Mean Annual Sediment Yield Estimation for the Neosho Basin

Introduction

In 2009 the Kansas Water Office, in response to requests to update previous mean annual sediment yield estimates in the state, reevaluated the Neosho Basin suspended sediment yields. The primary data sources used in the 2009 reevaluation for the Neosho Basin are Kansas Department of Health and Environment (KDHE) stream chemistry sampling network's total suspended solids (TSS) data (1990-2008), the unique contributing areas (watersheds) formed by the ambient surface water quality monitoring network and United States Geological Survey (USGS) stream statistics for the registered surface waters of Kansas. In addition, when available, USGS instantaneous flow gage data and USGS suspended sediment concentration (SSC) data were used calculate mean annual sediment yields. Mean annual sediment yields in the Neosho Basin were created based upon the method described in Sediment Engineering (Vanoni, 2006) for estimating long-term sediment yields by flow duration-sediment rating curves.

Due to a number of factors outlined within this 2009 yield assessment report, the uncertainty and potential sources for error in many of the updated mean annual sediment yield estimates remain high. The estimated yields should only be used at the planning level.

The results of the assessment found the sediment yields of the Neosho and Cottonwood Rivers are significantly higher than that of the tributaries feeding into them. This finding recapitulates other recent studies performed in the John Redmond drainage area which have pointed to stream bank sources along those main stems as being the primary sources of the sediment in the basin.

Methodology

KDHE has the most comprehensive (temporally and spatially) water quality monitoring network within the state. They collect ambient surface water samples every other month at fixed sites in the Neosho River Basin and every other month every fourth year at rotational sampling sites. The location of the sampling sites used to estimate mean annual sediment yields for contributing streams within Kansas in the Neosho River Basin is shown in **Figure 1**. The TSS data from the sites were provided by KDHE on 5/27/2009 and included all TSS data from 1990 through 2008.

USGS flow duration stream statistics (Perry, 2004) were assembled for streams segments on the Kansas Surface Water Register that contributed flow to the Neosho River in Kansas. The flow exceedence estimates from the USGS report were used to create an estimated flow duration curve for each stream segment with a coincident KDHE sampling site. Coupling the KDHE TSS loads with the estimated flow duration curves created the basis for most of the mean annual sediment yields in the Neosho Basin.

When data were available at USGS flow gaging stations (see **Figure 2** for locations), USGS SSC data and instantaneous flows were used to estimate sediment loads and the instantaneous flow used to create a mean annual flow duration curve for stream segments.

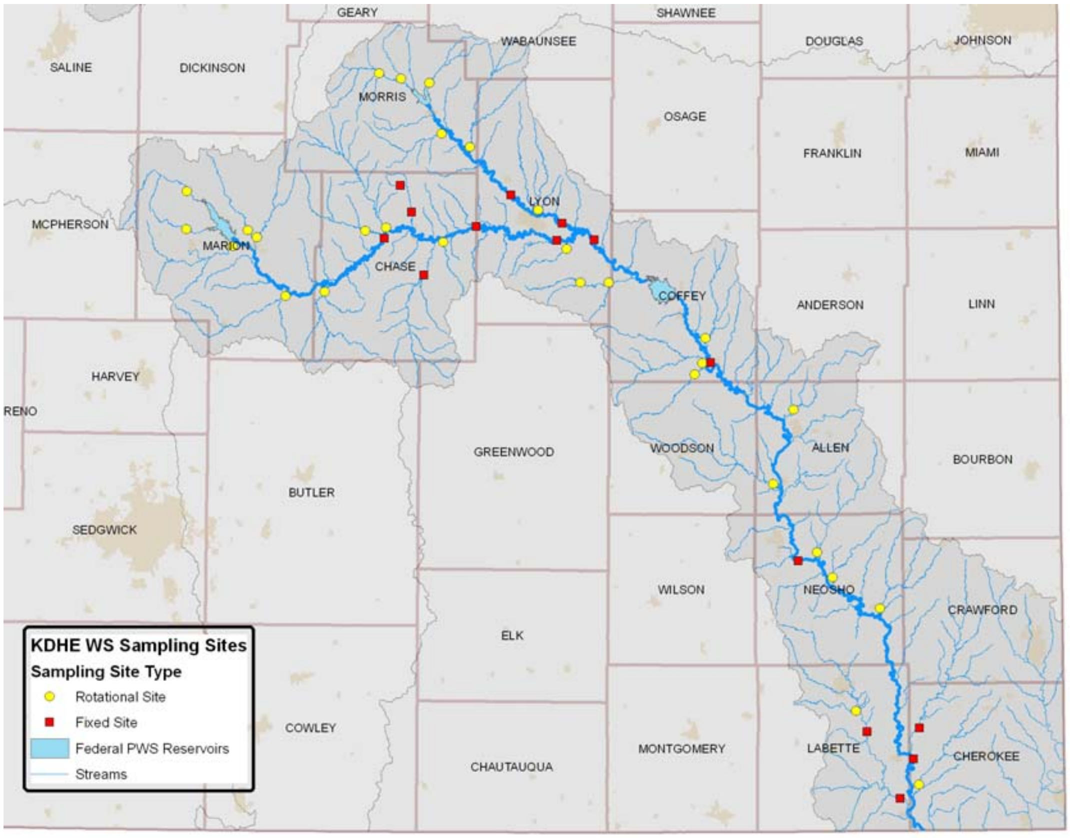


Figure 1: Sampling site locations of KDHE ambient stream water quality network in the Neosho Basin.

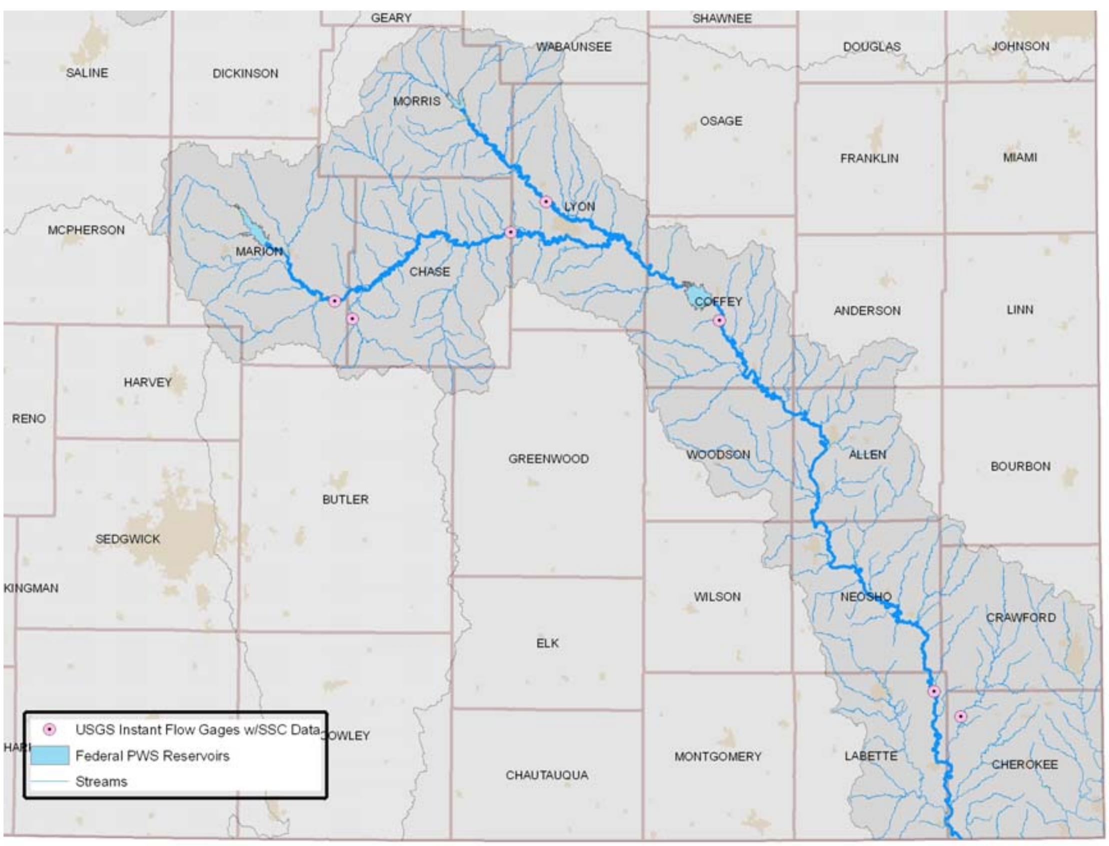


Figure 2: USGS SSC sampling and instantaneous flow gaging locations in the Neosho Basin.

This report assumes the mean annual sediment yields derived from USGS collected SSC data, whose samples generally include a greater number of high flow samples, and annual flow duration curves created by averaging the annual flow duration curves created from the gaged instantaneous flows from water years 1991 through 2008, have the least amount of error and are closest to the true mean annual sediment yields (Gray, 2000). Consequently, the mean annual sediment yields derived from these data have been used as calibration and comparison points to the KDHE TSS data/USGS stream stats derived mean annual sediment yields. The results of that comparison and the subsequent adjustments made to the estimated mean annual sediment yields are detailed below; however, a summarization of that comparison is:

1) KDHE TSS concentrations were consistently less than the SSC concentrations collected by USGS under high flows;
2) USGS stream statistic derived flow duration curves were slightly greater for higher flows than the instantaneous flow derived from averaging annual flow duration curves;
3) The magnitude of differences of 1) and 2) above, and their product, sediment yields, increased by drainage area. The larger the drainage area, the greater the magnitude of under-prediction by KDHE TSS/USGS stream statistics derived sediment yields.

The different methods of creating estimated mean annual sediment yields could only be compared at four sites in the Neosho Basin (**Table 1**). The rows in Table 1 reference site locations on **Figure 3**. The three remaining USGS gage locations, which had SSC sample data were used as sediment yield calibration points within the basin, but did not have a KDHE monitoring site located near enough to them to be included in the comparison.

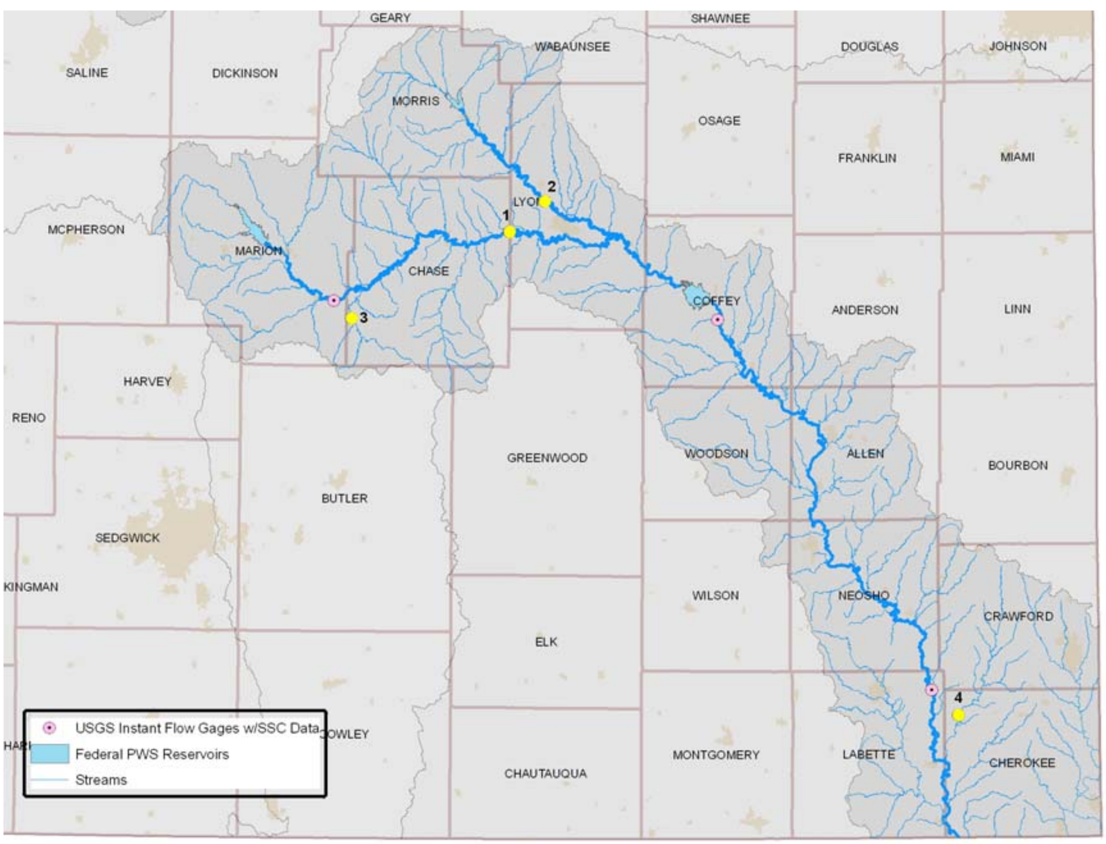


Figure 3: Sediment yield method comparison sites (numbers reference rows in Table 1).

Generally, the USGS derived estimate was created by using the mean annual instantaneous flow duration curve from water years 1991 through 2008 and USGS SSC samples collect at those sites. Sediment loads were generated by matching grab sample times to instantaneous flows. Those sediment loads were plotted by instantaneous flow (both natural log transformed) and the relation applied to the flows of the mean annual flow duration curve to generate the sediment load duration curve. The area under the curve is the estimated mean annual sediment yield.

For comparison there is the KDHE TSS derived estimate. USGS stream statistics were used to create an estimated mean annual flow curve. The sediment loads were estimated by matching the KDHE TSS sample to the *average daily* flow at each site. The sediment load estimate was plotted by flow (both natural log transformed) and the relation applied to the flows of the estimated mean annual flow duration curve to generate the sediment load duration curve. As before, the area under the curve was calculated for the estimate of mean annual sediment yield.

Sediment Yield Estimates (Tons/Year)

	Site	USGS SSC/ Mean Annual Flow Duration	KDHE TSS/ Stream Stats/ Avg Daily Flow	Drainage Area (SqMi)	Difference (USGS - KDHE yield)
1	Cttnwd R. nr Plymouth	872,845	622,419	1,740	250,426
2	Neosho R. nr Americus	298,191	143,514	622	154,677
3	Cedar Cr nr Cedar Point	28,864	30,217	110	-1,353
4	Lightning Cr nr McClune	64,169	65,546	197	-1,377

Table 1: Mean annual sediment yield estimates and drainage areas for select sites in the Neosho Basin.

From Table 1, note that as the drainage areas become very large the magnitude of the difference between the USGS instantaneous flow-SSC derived yields and the average daily flow-KDHE TSS yields increase. However for the Cedar Creek and Lightning Creek watersheds the different sources created yields that are quite similar.

Because of data coverage limitations with respect to SSC samples and USGS instantaneous flow gages, the primary method of estimating mean annual sediment yields fell to the KDHE TSS data and the USGS stream statistics estimations for average daily flow exceedence on ungaged stream segments. Table 1 indicates that the use of that method for much of the Neosho Basin can introduce a substantial amount of error to the mean annual sediment yield estimation. From the 4 sites where comparisons of the different methods were available (Table 1), the KDHE TSS/Stream Stats/Average Daily Flow method typically underestimated yields in watersheds with larger drainage areas and modestly overestimated yields in smaller watersheds. Although only 4 sites were available to make this comparison, this information was used to make proportional adjustments to the yields generated by KDHE TSS/Stream Stats/Average Daily Flow method. All six sites in the Neosho Basin where USGS SSC data and instantaneous flows were available to estimate mean annual sediment yields (Figure 1) were used to recalibrate estimates derived from the primary method. Generally this recalibration of KDHE TSS data based sediment yield was completed by inflating the KDHE TSS data based yields to the USGS SSC based data calibration point while holding the proportional relation on the KDHE based yields upstream of the calibration point the same.

Example Calculation of Mean Annual Sediment Yield Estimation

Following a more in-depth example of how the sediment yield methodology has been applied uses TSS data (mg/L) from stream chemistry site 583 (SC583) on Cedar Creek in Chase County.

The KDHE monitoring site is on a tributary to the Cottonwood River and a rotational sampling site (**Figure 4**).

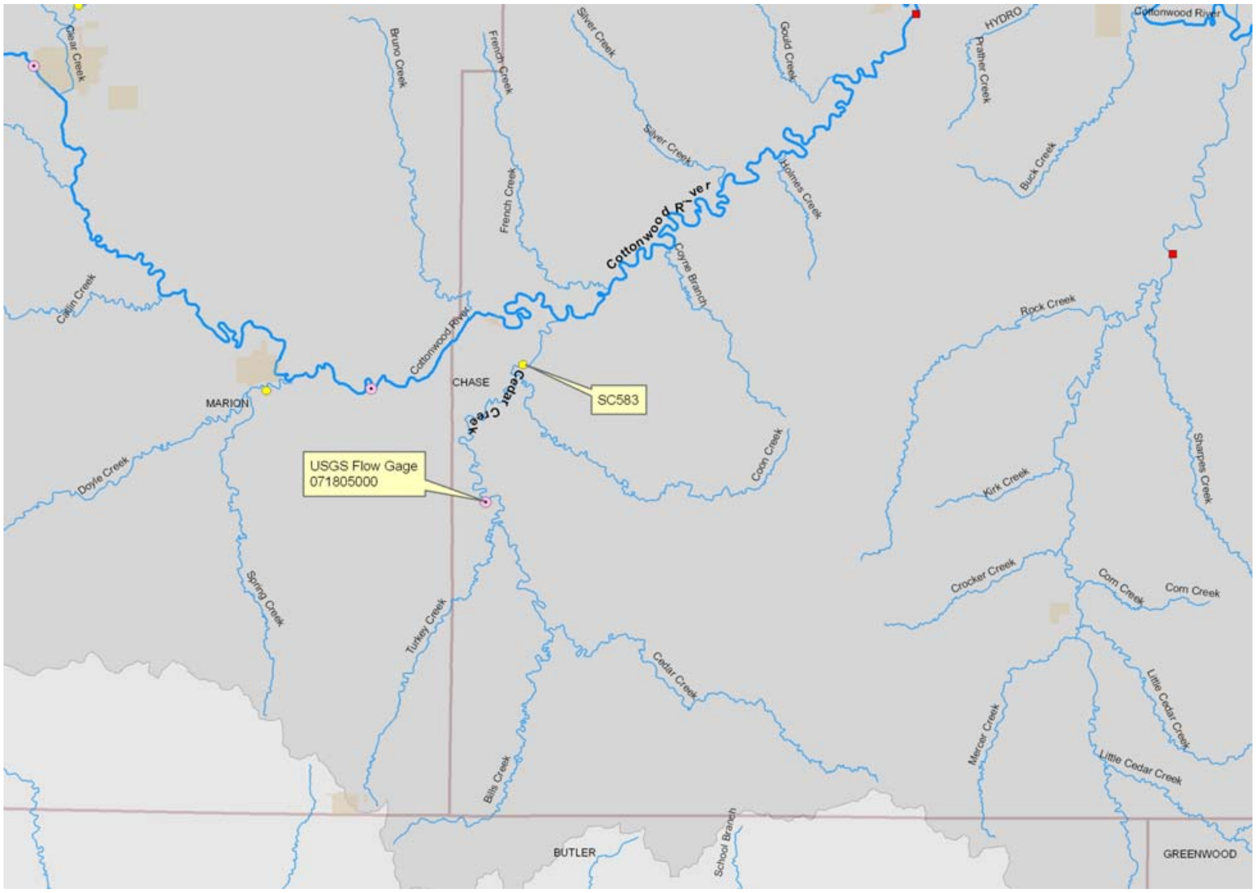


Figure 4: KDHE stream chemistry sampling location on Cedar Creek and USGS flow gage.

Using a starting date of 1990, the typical number of samples collected at KDHE sampling sites for their fixed site network is currently about 125. The rotational network sites have about 30 samples collected at them at the time of this report. This example, as a rotational monitoring site, had 26 discrete samples.

Stream flow data is from USGS station number 071805000 also on Cedar Creek and has been adjusted to the KDHE sampling site location by proportioning flow at the gage to the drainage area at site 583. Average daily stream flow, instantaneous flow for comparison, grab sample TSS concentration and the date of sample collection are recorded in **Table 2**.

Site #	Date	TSS (mg/L)	Avg Daily Flow (cfs)	Instantaneous Flow (cfs)
SC583	4/18/90	22	68.50	No Data
SC583	6/20/90	620	1382.45	No Data
SC583	8/22/90	47	12.45	No Data
SC583	10/17/90	21	6.35	6.5
SC583	4/6/94	6	5.60	5.7
SC583	6/8/94	60	14.95	14.9
SC583	8/3/94	50	2.86	2.9
SC583	10/5/94	21	0.52	0.6
SC583	12/27/94	4	6.10	6.0
SC583	2/11/98	6	51.06	49.8

Site #	Date	TSS (mg/L)	Avg Daily Flow (cfs)	Instantaneous Flow (cfs)
SC583	4/15/98	24	189.31	201.8
SC583	6/10/98	18	39.85	38.6
SC583	8/12/98	17	14.95	14.9
SC583	8/12/98	16	14.95	14.9
SC583	10/14/98	24	36.12	38.4
SC583	12/29/98	3	37.36	37.4
SC583	2/13/02	3	5.36	5.4
SC583	4/10/02	12	14.95	14.9
SC583	6/13/02	616	1370.00	1083.5
SC583	8/14/02	21	10.34	10.7
SC583	10/16/02	10	5.73	6.0
SC583	12/23/02	10	8.47	8.1
SC583	2/8/06	10	8.47	8.2
SC583	4/12/06	10	5.98	6.2
SC583	6/14/06	23	10.46	10.6
SC583	6/14/06	23	10.46	10.6
SC583	8/16/06	10	1.18	1.1
SC583	12/6/06	10	3.99	3.9

Table 2: TSS data collected at monitoring site 583 by KDHE on Cedar Creek.

One grab sample was excluded from the data; the October 2006 sample did not have any flow (0 cfs) at USGS gage on the date it was collected.

The flow duration curve was created by percentiles of flows for the USGS gaged mean daily flows from 1/1/1990 through 12/31/2008 proportioned to the drainage area at SC583 (**Figure 5**). For comparison purposes, flow values for the 90%, 75%, 50%, 25% and 10% exceedence from USGS stream statistics (Perry, 2004) for the stream segment upon which SC583 is located were added to the same figure and are displayed as red dots in Figure 5. The USGS stream statistics estimated 2-year peak flow was also added to the series at 0.1% exceedence to help complete the highest flow estimates for the location. The selection of 0.1% exceedence was based up a comparison of the 2-year peak flows to the mean annual instantaneous flows at USGS gages in the Neosho Basin (located in Figure 2). The result of that comparison showed that the 2-year peak was typically nearest the 0.1% exceedence for the 1990-2008 period. A transformed fit (Y-axis, natural log; X-axis, square root; 3rd degree polynomial fit) of the USGS stream statistics flow duration estimates is shown as a yellow line in Figure 5. This fit of the USGS stream statistics flow duration estimates was used for all stream segments in the Neosho Basin that could not be estimated from gaged flow data.

Since most of the annual sediment yield is derived from the highest stream flows, the proper fitment of the 2-year peak flow to a flow exceedence estimate is critical. However, peak flows and flow exceedences are two completely separate terms and calculated differently. The comparison of the 2-year peak flow to mean annual flow duration curves created at the six USGS gaged sites revealed that the 2-year peak flow often exceeded the 0.1% exceedence (**Table 3**), especially for the smaller drainage areas. This is another source of potential error that has been introduced to the mean annual sediment yield estimates for many stream segments in the Neosho Basin.

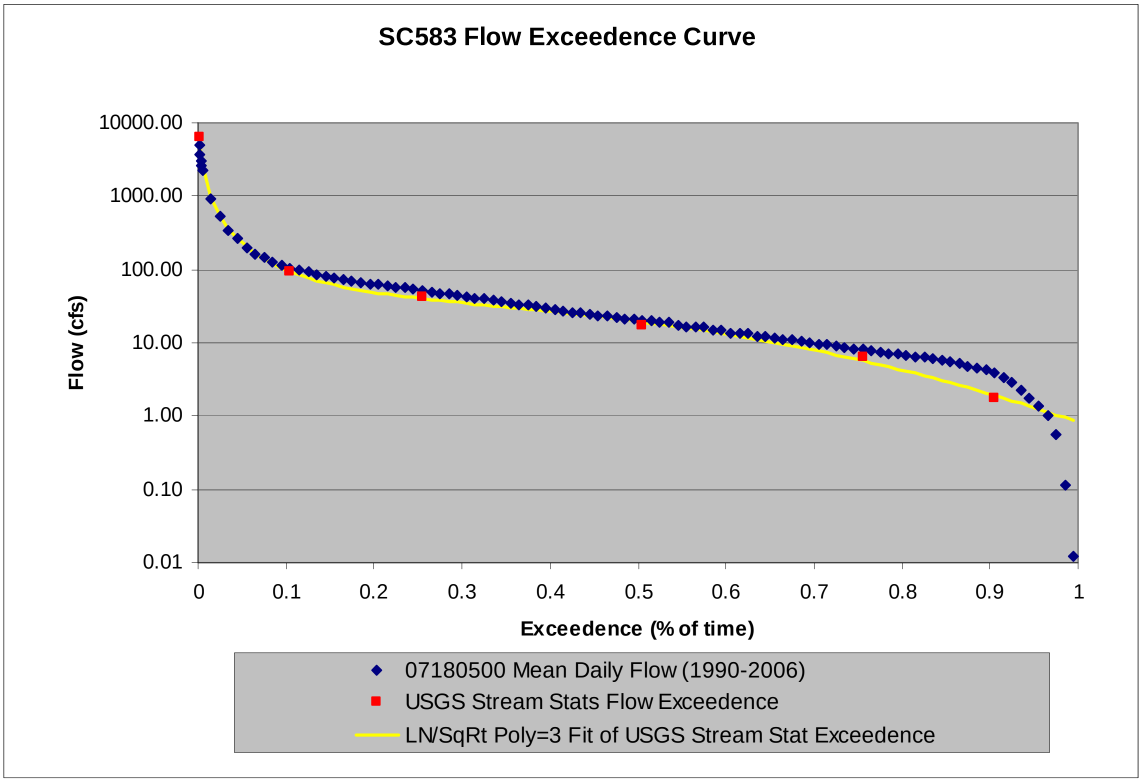


Figure 5: Comparison of mean daily flow exceedence value to estimated values derived from USGS stream statistics on Cedar Creek.

Flow Comparisons

Site	2-Year Peak Flow (cfs)*	0.1% Flow Exceedence**
Cttnwd R. nr Florence	8,610	5,742
Cedar Cr nr Cedar Point	6,314	4,357
Cttnwd R. nr Plymouth	14,500	14,059
Neosho R. nr Americus	7,400	6,397
Neosho R. at Burlington	10,900	9,184
Lightning Cr nr McClune	7,533	8,173
Neosho R. nr Parsons	29,040	29,777

* From USGS SIR 2004-5033 for period of record

** Mean annual flow exceedence (WY 1991-2008) instantaneous flows

Table 3: Comparison of 2-year peak flows to 0.1% flow exceedence values at select sites.

Mean daily flow on the day that the TSS sample was collected on Cedar Creek was matched to estimate the suspended sediment load for the day. Sediment load (TSS, really) in pounds/day was calculated from TSS and flow data by TSS (mg/L) * flow (mean daily in cfs) * 5.394 (constant to convert to lbs/day). A natural log transformation has been applied to daily flows and sediment loads in the column next to them to comply with normality assumptions of the regressions used in the next step (**Table 4**).

Date	TSS (mg/L)	Daily Flow (cfs)	LN Daily Flow (cfs)	SedLd (lbs/day)	LNSedLd (lbs/day)
4/18/90	**22**	**68.50**	4.23	8,128	9.003119
6/20/90	**620**	**1382.45**	7.23	4,623,109	15.34658
8/22/90	**47**	**12.45**	2.52	3,157	8.057476
10/17/90	**21**	**6.35**	1.85	719	6.578506
4/6/94	**6**	**5.60**	1.72	181	5.20058

Date	TSS (mg/L)	Daily Flow (cfs)	LN Daily Flow (cfs)	SedLd (lbs/day)	LNSedLd (lbs/day)
6/8/94	60	14.95	2.70	4,837	8.483995
8/3/94	50	2.86	1.05	773	6.649675
10/5/94	21	0.52	-0.65	59	4.081765
12/27/94	4	6.10	1.81	132	4.880273
2/11/98	6	51.06	3.93	1,653	7.410075
4/15/98	24	189.31	5.24	24,506	10.10668
6/10/98	18	39.85	3.69	3,869	8.260851
8/12/98	17	14.95	2.70	1,370	7.222863
8/12/98	16	14.95	2.70	1,290	7.162239
10/14/98	24	36.12	3.59	4,676	8.450093
12/29/98	3	37.36	3.62	605	6.404553
2/13/02	3	5.36	1.68	87	4.461971
4/10/02	12	14.95	2.70	967	6.874557
6/13/02	616	1370.00	7.22	4,551,902	15.33106
8/14/02	21	10.34	2.34	1,171	7.065521
10/16/02	10	5.73	1.75	309	5.733385
12/23/02	10	8.47	2.14	457	6.124251
2/8/06	10	8.47	2.14	457	6.124251
4/12/06	10	5.98	1.79	322	5.775944
6/14/06	23	10.46	2.35	1,298	7.168469
6/14/06	23	10.46	2.35	1,298	7.168469
8/16/06	10	1.18	0.17	64	4.156035
12/6/06	10	3.99	1.38	215	5.370479

Table 4: Sediment loads by flow exceedence on Cedar Creek.

Plotting the natural log of the sediment load (lbs/day) by the natural log of daily flow on Cedar Creek yields **Figure 6**. Notice that the KDHE sampling regime yields relatively few grabs samples collected under high flows. In fact, of the 26 samples collected at SC583, only two were collected for flows exceeded 10% of the time or less and those two samples have a disproportionately large impact on the estimation of sediment yield at that site. This relative dearth of high flow samples at the KDHE rotational sampling sites in the Neosho Basin can introduce substantial error to the estimates of sediment yields in those watersheds. As the number of samples collected at rotational sampling sites increases through time, we would assume that a greater incidence of higher flow samples will be collected and that error will decline. Therefore, the sediment yields should be re-estimated every 2 or 3 sampling cycles at rotational sites as new data are added.

Bivariate Fit of SC583 LN Sed Ld (lbs/day) By LN Daily Flow (cfs)

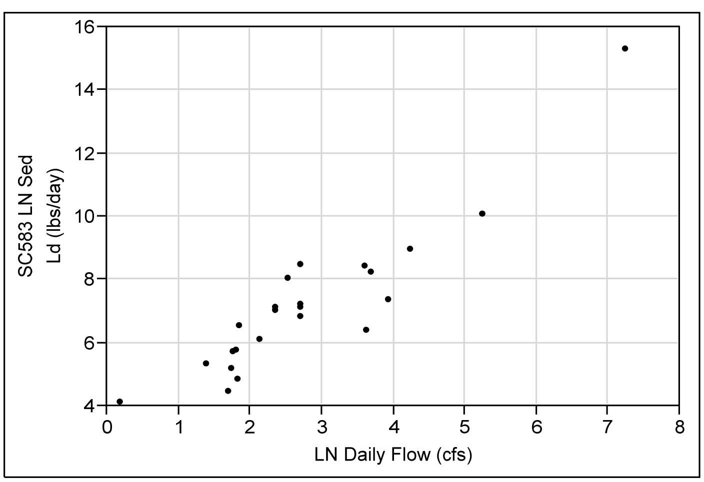
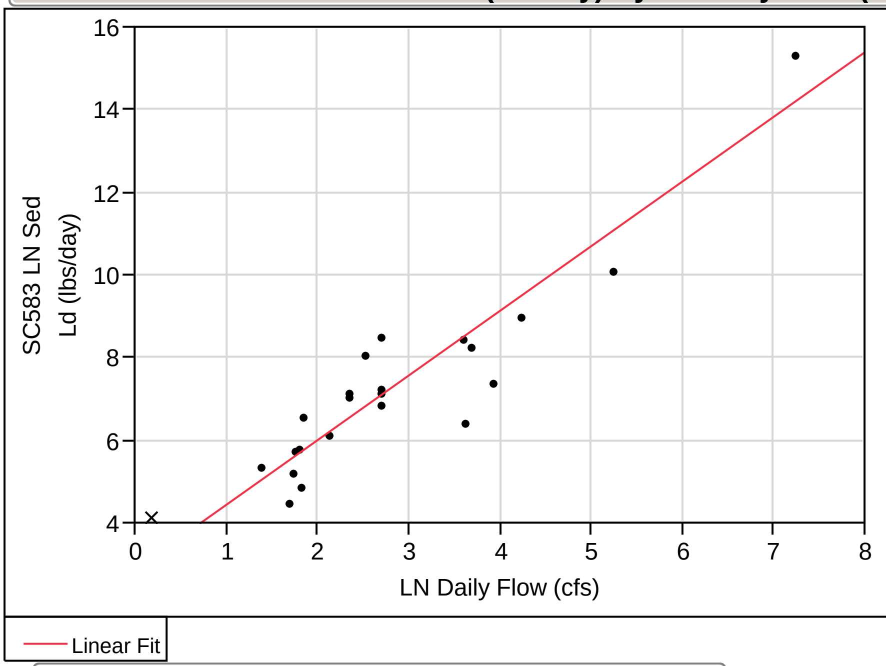


Figure 6: Cedar Creek sediment loads plotted by estimated flow exceedence.

A simple linear regression was used to create the typical (LN) relation between sediment load and flow for the watershed across the sampled flow conditions of 1990-2008 and is shown in **Figure 7** below.

Bivariate Fit of SC583 LN Sed Ld (lbs/day) By LN Daily Flow (cfs)



Linear Fit

SC583 LN Sed Ld (lbs/day) = 2.9056089 + 1.5671391*LN Daily Flow (cfs)

Summary of Fit

RSquare	0.894694
RSquare Adj	0.890306
Root Mean Square Error	0.900204
Mean of Response	7.458549
Observations (or Sum Wgts)	26

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	165.23892	165.239	203.9062
Error	24	19.44882	0.810	**Prob > F**
C. Total	25	184.68774		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.9056089	0.364457	7.97	<.0001*
LN Daily Flow (cfs)	1.5671391	0.109747	14.28	<.0001*

Figure 7: Sediment load by flow calculated for samples collected from Cedar Creek.

Since, as previously mentioned, most of the sediment yield is produced under flows that are only exceeded 5-10 percent of the time of less, it was determined that the fit needed to be improved for the highest flows. Of the methods applied to improve the fit of the regression line to data collected under high flows, the best was to exclude lower flow samples until any trend in residuals for the remaining higher flow data were removed.

The sediment yield curve was created by substituting the flow exceedences values from the USGS stream stats generated flow duration curve (the yellow line in Figure 5) for the flows in prediction equation from the regression in Figure 7. The result describes the typical sediment loading condition for the Cedar Creek watershed for the 1990-2008 sampling period.

Following Helsel and Hirsch (1992), Statistical Methods in Water Resources, when the objective is estimating the mass of sediment, the mean for each of many short time periods can be estimated by regression and summed to estimate the total mass over time.

Since sediment loads were converted into natural log units (Figure 7), a nonparametric or ‘smearing’ estimate of mass was used to remove the transformation bias.

The result is an equation that describes the typical sediment condition in Cedar Creek. That equation was used to create a table that predicts the typical sediment loads for each percent of flow exceedence (there are 104 of them; from 0.995 to 0.001 exceedence in **Table 5,** below). Finally the smearing estimate is applied to each of those loads. At this point notice the units in Table 5 were converted from lbs/day to tons/year. The interval between exceedence percentages was 1% for all but the highest flows. The highest flow interval (the delta p column in Table 5) was shortened for flows exceeded 5% of the time or less from 1% to 0.1% to improve the estimate in that section of the load curve since most of the sediment yield is generated at higher flows.

Flow Exceed (cfs)	Percent Exceed	delta p (interval)	Pred Sed Ld (lbs/day)	EXP(PredSedLd in T/yr)	Smeared Sed Ld (T/yr)
0.86	0.995	0.01	2.48	0.02	0.03
0.95	0.985		2.64	0.03	0.03
1.04	0.975		2.78	0.03	0.04
1.14	0.965		2.93	0.03	0.05
1.24	0.955		3.08	0.04	0.05
1.36	0.945		3.22	0.05	0.06
1.48	0.935		3.36	0.05	0.07
1.61	0.925		3.50	0.06	0.08
1.76	0.915		3.63	0.07	0.09
1.91	0.905		3.77	0.08	0.11
2.07	0.895		3.90	0.09	0.12
2.25	0.885		4.03	0.10	0.14
2.43	0.875		4.16	0.12	0.16
2.63	0.865		4.28	0.13	0.18
2.84	0.855		4.41	0.15	0.20
3.06	0.845		4.53	0.17	0.23
3.29	0.835		4.65	0.19	0.26
3.54	0.825		4.77	0.21	0.29
3.81	0.815		4.88	0.24	0.33
4.08	0.805		4.99	0.27	0.37
4.38	0.795		5.11	0.30	0.41
4.68	0.785		5.22	0.34	0.46
5.00	0.775		5.32	0.37	0.51
5.34	0.765		5.43	0.42	0.56
5.69	0.755		5.53	0.46	0.63
6.06	0.745		5.63	0.51	0.69
6.45	0.735		5.73	0.56	0.77
6.85	0.725		5.83	0.62	0.84
7.27	0.715		5.92	0.68	0.93
7.70	0.705		6.02	0.75	1.02
8.15	0.695		6.11	0.82	1.12
8.61	0.685		6.20	0.90	1.22
9.09	0.675		6.29	0.98	1.33
9.59	0.665		6.37	1.07	1.45
10.10	0.655		6.46	1.16	1.58
10.62	0.645		6.54	1.26	1.71
11.16	0.635		6.62	1.37	1.86
11.72	0.625		6.70	1.48	2.01
12.28	0.615		6.77	1.59	2.17
12.86	0.605		6.85	1.72	2.33
13.46	0.595		6.92	1.85	2.51

Flow Exceed (cfs)	Percent Exceed	delta p (interval)	Pred Sed Ld (lbs/day)	EXP(PredSedLd in T/yr)	Smeared Sed Ld (T/yr)
14.06	0.585		6.99	1.98	2.69
14.68	0.575		7.06	2.13	2.89
15.30	0.565		7.13	2.27	3.09
15.94	0.555		7.19	2.43	3.30
16.59	0.545		7.26	2.59	3.52
17.24	0.535		7.32	2.76	3.75
17.91	0.525		7.38	2.93	3.98
18.58	0.515		7.44	3.11	4.23
19.26	0.505		7.50	3.30	4.48
19.95	0.495		7.56	3.49	4.74
20.64	0.485		7.61	3.69	5.01
21.34	0.475		7.66	3.89	5.28
22.04	0.465		7.72	4.10	5.57
22.75	0.455		7.77	4.31	5.86
23.47	0.445		7.82	4.54	6.16
24.19	0.435		7.87	4.76	6.47
24.92	0.425		7.91	5.00	6.79
25.65	0.415		7.96	5.24	7.12
26.39	0.405		8.01	5.48	7.45
27.14	0.395		8.05	5.74	7.80
27.90	0.385		8.10	6.00	8.15
28.67	0.375		8.14	6.27	8.52
29.46	0.365		8.18	6.55	8.89
30.25	0.355		8.23	6.83	9.29
31.07	0.345		8.27	7.13	9.69
31.90	0.335		8.31	7.45	10.12
32.76	0.325		8.36	7.77	10.56
33.65	0.315		8.40	8.11	11.03
34.57	0.305		8.44	8.48	11.52
35.53	0.295		8.49	8.86	12.04
36.54	0.285		8.53	9.27	12.60
37.61	0.275		8.58	9.71	13.20
38.74	0.265		8.63	10.19	13.84
39.94	0.255		8.68	10.70	14.54
41.24	0.245		8.73	11.27	15.32
42.65	0.235		8.78	11.90	16.17
44.19	0.225		8.84	12.60	17.12
45.87	0.215		8.90	13.38	18.19
47.75	0.205		8.96	14.28	19.40
49.84	0.195		9.03	15.30	20.79
52.19	0.185		9.11	16.48	22.40
54.87	0.175		9.19	17.87	24.28
57.94	0.165		9.28	19.51	26.52
61.50	0.155		9.37	21.48	29.20
65.67	0.145		9.48	23.89	32.46
70.62	0.135		9.60	26.86	36.49
76.55	0.125		9.73	30.60	41.58
83.79	0.115		9.87	35.40	48.11
92.77	0.105		10.04	41.72	56.70
104.12	0.095		10.22	50.27	68.31
118.80	0.085		10.44	62.20	84.53
138.35	0.075		10.68	79.55	108.10
165.29	0.065		10.97	106.02	144.07
204.09	0.055		11.31	149.02	202.50
263.33	0.045		11.72	224.88	305.60
361.48	0.035		12.23	375.05	509.67
545.29	0.025		12.90	728.42	989.88
971.08	0.015		13.83	1,849.48	2,513.32
2618.81	0.005		15.43	9,177.06	12,471.04
3070.78	0.004	.001	15.69	1,186.71	1,612.66
3698.06	0.003		15.99	1,602.08	2,177.13
4643.87	0.002		16.36	2,314.09	3,144.70
6324.33	0.001		16.85	3,810.28	5,177.93

Table 5: Sediment yield expressed in tabular form by percent exceedence.

Plotting the unadjusted predicted and the ‘smeared’ estimate of sediment yield creates a graph like **Figure 8**. The larger the smearing estimate, the greater the separation the two curves.

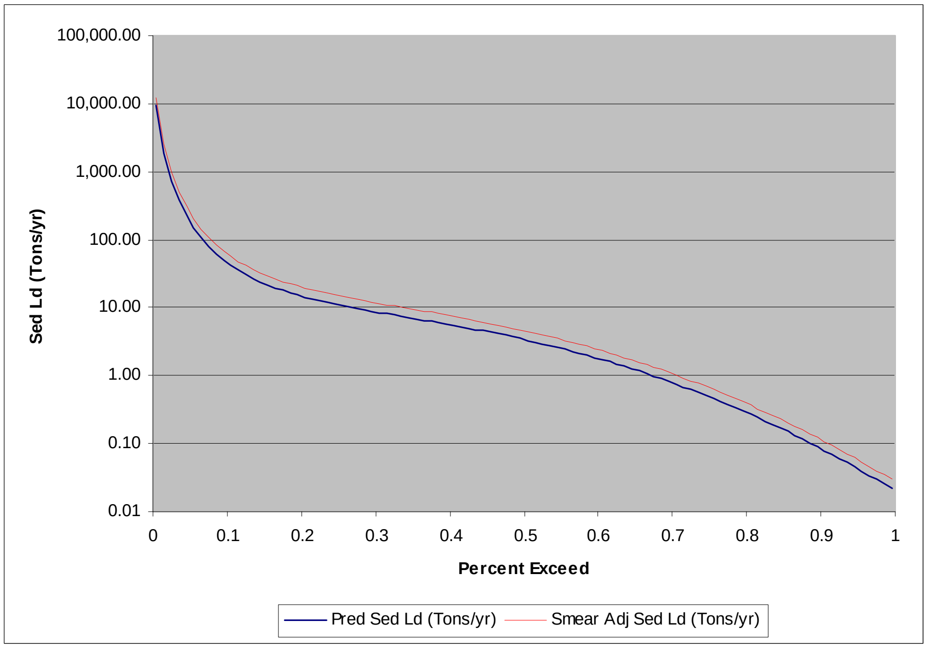


Figure 8: Predicted Cedar Creek sediment yield and the adjusted sediment yield using a smearing estimate of 1.36 as calculated from the residuals in Figure 9.

The area under the curve represents the estimate of the mean annual sediment load for the Cedar Creek watershed. A close approximation of that area is solved by Table 5. The change in percent exceedence (recall delta p in Table 5) from one row to the next is assigned as the width for 104 narrow columns. The height of each of those columns is the smeared sediment load estimate for each row in the table above. Height times width gives area. The sum of all 104 column areas approximates the area under the curve. The column area solution to integrating the area beneath the smeared load curve is conceptually shown below in **Figure 9**.

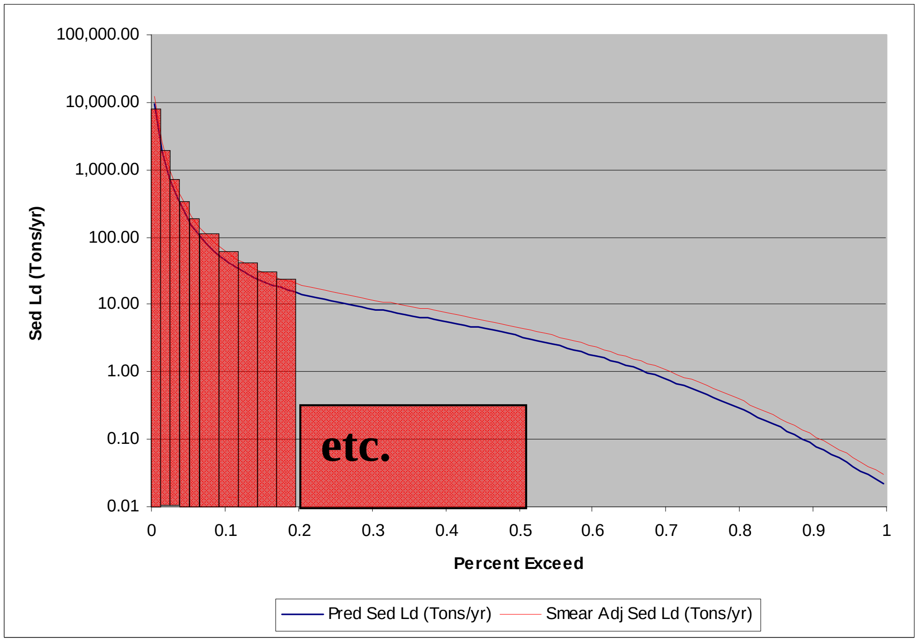


Figure 9: Conceptual representation of the column approximation method of calculating the area under a curve for sediment yield analyses.

If we sum all the unadjusted sediment loads (the second column from the right in the Table 5) we get 22,236 tons/year. If we do the same for the adjusted (smeared) sediment load the result is 30,217 tons/year (the smearing estimate was ~1.36 in this example).

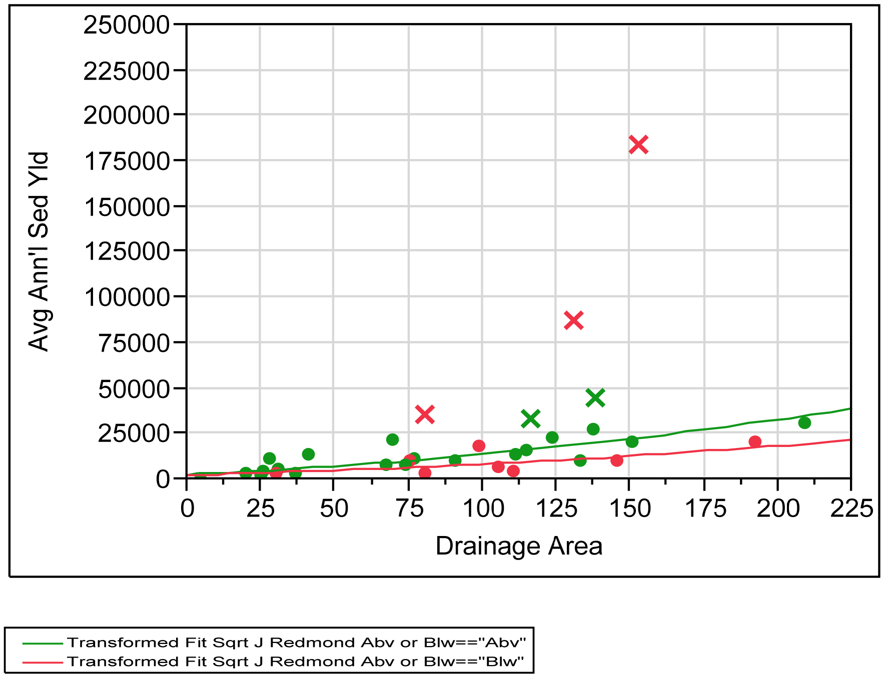
In most instances the flow in the stream on the day a KDHE TSS sample was collected at one of their monitoring locations was not known. That flow had to be estimated from a flow duration curve developed at a nearby USGS gage. The percent flow exceedence of the nearby gage was noted on the sample collection date on the gaged stream and matched on the flow duration curve developed from the USGS stream statistics on the ungaged stream. This method was used to estimate the flow on the stream of interest for the date TSS grab samples were collected by KDHE. The basis for this estimation is the assumption that if the flow at a nearby gaged stream is high (or low), the ungage stream's flow will also be proportionately high (or low). In truth, that assumption is occasionally inaccurate. This inconsistency in the assumption will also introduce some error to the estimate of mean annual sediment yields on ungaged stream segments, however, there is no bias in the assumption. The source of error should be smaller than other potential sources referenced in this report. As sample sizes increase, any bias in the similar flow exceedence assumption becomes smaller.

The method outlined above was performed at all forty-four KDHE monitoring sites on the main stem in the Neosho Basin and tributary sites that directly contributed to the Neosho River within Kansas. Due to a lack of long term information about the trapping efficiency of the federal reservoirs in the Neosho Basin, Marion, Council Grove and John Redmond were assigned a trapping efficiency of one hundred percent. Technically, sediment yields were not transported past these impoundments to downstream segments, however the Burlington gage just below Redmond which had USGS SSC data was used create a sediment yield estimate at that location.

Returning to Figure 1, note that not all tributaries to the Neosho main stem were monitored by the KDHE sampling network and there was seldom more than one monitoring site within a subwatershed on the tributaries that were monitored. A method of estimating sediment yields from unmonitored stream segments was developed based upon the sediments yields derived from the monitoring sites in the previous step. The result of this operation created estimates for annual sediment yields for every stream segment on the Kansas Surface Water Register in the Neosho Basin with direct contribution to the main stem within the state.

Two regression models were created to relate sediment yield from the monitoring stations along the Neosho River main stem using the contributing area (square miles) to those monitoring sites as a predictor (**Figure 10**). One regression model was for stations above John Redmond Reservoir (green markers and line in Figure 10) and the other was for stations below Redmond (red markers and line in Figure 10). A total of 33 monitoring sites had drainages of 250 square miles or less. Five sites, shown as 'x' markers below, were excluded from the generalized regression models due to excess sediment yields given their drainage areas. Initially the regression intercept was forced to zero but it was later determined that the specific yields within subwatersheds did not appreciably increase as the drainage areas declined for smaller streams in the subwatershed. This was contrary to a number of findings in textbooks and papers, so the intercept was left in the final generalized regression models.

Bivariate Fit of Avg Ann'l Sed Yld By Drainage Area



Transformed Fit Sqrt J Redmond ="Abv"

Sqrt(Avg Ann'l Sed Yld) = 52.346944 + 0.6466368*Drainage Area

Summary of Fit

RSquare	0.680391
RSquare Adj	0.662635
Root Mean Square Error	24.69427
Mean of Response	103.0045
Observations (or Sum Wgts)	20

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	23367.071	23367.1	38.3188
Error	18	10976.523	609.8	**Prob > F**
C. Total	19	34343.594		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	52.346944	9.872166	5.30	<.0001*
Drainage Area	0.6466368	0.104461	6.19	<.0001*

Transformed Fit Sqrt J Redmond ="Blw"

Sqrt(Avg Ann'l Sed Yld) = 48.935616 + 0.4327173*Drainage Area

Summary of Fit

RSquare	0.415451
RSquare Adj	0.318026
Root Mean Square Error	26.88356
Mean of Response	94.19243
Observations (or Sum Wgts)	8

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	3081.9329	3081.93	4.2643
Error	6	4336.3538	722.73	**Prob > F**
C. Total	7	7418.2867		0.0845

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	48.935616	23.88822	2.05	0.0864
Drainage Area	0.4327173	0.209546	2.07	0.0845

Figure 10: Generalized relation between sediment yield and drainage areas for site above and below John Redmond Reservoir.

In the case of the example of Cedar Creek, the calculated sediment yield for the stream segment upon which the KDHE monitoring site was located (recall 30,217 tons/year) was compared to the drainage area derived estimate from the area-derived generalized sediment yield equation for above Redmond sites in Figure 10 (19,863 tons/year for the 243.3 drainage area of Cedar Creek). The ratio of the two yields estimates (1.52) was used as a rescaling factor all the sediment yields derived from the area-based estimate from Figure 10 for the stream segments in the Cedar Creek watershed. A schematic of the stream system in the Cedar Creek watershed (Figure 11) was created to as a visual aid in help keep track of stream segments and the table of estimated yields (Figure 11 and Table 6, below).

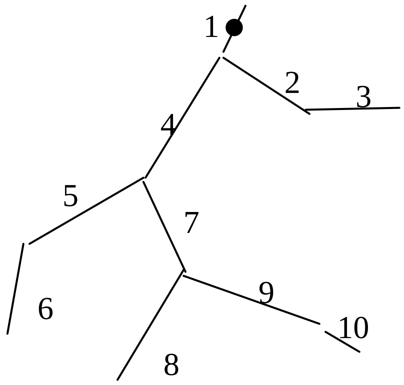


Figure 11: Schematic of registered surface waters (stream system) within the Cedar Creek watershed – segment numbers reference Table 6.

Segment #	Stream Name	Rescaled Sed Yld (T/yr)	Area-Based Rgrn Yld (T/yr)	Cumulative Area(Sq Mi)
1	Cedar Cr	30,217	19,863	137
2	Coon Cr	7,648	5,028	28.7
3	Coon Cr	6,054	3,979	16.6
4	Cedar Cr	20,530	13,495	98.7
5	Turkey Cr	6,782	4,458	22.3
6	Turkey Cr	4,882	3,209	6.65
7	Cedar Cr	13,662	8,981	65.6
8	Bills Cr	6,716	4,415	21.8
9	Cedar Cr	9,016	5,927	38.1
10	Cedar Cr	5,084	3,342	8.45

Table 6: Distributing sediment yield within a monitored watershed by use of drainage area.

The only exception to this method was for monitoring sites on the Cottonwood River and Neosho River. A number of small unmonitored tributaries feed direction into the Cottonwood and Neosho River between the monitoring sites on those main stems. Rather than use the rescaling factor on those tributaries, the area-based sediment yield regression was used without rescaling the predicted yield in that case. The segments on the main stems located above monitoring points on the main stems did use the rescaling factor method described above.

Cottonwood and Neosho River yields calculated from KDHE monitoring data on those main stems were recalibrated to match sediment yields estimated via USGS SSC data at gages with instantaneous flows. When possible, the change in yields from upstream to downstream KDHE monitoring data was preserved during its adjustment to USGS SSC derived yields but the yield magnitudes were generally increased during recalibration.

Results

This procedure outlined above was followed for all monitored watersheds in the Neosho River basin. The result is the sediment yield map shown below in Figure 12.

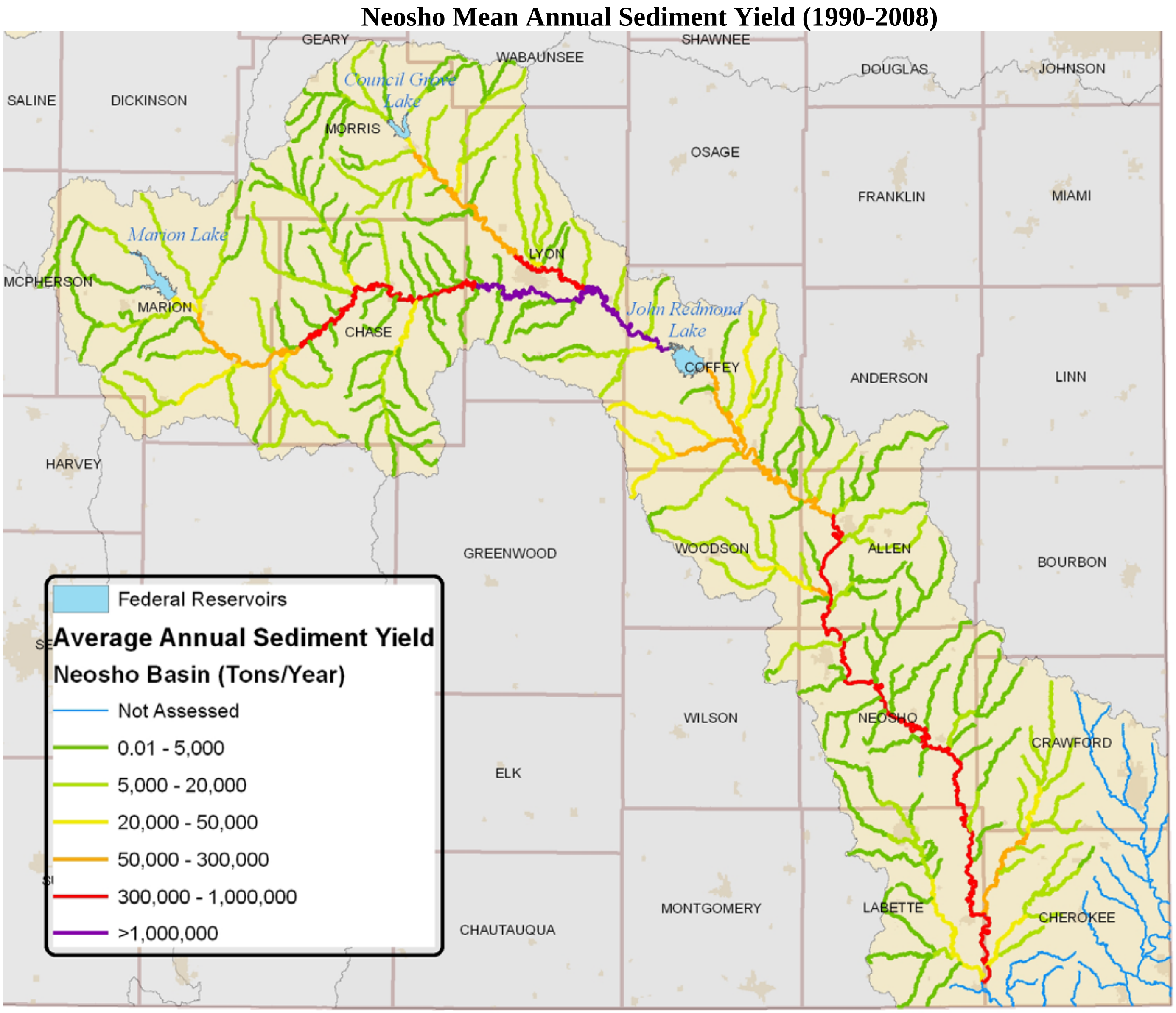


Figure 12: Estimated sediment yields for the Neosho River and directly contributing streams within Kansas on the Surface Water Register

Conclusions

Although sediment yields in some of the larger tributaries to Cottonwood and Neosho Rivers are relatively large, most of the sediment in the Neosho Basin appears to be generated from within the main stems of the Cottonwood and Neosho Rivers itself. The Big Creek subwatershed located south of John Redmond Reservoir and contributing its sediment load to the Neosho River down stream of Redmond has the largest sediment yield of all the tributaries assessed, yet its yield is only a 10^{th} of the sediment yield of the Neosho River at the point of its exit from the state. The largest sediment loading tributary above John Redmond on a yield per unit area basis is Doyle Creek, located south of Marion Reservoir. Unlike the land uses of most other major tributaries above Redmond which are grasslands, Doyle Creek's watershed is dominated by crop land.

Like the findings in USGS SIR 2008-5123 (Lee, 2008) the sediment yield of the Neosho River above John Redmond Reservoir is substantially greater than the yield below the reservoir indicating that Redmond remains efficient at trapping sediment from upstream sources. Given a reasonable estimate of bulk densities for sediments in John Redmond Reservoir (35-75 lbs/sq foot) the current estimate of the sedimentation rate of John Redmond is lower than would be anticipated given the size of the estimated sediment yield above the reservoir, but this is most likely because a large portion of the sediment is trapped by the substantial logjam located immediately above the reservoir (Lee, 2008).

Although every effort has been made to minimize the potential sources of error during the estimation of sediment yields in the Neosho Basin, the spatial coverage, frequency of sampling of sediment concentrations and the flow information associated with those samples has introduced many potential sources of error into the estimated yields. KDHE TSS data tended to under estimate sediment concentrations under higher flows when compared to USGS SSC concentrations. USGS stream statistics derived flow duration curves tended to over estimate the highest flows when compared to the average annual flow duration curves generated from instantaneous flows at USGS gaging stations. Relatively few high flow samples have been collected at KDHE rotational monitoring locations. Variation exists in the relation between sediment load and flows for each watershed. Since most of the sediment yield is generated under higher flow conditions, all of the above sources of potential error could substantially impact the estimate for sediment yields in any watershed.

The unmonitored tributaries in the Neosho Basin were assigned sediment yields based upon a relation between monitored tributaries and their drainage areas. However, there were certain tributaries with very high sediment yields that did not fit the generalized trend between yield and drainage area. There is no evidence on the unmonitored tributaries to show that they could not also have very large sediment yields (like those excluded from the generalized fit, Figure 10).

The estimated sediment yields in this report are suspended sediment estimates. The sediment yield from bed sources given the soil types (low in sand) in the Neosho Basin could be between 5 and 12% of the suspended sediment yield (Das, 2009).

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