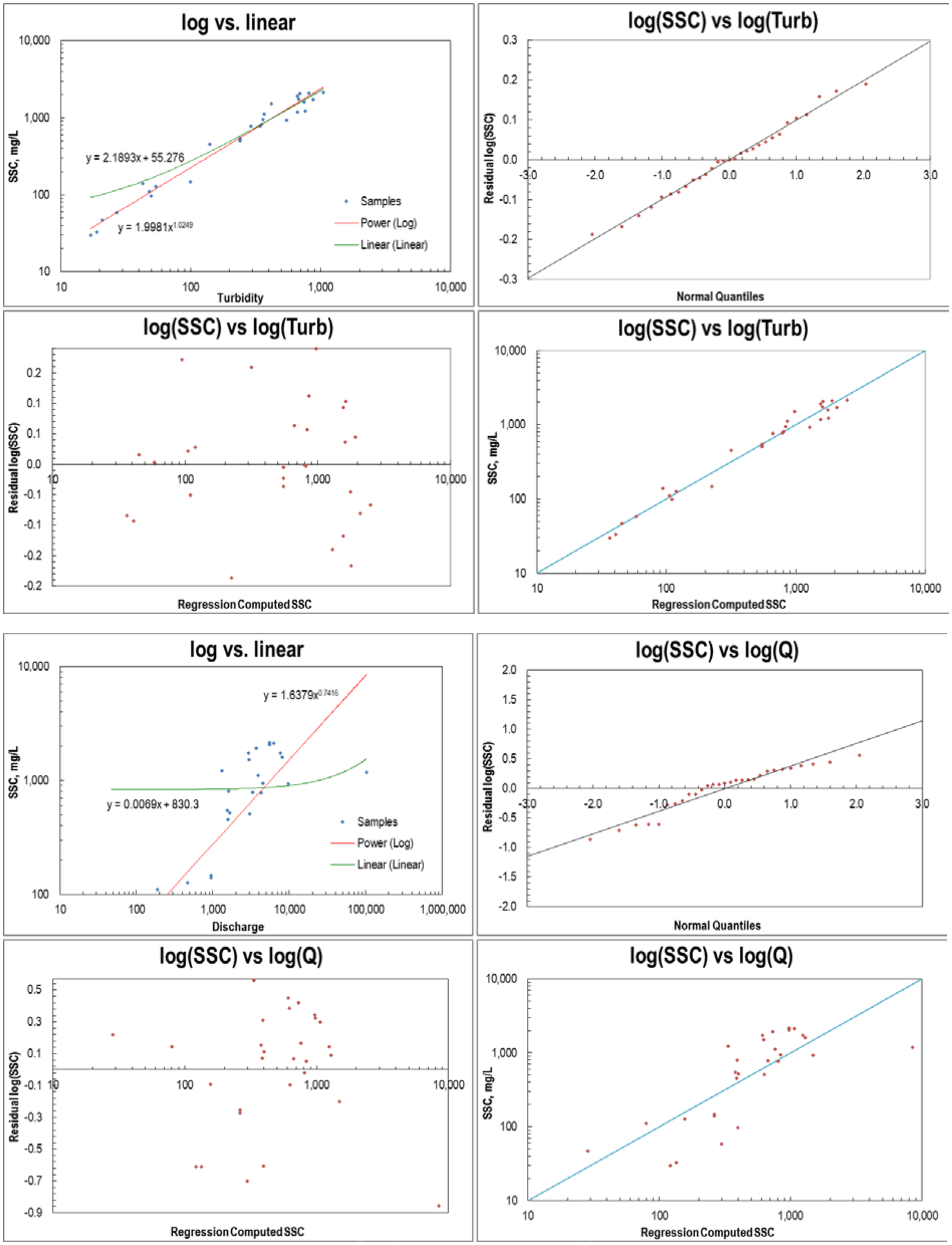


**Figure 2–1.** Sediment Spreadsheet (Rasmussen, 2010) output plots for Cottonwood River near Neosho Rapids, Kansas (site 07182280), east-central Kansas. [SSC, suspended-sediment concentration; Turb, turbidity, in formazin nephelometric units; Q, streamflow, in cubic feet per second]

# Appendix 3. Complete Review Package for Neosho River at Neosho Rapids, Kansas

**SITE NUMBER**—07182390

**SITE NAME**—Neosho River at Neosho Rapids, Kansas

**DATE CREATED**—October 31, 2013

**MODEL-CALIBRATION DATA SET**—All data were collected using U.S. Geological Survey (USGS) protocols (Wagner 2006) and are stored in USGS databases. The regression model is based on 28 concurrent measurements of turbidity and streamflow and suspended-sediment samples collected from June 17, 2009, through September 27, 2012. Samples were collected throughout the range of continuously observed hydrologic and turbidity conditions. Turbidity and streamflow values are time-averaged approved unit values corresponding with the duration of sample collection. Water-quality data were collected using a YSI 6600 monitor with a 6136 turbidity sensor (FNU). No outliers were removed, as analysis of their removal did not result in substantial improvements to the model, and no obvious errors were indicated in the field or lab sheets. Summary statistics and complete model-calibration data set are included.

**MODEL DEVELOPMENT**—The use of turbidity or streamflow as explanatory variables has been documented in several USGS publications and the procedure has been documented by Rasmussen and others (2009). Regression analysis was done using the Sediment Spreadsheet (Rasmussen, 2010), which examined both turbidity and streamflow together as explanatory variables for estimating suspended-sediment concentration. Different combinations of untransformed and $\log_{10}$-transformed data were evaluated. The model incorporating suspended-sediment concentration and $\log_{10}$-transformed turbidity data were selected as the best model on the basis of comparisons of residual plots, coefficient of determination ($R^2$), Adjusted coefficient of determination ($R^2_a$), Mallow's $C_p$, root mean square error (RMSE), model standard percentage error (MSPE), and prediction error sum of squares (*PRESS*). For periods when turbidity data are not available, the best flow-based model was selected using the same statistical parameters.

**MODEL SUMMARY**—Summary of final regression analysis for suspended-sediment concentration at 07182390 Neosho River at Neosho Rapids, Kansas.

Primary turbidity-based model:

$$\log_{10}(SSC) = 1.06\log_{10}(turb) + 0.17,\ BCF = 1.03 \quad (5)$$

where

| | |
|---|---|
| $SSC$ = | Suspended-sediment concentration, in mg/L; |
| $turb$ = | turbidity in formazin nephelometric units (FNU); and |
| $BCF$ = | Bias correction factor (Duan 1983). |

Model information.—
Number of measurements ($n$) = 28
Root-mean-squared error (RMSE) = 0.11
Mallow's $C_p$ = 1.35
Model standard percentage error (MSPE) = +29.6 and -22.8 percent
90-percent prediction intervals = ± 46 percent
Adjusted coefficient of determination ($R^2_a$) = 0.97
Prediction error sum of squares (*PRESS*) = 0.38

Secondary flow-based model:

$$\log_{10}(SSC) = 0.700\log_{10}(Q) + 0.32,\ BCF = 1.54 \quad (6)$$

where

| | |
|---|---|
| $SSC$ = | Suspended-sediment concentration, in mg/L; |
| $Q$ = | streamflow in cubic feet per second; and |
| $BCF$ = | Bias correction factor (Duan 1983). |

Model information—
Number of measurements ($n$) = 28
Root-mean-squared error (RMSE) = 0.44
Mallow's $C_p$ = 365
Model standard percentage error (MSPE) = +176 and -63.8 percent
90 percent prediction intervals = ± 407 percent
Adjusted coefficient of determination ($R^2_a$) = 0.51
Prediction error sum of squares (*PRESS*) = 5.69

**REMARKS**—Site location, equipment, and other gage information are documented on the USGS website, *http://waterdata.usgs.gov/ks/nwis*.

**Sediment Spreadsheet (Rasmussen, 2010) Outputs**—

**Table 3–1.** Suspended-sediment concentration linear regression dataset for Neosho River at Neosho Rapids, Kansas (site 07182390), east-central Kansas, June 2009 through September 2012.

[mg/L, milligrams per liter; FNU, formazin nephelometric units; ft³/s, cubic feet per second; <, less than; µm, micrometers; log, $\log_{10}$; *SSC*, suspended-sediment concentration; *turb*, turbidity, in formazin nephelometric units; *Q*, streamflow in cubic feet per second]

| Sample date | Suspended-sediment concentration (mg/L) | In-place turbidity (FNU) | Streamflow (ft³/s) | Percent < 63 µm | log(*SSC*) | log(*turb*) | Turbidity model regression computed *SSC* | Turbidity model residual log(*SSC*) | Turbidity model normal quantiles | log(*Q*) | Streamflow model regression computed *SSC* | Streamflow model residual log(*SSC*) | Streamflow model normal quantiles |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Sample statistics | | | | | | |
| 6/17/2009 | 1,110 | 590 | 15,900 | 97 | 3.05 | 2.77 | 1,307 | -0.07 | -0.85 | 4.20 | 1,807 | -0.21 | -0.41 |
| 7/22/2009 | 965 | 740 | 10,100 | 98 | 2.99 | 2.87 | 1,663 | -0.24 | -2.03 | 4.00 | 1,315 | -0.13 | -0.13 |
| 8/4/2009 | 76 | 51 | 441 | 99 | 1.88 | 1.71 | 96.9 | -0.11 | -0.98 | 2.64 | 147 | -0.29 | -0.85 |
| 8/12/2009 | 112 | 68 | 628 | 99 | 2.05 | 1.83 | 132 | -0.07 | -0.73 | 2.80 | 188 | -0.22 | -0.61 |
| 8/27/2009 | 2,120 | 900 | 2,570 | 99 | 3.33 | 2.95 | 2,048 | 0.01 | 0.22 | 3.41 | 504 | 0.62 | 1.58 |
| 9/9/2009 | 1,560 | 470 | 5,800 | 87 | 3.19 | 2.67 | 1,027 | 0.18 | 1.58 | 3.76 | 892 | 0.24 | 0.41 |
| 10/9/2009 | 166 | 97 | 1,250 | 97 | 2.22 | 1.99 | 192 | -0.06 | -0.61 | 3.10 | 304 | -0.26 | -0.73 |
| 10/29/2009 | 1,150 | 370 | 1,590 | 89 | 3.06 | 2.57 | 796 | 0.16 | 1.14 | 3.20 | 360 | 0.50 | 0.98 |
| 10/30/2009 | 627 | 280 | 6,250 | 98 | 2.80 | 2.45 | 592 | 0.02 | 0.41 | 3.80 | 940 | -0.18 | -0.22 |
| 11/19/2009 | 128 | 69 | 3,130 | 99 | 2.11 | 1.84 | 134 | -0.02 | -0.04 | 3.50 | 579 | -0.66 | -1.58 |
| 3/9/2010 | 2,420 | 780 | 4,980 | 98 | 3.38 | 2.89 | 1,759 | 0.14 | 0.98 | 3.70 | 801 | 0.48 | 0.85 |
| 5/13/2010 | 1,310 | 460 | 1,070 | 97 | 3.12 | 2.66 | 1,003 | 0.12 | 0.85 | 3.03 | 273 | 0.68 | 2.03 |
| 6/10/2010 | 1,950 | 960 | 11,500 | 97 | 3.29 | 2.98 | 2,194 | -0.05 | -0.41 | 4.06 | 1,440 | 0.13 | 0.22 |
| 6/15/2010 | 691 | 360 | 21,900 | 98 | 2.84 | 2.56 | 773 | -0.05 | -0.32 | 4.34 | 2,261 | -0.51 | -1.14 |
| 6/16/2010 | 579 | 350 | 24,900 | 99 | 2.76 | 2.54 | 751 | -0.11 | -1.14 | 4.40 | 2,473 | -0.63 | -1.33 |
| 7/15/2010 | 924 | 570 | 11,800 | 99 | 2.97 | 2.76 | 1,260 | -0.13 | -1.33 | 4.07 | 1,466 | -0.20 | -0.32 |
| 9/16/2010 | 286 | 140 | 922 | 98 | 2.46 | 2.15 | 283 | 0.00 | 0.04 | 2.97 | 246 | 0.07 | 0.13 |
| 9/17/2010 | 1,610 | 590 | 3,610 | 97 | 3.21 | 2.77 | 1307 | 0.09 | 0.73 | 3.56 | 640 | 0.40 | 0.73 |
| 12/6/2010 | 33 | 17 | 1,030 | 94 | 1.52 | 1.23 | 30.1 | 0.04 | 0.51 | 3.01 | 266 | -0.91 | -2.03 |
| 3/28/2011 | 68 | 25 | 745 | 99 | 1.83 | 1.40 | 45.4 | 0.18 | 1.33 | 2.87 | 212 | -0.49 | -0.98 |
| 4/11/2011 | 1,610 | 1,020 | 1,970 | 100 | 3.21 | 3.01 | 2,340 | -0.16 | -1.58 | 3.29 | 419 | 0.59 | 1.14 |
| 6/9/2011 | 62 | 38 | 262 | 99 | 1.79 | 1.58 | 70.8 | -0.06 | -0.51 | 2.42 | 102 | -0.22 | -0.51 |
| 10/24/2011 | 27 | 17 | 49 | 96 | 1.43 | 1.23 | 30.1 | -0.05 | -0.22 | 1.69 | 31.5 | -0.07 | 0.04 |
| 12/20/2011 | 842 | 430 | 2,270 | 99 | 2.93 | 2.63 | 934 | -0.05 | -0.13 | 3.36 | 462 | 0.26 | 0.51 |
| 3/1/2012 | 1,930 | 810 | 2,530 | 98 | 3.29 | 2.91 | 1,831 | 0.02 | 0.32 | 3.40 | 499 | 0.59 | 1.33 |
| 3/22/2012 | 2,110 | 590 | 5,620 | 86 | 3.32 | 2.77 | 1,307 | 0.21 | 2.03 | 3.75 | 872 | 0.38 | 0.61 |
| 3/23/2012 | 1,750 | 710 | 9,590 | 97 | 3.24 | 2.85 | 1,592 | 0.04 | 0.61 | 3.98 | 1,268 | 0.14 | 0.32 |
| 9/27/2012 | 74 | 39 | 236 | 98 | 1.87 | 1.59 | 72.8 | 0.01 | 0.13 | 2.37 | 94.7 | -0.11 | -0.04 |
| | | | | | | | Summary statistics | | | | | | |
| Minimum | 27 | 17 | 49 | 86 | 1.43 | 1.23 | 30 | -0.24 | -2.03 | 1.69 | 32 | -0.91 | -2.03 |
| 1st quartile | 124 | 68.8 | 1,003 | 97 | 2.09 | 1.84 | 133 | -0.06 | -0.64 | 3.00 | 261 | -0.23 | -0.64 |
| Median | 883 | 400 | 2,550 | 98 | 2.95 | 2.60 | 865 | -0.01 | 0.00 | 3.41 | 501 | -0.09 | 0.00 |
| Mean | 939 | 412 | 5,452 | 97 | 2.68 | 2.36 | 913 | -0.00 | 0.00 | 3.38 | 745 | -0.00 | -0.00 |
| 3d quartile | 1,610 | 620 | 7,085 | 99 | 3.21 | 2.79 | 1,378 | 0.05 | 0.64 | 3.84 | 1,022 | 0.39 | 0.64 |
| Maximum | 2,420 | 1,020 | 24,900 | 100 | 3.38 | 3.01 | 2,340 | 0.21 | 2.03 | 4.40 | 2,473 | 0.68 | 2.03 |
| Standard deviation | 781 | 324 | 6,578 | 3.6 | 0.63 | 0.58 | 742 | 0.11 | 0.98 | 0.65 | 660 | 0.43 | 0.98 |

**Covariance matrix**

| | Intercept | log(*turb*) |
|---|---|---|
| Intercept | 1 | -0.972 |
| log(*turb*) | -0.972 | 1 |
| | Intercept | log(*Q*) |
| Intercept | 1 | -0.983 |
| log(*Q*) | -0.983 | 1 |

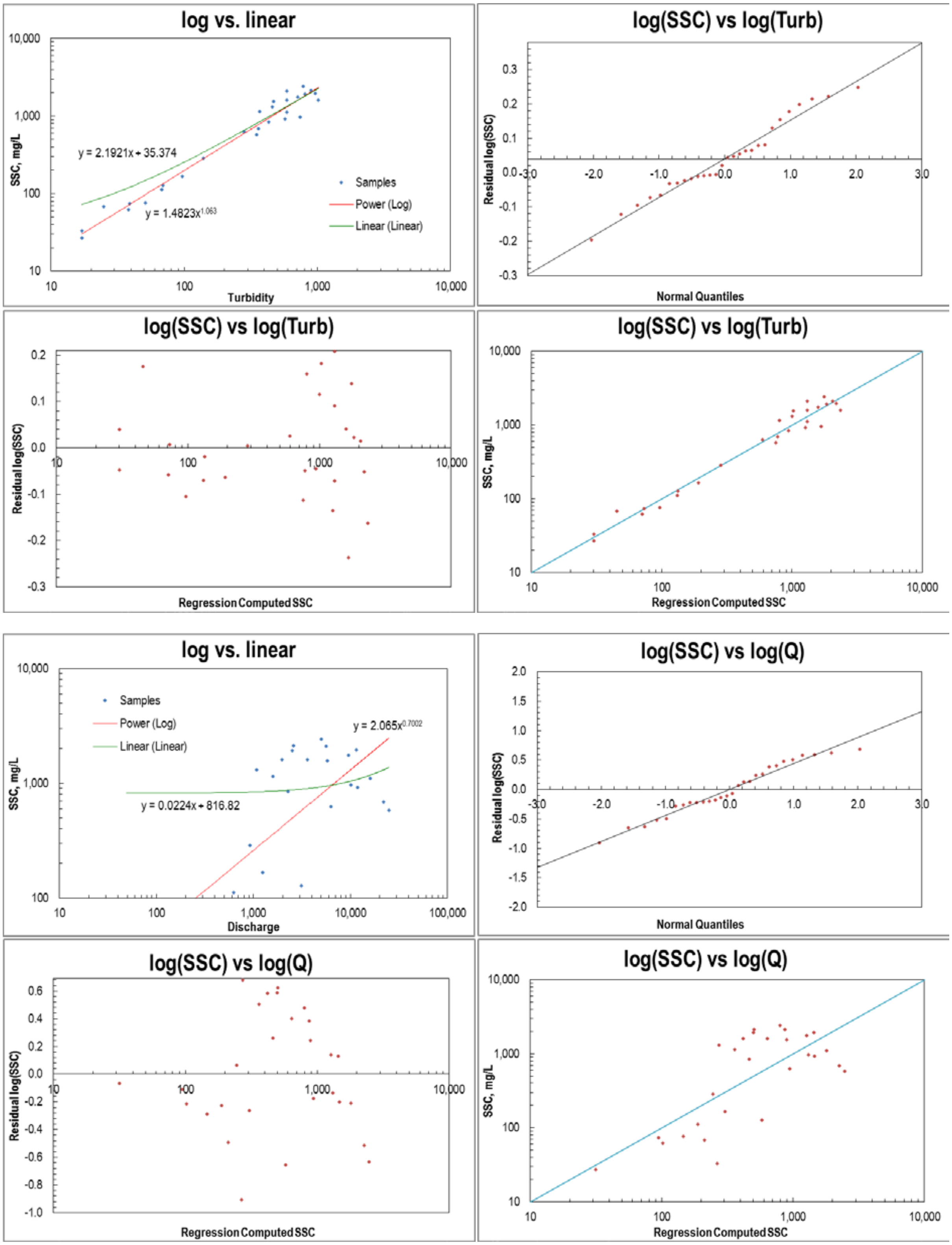


**Figure 3–1.** Sediment Spreadsheet (Rasmussen, 2010) output plots for Neosho River at Neosho Rapids, Kansas (site 07182390), east-central Kansas. [SSC, suspended-sediment concentration; Turb, turbidity, in formazin nephelometric units; Q, streamflow, in cubic feet per second]

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