Application of Dimensionless Sediment Rating Curves to Predict Suspended-Sediment Concentrations and Bedload for Rivers in Minnesota

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Abstract

The U.S. Geological Survey, in cooperation with the Minnesota Pollution Control Agency and the Minnesota Department of Natural Resources, completed a study to evaluate the use of dimensionless sediment rating curves (DSRCs) to predict suspended-sediment concentrations (SSCs) and bedload for selected rivers and streams in Minnesota based on data collected during 2007 through 2013. This study included the application of DSRC models developed for a small group of streams located in the San Juan River Basin near Pagosa Springs in southwestern Colorado to rivers in Minnesota. Regionally based DSRC models for Minnesota also were developed and compared to DSRC models from Pagosa Springs, Colorado, to evaluate which model provided more accurate predictions of SSCs and bedload in Minnesota.

More than 600 dimensionless ratio values of SSC, bedload, and streamflow were evaluated and delineated according to Pfankuch stream stability categories of “good/fair” and “poor” to develop four Minnesota-based DSRC models. The basis for Pagosa Springs and Minnesota DSRC model effectiveness was founded on measures of goodness-of-fit that included proximity of the model(s) fitted line to the 95-percent confidence intervals of the site-specific model and Nash-Sutcliffe Efficiency values.

Composite plots comparing Pagosa Springs DSRCs, Minnesota DSRCs, site-specific regression models, and measured data indicated that regionally developed DSRCs (Minnesota DSRC models) more closely approximated measured data for nearly every site. Pagosa Springs DSRC models had markedly larger exponents (slopes) when compared to the Minnesota DSRC models and over-represented SSC and bedload at streamflows exceeding bankfull. The Nash-Sutcliffe Efficiency values for the Minnesota DSRC model for suspended-sediment concentrations closely matched Nash-Sutcliffe Efficiency values of the site-specific regression models for 12 of 16 sites. Pagosa Springs DSRC models were less accurate than the mean of the measured data at predicting SSC values for one-half of the good/fair stability sites and one-half of the poor stability sites.

Results of data analyses indicate that DSRC models developed using data collected in Minnesota were more effective at compensating for differences in individual stream characteristics across a variety of basin sizes and flow regimes than DSRC models developed using data collected for Pagosa Springs, Colorado. Minnesota DSRC models retained a substantial portion of the unique sediment signatures for most rivers, although deviations were observed for streams with limited sediment supply and for rivers in southeastern Minnesota, which had markedly larger regression exponents. The results from this study indicated that regionally based DSRCs can be used to estimate reasonably accurate values of SSC and bedload.

Introduction

Beginning in 2007, the U.S. Geological Survey (USGS), in collaboration with the Minnesota Pollution Control Agency (MPCA), identified a group of existing gage stations across Minnesota and began collecting water samples for analyses of suspended-sediment concentrations (SSCs), turbidity, and total suspended-solids (TSS) to improve understanding of fluvial sediment relations and transport processes. In 2012, the USGS, in cooperation with the U.S. Army Corps of Engineers (USACE), the Minnesota Department of Natural Resources (MNDNR), and the Lower Minnesota River Watershed District (LMRWD), expanded sediment sampling from 8 to 22 sites. In addition to collecting SSC samples, the USGS began collecting bedload samples in 2012 to quantify the contribution of bedload to total sediment loads. During this time, hundreds of streamflow measurements and SSC, turbidity, TSS, and bedload samples were collected to develop statistical relations among these constituents (U.S. Geological Survey National Water Information System, http://dx.doi.org/10.5066/F7P55KJN; Ellison and others, 2014).

Mandates to reduce costs, eliminate data gaps, and improve data accuracy have guided Federal and State interests in pursuing alternative methods of measuring and estimating SSCs and bedload. Physically collected samples for analysis of SSCs and bedload remain the most accurate and reliable means for determining sediment loads; however, the specialized equipment, training, and labor required to collect samples are time consuming, expensive, and potentially hazardous in certain conditions.

One alternative to collecting physical sediment samples is the use of dimensionless sediment rating curves (DSRCs) to reduce costs and improve the accuracy of predicting sediment transport (Troendle and others, 2001; Barry and others, 2008; Rosgen, 2006, 2010). Dimensionless rating curves have demonstrated potential to predict constituents of interest by scaling existing data at several regionally representative sites and applying the curves at sites where data are sparse or nonexistent (Leopold and others, 1964; Padmanabhan and Johnson, 2010; Dietrich and others, 1989; Troendle and others, 2001). Anticipated benefits of developing a curve model for SSCs and bedload include (1) improved sediment budgets, (2) reduced costs associated with extensive sediment data collection, (3) ability to identify streams that depart from reference conditions, (4) access to a tool for restoration prioritization, and (5) access to important information for planning river restoration activities.

In 2011, the USGS proposed to the MPCA and MNDNR that DSRCs be evaluated for application in Minnesota Rivers. Subsequently, the USGS, in cooperation with the MPCA and the MNDNR, completed a study to evaluate the use of DSRCs to predict SSCs, bedload, and annual sediment loads for selected rivers and streams in Minnesota based on data collected during 2007 through 2013. This study included the application of DSRCs developed by Rosgen (2010) from data collected from a small group of streams located in the San Juan River Basin near Pagosa Springs in southwestern Colorado to rivers in Minnesota. Regionally based DSRC models also were developed and compared to DSRCs from Pagosa Springs, Colorado, to assess how well Minnesota systems are described by the Pagosa Springs models and to evaluate the improvements gained through the development of a regional model.

Background Information on Dimensionless Sediment Rating Curves

The DSRC method relies on the intrinsic relations among streamflow, SSC, and bedload. Rosgen (2006, 2007, and 2010) continued work by Barry and others (2004) and Troendle and others

(2001) by expanding the application of dimensionless relations to improve predictions of suspended sediment and bedload in rivers. Rosgen's objectives for developing DSRC models were to provide a tool for river restoration planning and design, reduce the error from theoretical sediment prediction models, and help identify rivers that depart from known reference conditions. The Rosgen method (Rosgen, 2010) involves developing dimensionless relations between SSC and streamflow and between bedload and streamflow, and uses bankfull streamflow as a normalization parameter to develop the DSRC models.

Results from Rosgen (2010) indicated that DSRCs developed from a small group of streams located in the San Juan River Basin near Pagosa Springs in southwestern Colorado could be used to estimate sediment transport for geographically far-removed streams with different flow regimes, geology, and climate. Rosgen (2010) developed four reference DSRC model equations delineated by Pfankuch (1975) stream stability categories using data collected from the streams in Colorado. The four DSRC equations developed by Rosgen (2010) for good/fair and poor stability ratings for the Pagosa Springs DSRC models follow:

$$\text{Suspended DSRC (good/fair stability): } SSC = 0.0636 + 0.9326Q^{2.4085} \quad (1)$$

$$\text{Bedload DSRC (good/fair stability): } Qb = -0.0113 + 1.0139Q^{2.1929} \quad (2)$$

$$\text{Suspended DSRC (poor stability): } SSC = 0.0989 + 0.9213Q^{3.659} \quad (3)$$

$$\text{Bedload DSRC (poor stability): } Qb = 0.07176 + 1.02176Q^{2.3772} \quad (4)$$

where

SSC is a dimensionless ratio value of suspended-sediment concentration,
Q is a dimensionless ratio value of streamflow, and
Qb is a dimensionless ratio value of bedload.

Description of Study Area

Minnesota encompasses 86,939 square miles (mi^2) in the upper midwestern United States (Minnesota Department of Natural Resources, 2016a). Minnesota is in a transition zone between the moist eastern United States and the Great Plains (not shown) and has a continental climate with cold winters and warm to hot summers (Minnesota Department of Natural Resources, 2016b). Mean annual precipitation across the State ranges from 35 inches in the southeast to 20 inches in the northwest (Minnesota Department of Natural Resources, 2016b). The six hydrologic unit code (HUC) HUC–level 4 basins (Rainy River, Red River, Western Lake Superior, Mississippi Headwaters, Minnesota, and Upper Mississippi – Black-Root [Minnesota Department of Natural Resources, 2016c; Minnesota Geospatial Information Office, 2016]) selected for this study represent a cross section of basin characteristics present in Minnesota (fig. 1).

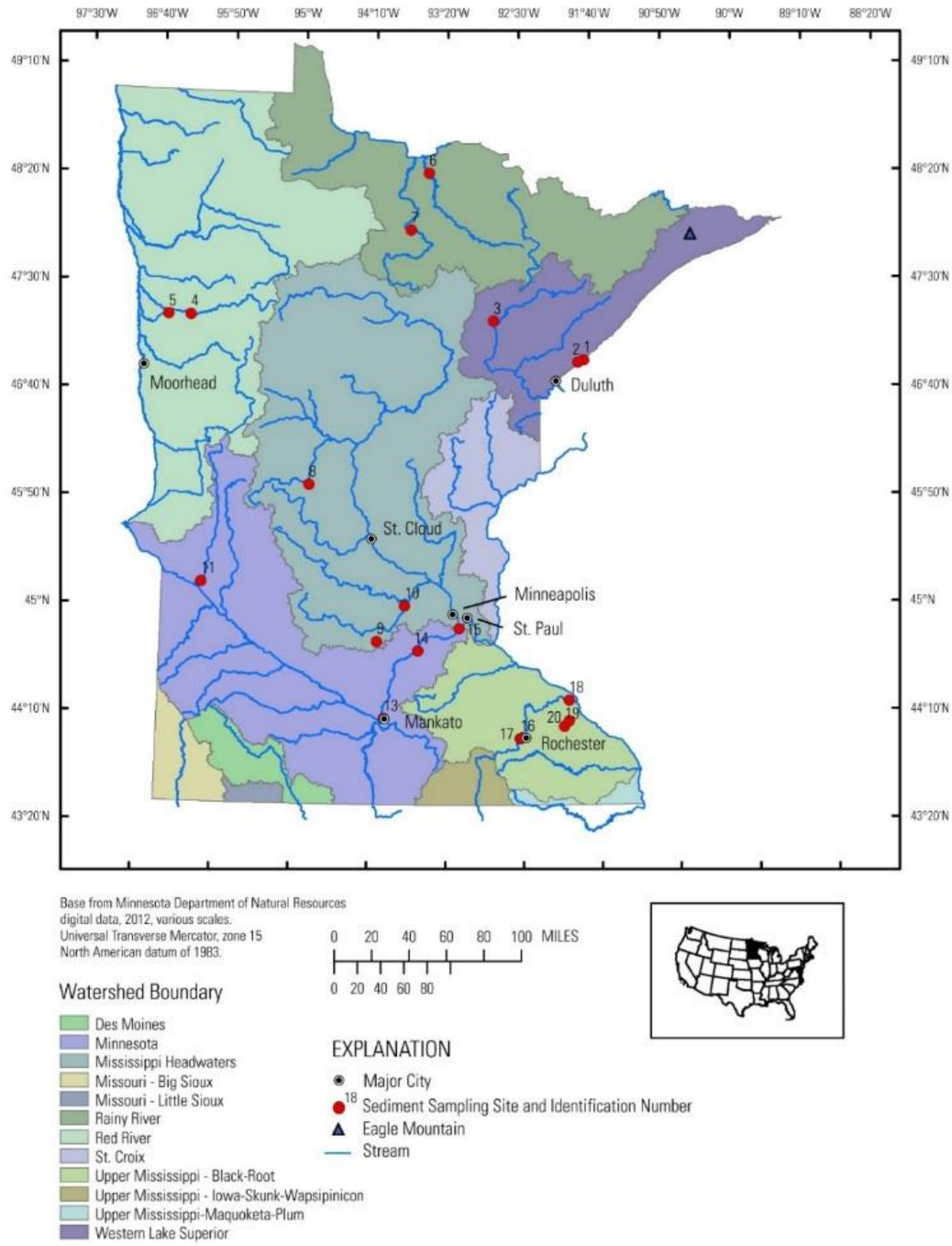

Figure 1. Study area and monitoring sites

Methods of Data Collection and Analysis

Information on sediment sampling sites (that is, site number, USGS station number, station name, position, elevation, drainage area, sampling period, type of streamflow record, and number of samples collected) is available in Ellison and others (2016).

Suspended-Sediment Concentrations

Depth-integrated suspended-sediment samples were collected at equal-width intervals across stream transects using isokinetic samplers according to procedures by Edwards and Glysson (1999). Following collection, samples were transported to the USGS sediment laboratory in Iowa City, Iowa, where they were composited into a single sample and analyzed for SSC and particle-size fraction according to Guy (1969).

Bedload

Two types of USGS-approved pressure-differential bag samplers, the Helley-Smith and the BL-84 sampler (Davis, 2005), were used to collect bedload samples. The single equal-width-increment method of collecting bedload samples according to Edwards and Glysson (1999) was used at all sites and bedload samples were collected concurrently with suspended-sediment samples. Bedload samples were analyzed for nine particle-size distributions (ranging from 0.0625 to 16 mm) using the dry-sieve method (Guy, 1969) at the University of Minnesota Civil Engineering Department by USGS Minnesota Water Science Center (WSC) staff.

Bankfull Streamflow Determination

Bankfull elevations were determined using methods outlined by Leopold and others (1964) and Rosgen (1994, 1996). A combination of field elevation surveys and bankfull field indicators, such as change in slope, changes in vegetation, stain lines, top of point bars, changes in bank material, or bank undercuts along streambanks were used to establish the point on the bank for bankfull stage at each site. For sites with continuous-record streamgages, bankfull elevations were referenced to the wire-weight gage height.

Determining Suspended-Sediment Concentration and Bedload at Bankfull Streamflow

Samples used to determine SSC and bedload at bankfull streamflow were limited to samples collected within the range of one-half to 2 times bankfull streamflow. Samples within this range of streamflow were collected during snowmelt runoff or summer precipitation events and included bankfull stage for at least one sampling event at each site. Based on availability, equal numbers of samples on the ascending and descending limb of the hydrograph were used to minimize disproportionate effects of individual samples from the effects of hysteresis. Once the samples were selected, SSC and bedload were paired with their corresponding instantaneous streamflows, and the mean values of SSC, bedload, and streamflow were calculated. Ratio estimators for SSC and bedload at bankfull streamflow were calculated for each site by dividing each mean SSC and bedload value by the corresponding mean instantaneous streamflow. Site-specific SSC and bedload values at bankfull streamflow were determined by multiplying the ratio estimator and the bankfull streamflow at that site.

Data Analysis

Suspended-sediment concentrations, bedload, and instantaneous and daily mean streamflows were formatted for analysis using S-plus statistical software (TIBCO® Software Inc., 2010) and the R statistical environment (R Development Core Team, 2011). Summary statistics, Kendall's tau analysis, Nash-Sutcliffe Efficiencies (NSE), weighted nonlinear regression analyses, and simple linear regression analyses composed the analyses. The Pagosa Springs and Minnesota DSRC models were evaluated using measures of goodness-of-fit that included the proximity of the model(s) fitted line to the 95-percent confidence intervals of the site-specific model and NSE values.

Kendall's tau analyses (Kendall, 1938, 1975) were used to test for significance and measure the strength of the relations between SSC and streamflow and between bedload and streamflow at each site; p-values less than 0.05 indicated statistically significant monotonic relations. Data from sites without significant relations among variables (*p*-values of 0.05 or greater) were not used to develop models.

Data collected from rivers in Minnesota were used to develop DSRCs similar to methods described in Rosgen (2010). Minnesota DSRC model prediction efficiency was optimized using a weighted parameter method. More than 600 dimensionless ratio values were calculated using available SSCs, bedload, and streamflow data. Dimensionless ratio values were evaluated and delineated according to Pfankuch stream stability categories of good/fair and poor (Pfankuch, 1975), and selected dimensionless ratio values were used to develop four Minnesota-based DSRC models. Data from sites identified through the Kendall's tau correlation analyses with no relation (that is, *p*-values of 0.05 or greater) between SSC and streamflow or between bedload and streamflow were not used in the development of Minnesota DSRC models.

A weighted nonlinear least squares regression approach (nls function) was used for the analyses in the R statistical environment (R Development Core Team, 2011; Chaterjee and others, 2000).

As part of model development, a framework was incorporated so that the values of the model coefficients ($B1$) and numerical constant ($1 - B1$) ensured that the fitted trendline of the model would pass through the point of interception of the calculated values of SSC and bedload at bankfull with bankfull streamflow. The form of DSRC models for Minnesota was

$$Y_i = (1 - B_1) + B_1 X_i^{B_2} + \varepsilon_i \qquad (5)$$

where

- Yi is a dimensionless ratio value of SSC or bedload,
- $(1 - B1)$ is the intercept determined from the data,
- $B1$ is a coefficient determined from the data,
- Xi is a dimensionless ratio value of streamflow,
- $B2$ is the slope determined from the data, and
- εi is the random error representing the discrepancy in the approximation accounting for the failure of the model to fit the data exactly.

Site-specific simple linear regression (SLR) models were developed for each site for SSC and bedload for use in evaluating the goodness-of-fit of Minnesota and Pagosa Springs DSRC models. The site-specific SLR models were used to construct reference trendlines from which to evaluate the goodness-of-fit of the Minnesota and Pagosa Springs DSRC models.

Nash-Sutcliffe Efficiency values (Nash and Sutcliffe, 1970) were used to evaluate the effectiveness of Pagosa Springs and Minnesota DSRC models to approximate measured SSCs and bedload values. The NSE value is calculated using the measured values of the sampled data, modeled values, and the mean of the measured values. Nash-Sutcliffe Efficiency values can range from negative infinity to 1. An NSE value of 1 indicates that the model matches the observed values exactly, an NSE value of 0 indicates that the model is predicting values that are no better than the mean of the measured values, and negative values of NSE indicates that the mean of the measured values is better than the model at approximating individual measured values.

Dimensionless Sediment Rating Curves

This section of the report presents DSRCs developed using data collected in Minnesota and provides an assessment of the ability of the Pagosa Springs and Minnesota DSRC models to predict SSC and bedload. Evaluations of DSRC models were based on measures of goodness-of-fit that included proximity of the model(s) fitted line to the 95-percent confidence intervals of the site-specific model and Nash-Sutcliffe Efficiency values.

More than 600 samples were used to develop Minnesota DSRCs for SSC and bedload for good/fair and poor Pfankuch stream stability categories. Four weighted nonlinear regression models were developed using the R statistical environment (nls function; R Development Core Team, 2011). Dimensionless ratio values of streamflow, SSC, and bedload were used to develop the following regression equations:

$$\text{Suspended DSRC (good/fair stability): } SSC = 0.026 + 0.974Q^{0.951} \quad (6)$$

$$\text{Bedload DSRC (good/fair stability): } Qb = -0.054 + 1.054Q^{1.316} \quad (7)$$

$$\text{Suspended DSRC (poor stability): } SSC = 0.066 + 0.934Q^{1.006} \quad (8)$$

$$\text{Bedload DSRC (poor stability): } Qb = 0.012 + 0.988Q^{1.306} \quad (9)$$

where

SSC is a dimensionless ratio value of suspended-sediment concentration,
Q is a dimensionless ratio value of streamflow, and
Qb is a dimensionless ratio value of bedload.

Dimensional values of SSC and bedload are derived from dimensionless ratio values of streamflow using the regression equations 6 through 9 (models). This entails converting streamflow to a dimensionless value by dividing streamflow by the known bankfull streamflow at the selected site. This dimensionless streamflow value is used as the input value in one of the dimensionless regression equations (equations 6 through 9) to calculate a dimensionless SSC or bedload value. Finally, the calculated dimensionless SSC or bedload value is multiplied by the known SSC or bedload value at bankfull streamflow from the site of interest to determine the dimensional SSC or bedload value.

The Pagosa Springs and Minnesota DSRC models for SSC and bedload were evaluated in comparison to site-specific regression models for model ability to predict suspended-sediment concentrations and bedload. As previously mentioned and described in the following subsections, methods used to assess the model effectiveness in predicting SSC and bedload included the comparison of regression trendlines (proximity of the fitted line of the DSRC model to the 95-percent confidence intervals of the site-specific model) and Nash-Sutcliffe Efficiencies.

Regression Trendlines:

Modeled (predicted) values of SSC and bedload using Pagosa Springs and Minnesota DSRC models were compared to measured values of SSC and bedload by plotting the measured values and the regression trendlines of each of the models on a log-log scale. Site-specific model regression trendlines with 95-percent confidence intervals were included to demonstrate the relations between measured SSC and streamflow and measured bedload and streamflow and to examine the level of agreement between DSRC models and site-specific regression models. Pagosa Springs DSRC models, Minnesota DSRC models, and site-specific regression models are presented for Pfankuch stability rating of good/fair in figure 2 for SSC and in figure 3 for bedload for Pfankuch stability rating of poor (SSC models for Pfankuch stability rating of poor and bedload models for Pfankuch stability rating of good/fair are available in Ellison and others [2016]). Pagosa Springs and Minnesota DSRC models were compared to site-specific regression models to evaluate their effectiveness in predicting SSC and bedload. Site-specific regression models are assumed to provide the most accurate predictions of suspended sediment and bedload across a range of streamflow.

Suspended-Sediment Concentrations:

Unique characteristics were observed among sites for the Pagosa Springs DSRC models developed to approximate SSC. Specifically, low sensitivity (little change in slope) at lower streamflows coupled with an identifiable inflection point associated with a marked increase in slope of the fitted trendline was observed for the Pagosa Springs DSRC models (fig. 2).

A notable concern is the disparity in values between regression exponents (slopes) from the Pagosa Springs DSRCs and site-specific regression exponents for rivers in Minnesota. Inspecting each site-specific regression model trendline alongside the regression trendlines for the Pagosa Springs DSRC models at flows near bankfull indicated that Pagosa Springs DSRC models resulted in markedly larger slopes than the site-specific regression models for SSC (fig. 2). For good/fair stability sites, the mean slope of the Pagosa Springs DSRC models for estimating SSC was 3.5 times larger than the mean slope of the site-specific regression models. For poor stability sites, the mean slope of the Pagosa Springs DSRC models (3.66) was 4.7 times larger than the mean slope of the site-specific regression models (0.78) (Ellison and others, 2016). Consequently, predictions of SSC derived from Pagosa Springs DSRC models will overestimate SSC and suspended-sediment loads at streamflows exceeding bankfull compared to the site-specific regression models.

Compared to Pagosa Springs DSRC models, Minnesota DSRC models for SSC more closely approximated the site-specific regression models developed from the measured data (fig. 2). Inspection of the regression trendlines for the Minnesota and Pagosa Springs DSRC models and the site-specific regression models indicate that the regional Minnesota DSRCs are more applicable to rivers in Minnesota. For example, Minnesota DSRC models were more sensitive to variability in streamflow during lower streamflows for SSC, unlike the Pagosa Springs DSRC models, which indicated little response in SSC to changes in streamflow at low streamflows. Also, the regression exponents for the Minnesota DSRC models more closely matched the site-specific regression exponents and were markedly lower than regression exponents from the Pagosa Springs DSRC models. For example, the mean slopes of 0.951 and 1.006 for SSC for the Minnesota DSRC models for good/fair and poor stability streams, respectively, were markedly lower than mean slopes of 2.41 and 3.66, respectively, for the Pagosa Springs DSRC models. Large differences in model slopes indicate that the individual river sediment signatures for

Minnesota's rivers were not as well represented in the Pagosa Springs DSRC models as compared to the Minnesota DSRC models. Overall, the Minnesota DSRC models approximated the site-specific regression models more closely than the Pagosa Springs DSRC models for 14 of 16 sites.

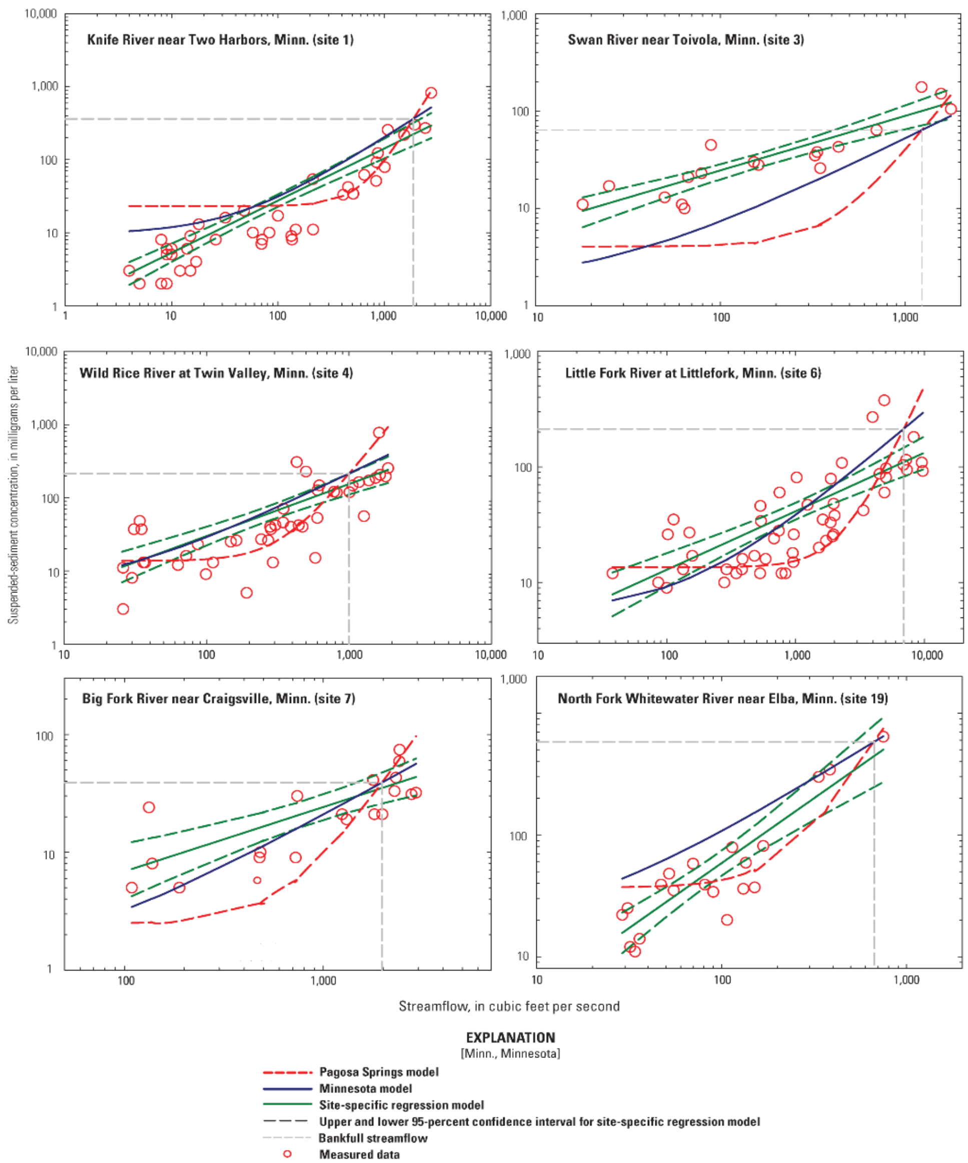

Figure 2. Pagosa Springs and Minnesota dimensionless suspended-sediment rating curves and site-specific regression trendlines for good/fair sites for selected rivers in Minnesota, 2007 through 2013

Bedload:

Regression trendlines for bedload for the Pagosa Springs and Minnesota DSRC models and site-specific regression models for poor stability categories are shown in figure 3 (good/fair stability models available in Ellison and others [2016]). For bedload, Pagosa Springs DSRC models had characteristics similar to those demonstrated by the SSC DSRC models. Similar to the SSC DSRC models, the slopes of the regression trendlines for bedload at streamflows exceeding bankfull were larger for the Pagosa Springs DSRC models than for the Minnesota DSRC and site-specific regression models for most sites. For example, mean slopes for the Minnesota DSRC models were 1.316 and 1.306 for good/fair and poor stability streams, respectively, compared to mean slopes of 2.19 and 2.38, respectively, for the Pagosa Springs DSRC models (Ellison and others, 2016). In contrast to SSC models, all bedload models nearly intercepted the y-axis at 0 during periods of no streamflow, which corresponds to the expected response of little bedload transport during low streamflows (Bagnold, 1973; Leopold and Emmett, 1976).

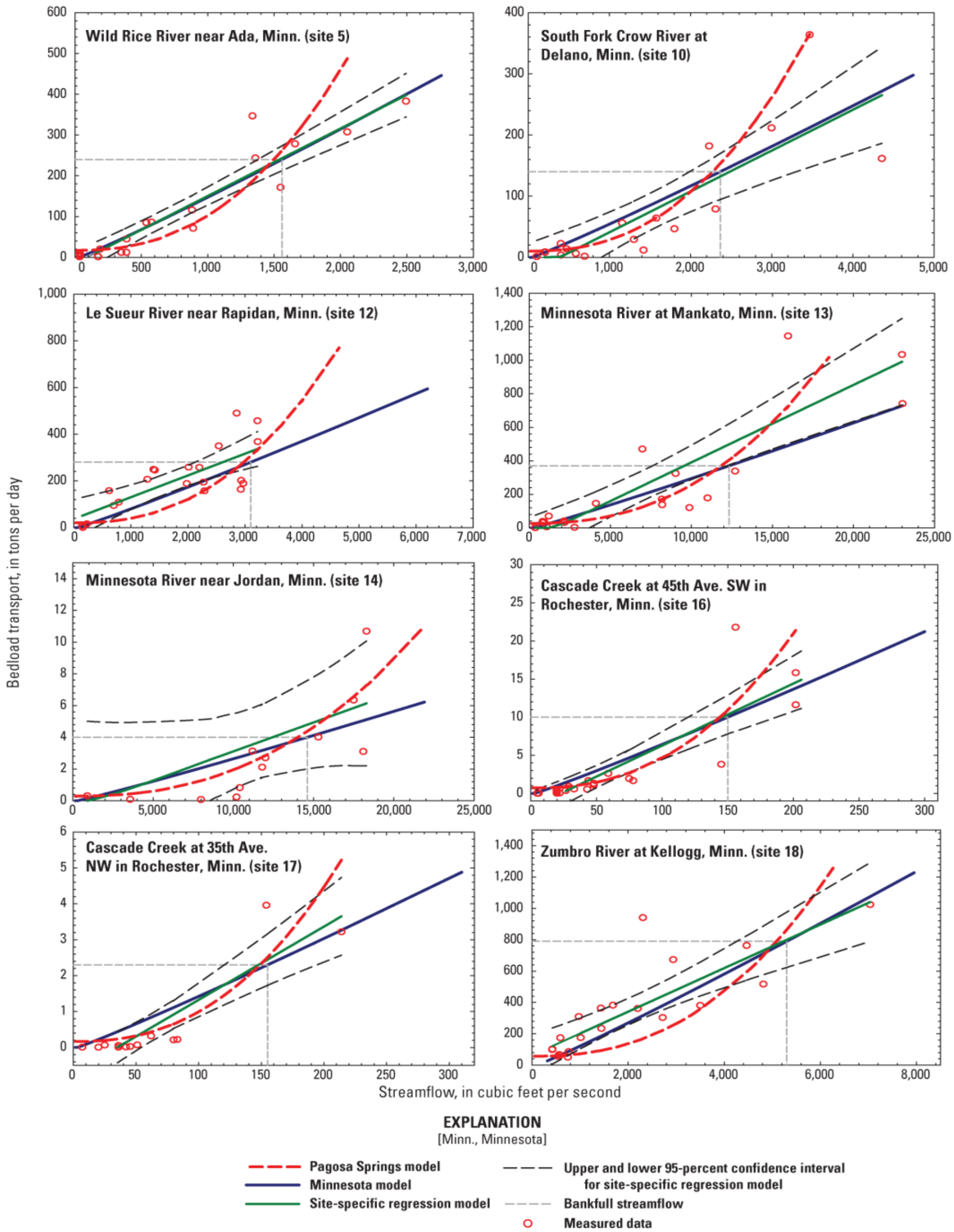

Figure 3. Pagosa Springs and Minnesota dimensionless bedload rating curves and site-specific regression trendlines for Pfankuch stability categories of poor for selected rivers in Minnesota, 2007 through 2013

In general, the predicted values of bedload from the Pagosa Springs and Minnesota DSRC models are contained within the 95-percent confidence intervals of site-specific regression models; however, the Minnesota models more closely approximated the site-specific regression models than did the Pagosa Springs DSRC models for most sites during streamflows near and exceeding bankfull streamflow (fig. 3). At lower streamflows, the Minnesota and Pagosa Springs DSRC models indicate similar fits to the measured data.

Nash-Sutcliffe Model Efficiencies:

Nash-Sutcliffe Efficiency values were determined for the Pagosa Springs DSRC models, Minnesota DSRC models, and site-specific regression models for each of the study sites. The NSE values are presented in figure 4 for SSC and in figure 5 for bedload.

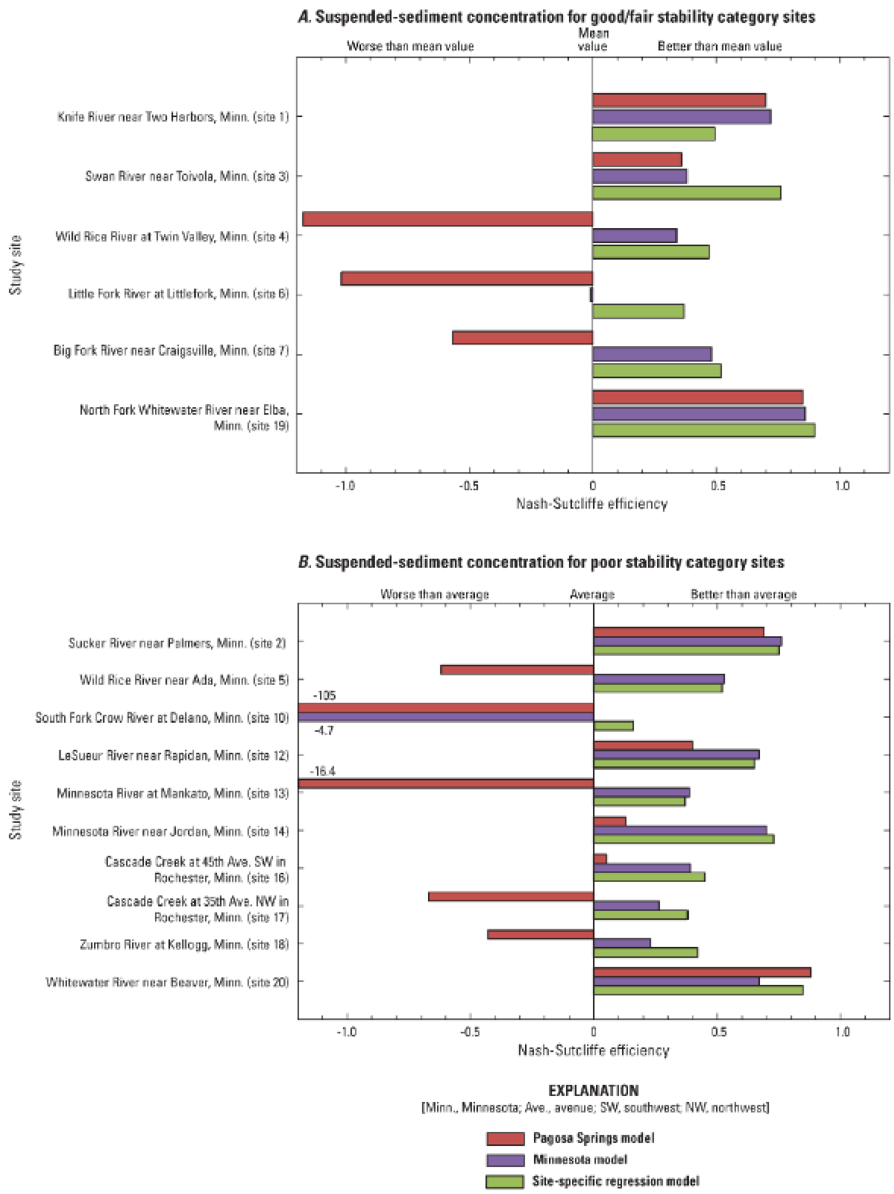

Figure 4. Nash-Sutcliffe Efficiency values for Pagosa Springs and Minnesota dimensionless rating curves and site-specific models for suspended-sediment concentrations for Pfankuch stability categories of good/fair (A) and poor (B) for selected rivers in Minnesota

Among models for SSC, the site-specific regression models provided the overall best fits for 10 of 16 sites (fig. 4) based on the NSE values. For SSC at the good/fair stability sites, the NSE values associated with the Pagosa Springs DSRC model indicated that fits were better than using the mean value of the measured data for 3 of 6 sites (sites 1, 3, and 19) and fits were worse than using the mean value for the remaining 3 sites (sites 4, 6, and 7; fig. 4A).

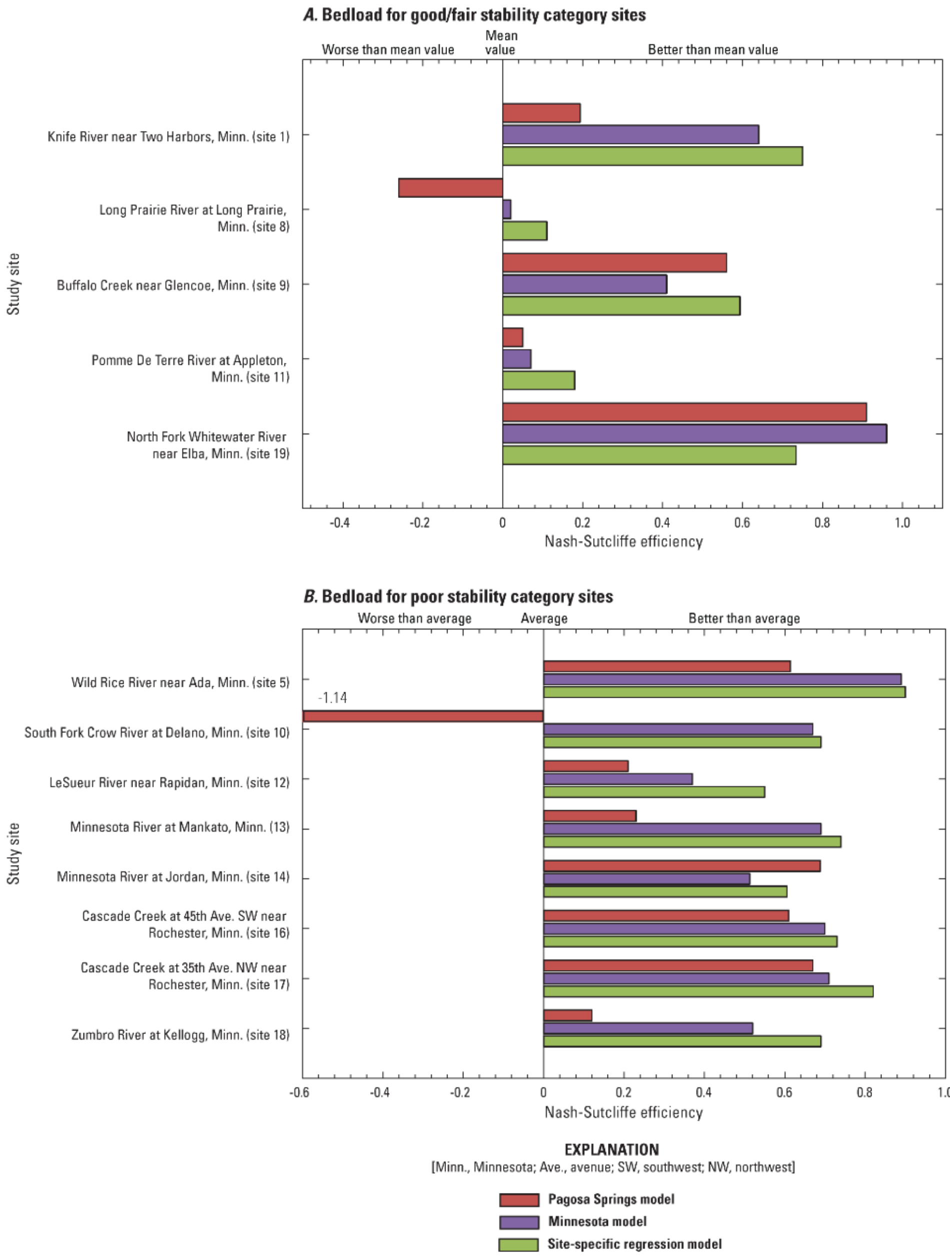

Figure 5. Nash-Sutcliffe Efficiency values for Pagosa Springs and Minnesota dimensionless rating curves and site-specific models for bedload for Pfankuch stability categories of good/fair (A) and poor (B) for selected rivers in Minnesota

Conversely, the Minnesota DSRC models provided a better fit for good/fair stability sites than using the mean value of the measured data for 5 of 6 sites. For poor stability sites for SSC models were similar to those for the good/fair stability sites (fig. 4*B*). The Pagosa Springs DSRC models provided fits that were better than the mean value of the measured data for 3 of 10 sites (sites 2, 12, and 20), slightly better fits than the mean value of the measured data for 2 sites (sites 14 and 16), and worse fits than the mean value for the measured data for the remaining 5 sites. The Minnesota DSRC models provided fits that were better than the mean value of the measured data for 9 of 10 poor stability sites and a worse fit than the mean for one site (site 10). The exceptions were sites 8 and 10, which had negative NSE values of -0.26 and -1.14, respectively. For the 11 sites with positive NSE values using the Pagosa Springs DSRC models, 5 sites (sites 5, 14, 16, 17, and 19) had NSE values that exceeded 0.6, 4 sites had NSE values that ranged between 0.2 and 0.6, and 2 sites (sites 11 and 18), had NSE values (0.05 and 0.12, respectively) that were only slightly better than using the measured samples mean value. The Minnesota bedload DSRC models indicated markedly better NSE values than the Pagosa Springs DSRC models for nearly every site. For the Minnesota DSRC models, all 13 sites had positive NSE values and closely approximated the site-specific regression model results.

Implications of the Model Assessments

Results of data analyses indicate that DSRC models developed using data collected in Minnesota were more effective at compensating for differences in individual stream characteristics across a variety of basin sizes and flow regimes than DSRC models developed using data collected near Pagosa Springs, Colorado. Minnesota DSRC models retained a substantial portion of the unique sediment signatures for most rivers, although deviations were observed for streams with limited sediment supply and for rivers in southeastern Minnesota, which had markedly larger regression exponents. Compared to Pagosa Springs DSRC models, Minnesota DSRC models had regression slopes that more closely matched the slopes of site-specific regression models and had greater Nash-Sutcliffe Efficiency values.

The results presented in this report indicate that regionally based DSRCs can be used to estimate reasonably accurate values of SSC and bedload. Practitioners are cautioned that DSRC reliability is dependent on representative measures of bankfull streamflow, SSCs, and bedload. It is, therefore, important that samples of SSC and bedload, which will be used for estimating SSC and bedload at the bankfull streamflow, are collected over a range of conditions that includes the ascending and descending limbs of the event hydrograph. Applicability of DSRC models may have substantial limitations under certain conditions. For example, DSRC models should not be used to predict SSC and loads for extreme streamflows, such as those that exceed twice the bankfull streamflow value because this constitutes conditions beyond the realm of current (2016) empirical modeling capability. Also, if relations between SSC and streamflow and between bedload and streamflow are not statistically significant, DSRCs should not be used to predict SSC or bedload, as this could result in large errors. For streams that do not violate these conditions, DSRC estimates of SSC and bedload can be used for stream restoration planning and design, and for estimating annual sediment loads for streams where little or no sediment data are available.

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