Predictability of Annual Sediment Loads Based on Flood Events

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Abstract: Water resources managers always are searching for cost-effective monitoring programs that provide maximum information for minimum cost. Monitoring of sediment discharges from streams and rivers is one of the expensive efforts that is always reduced or cut when financial resources are limited. This has resulted in a very limited number of long-term sediment monitoring sites in the United States. Instead of long-term continuous monitoring programs, alternative monitoring approaches could potentially provide reliable estimates of sediment loads at reduced cost. One of those approaches is monitoring sediment loads during flood events and then using that information to estimate annual sediment loads. To test this approach, annual suspended sediment loads calculated based on continuous sediment monitoring were compared with the loads calculated based on monitoring the major floods only. Streams transport large percentages of the annual sediment loads from a watershed during a small number of floods that occur over relatively short time periods in a year. It was found that in Illinois, on average, the single highest, two highest, three highest, and four highest floods in a year transport 32, 49, 61, and 68% of the annual load, respectively. Consequently, the annual sediment loads were correlated highly with sediment transported during the highest floods. Thus, annual sediment loads can be predicted based on the sediment data during the highest floods. The predictions were tested on 27 small and medium streams in Illinois, for the period 1977–2000. The median error for predicting the annual load ranged from 42% for the single highest flood to 16% for the four highest floods. When resources are limited and the main purpose of the monitoring is estimation of annual sediment loads, a monitoring program based on flood events represents a more economical option.

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Introduction

Sediment loads/discharges of streams and rivers are monitored to estimate trends in erosion and sediment delivery rates from watersheds and the impacts on downstream lakes, reservoirs, wetlands, and river channels. This requires collecting water samples on a regular basis at streamgaging stations. Sediment gaging networks provide crucial data needed to establish an accurate sediment budget (Guo et al. 2002), provide flow and sediment data on small to medium size streams, identify and analyze major erosion sources (Prosser and Rustomji 2000), evaluate the impacts of best management practices on sediment loads, quantify basic hydrologic parameters for ungaged locations, and evaluate the effects of land-use changes and climate variations.

The existence of statistical relationships between the annual sediment load and the sediment load during a few floods could provide an alternative strategy for sediment load monitoring programs, as well as the procedures for calculating the annual sediment loads transported by streams (Demissie 1996; Öztürk et al. 2001). For example, the development of equations relating annual sediment load and the sediment load during the highest flood in 1 year could provide a simple procedure for estimating the annual sediment load based on the sediment load during the flood. Such a procedure could result in significant savings for agencies responsible for monitoring and evaluating watershed erosion, reservoir sedimentation, and conservation practices. It also could serve as an important tool in project design of reservoirs for which limited or no sediment data are available.

This research, an extension of the study performed by Demissie (1996), explores the predictability of annual load predictions based on monitoring during major storm events, ranging from one to four of the highest floods in a year. Data used in Demissie (1996) were collected primarily during a short time period (1978–1981). Much more data have been collected for various watersheds in Illinois since then, however. One purpose of this study was to determine the effects of more extensive data sets (1977–2000) on the results of the original study. Several other issues also were explored. First, correlations were computed between the suspended sediment loads during the major floods and total annual loads that were observed simultaneously at various locations during a single water year. In addition to this spatial averaging, a temporal averaging of the regression was described for the entire period of record available at a single location.

Sensitivity of the established regression lines was evaluated using the analysis of covariance (ANCOVA) (Snedecor and Cochran 1980) by comparing regressions based on earlier and later periods, as well as wet and dry periods to determine whether

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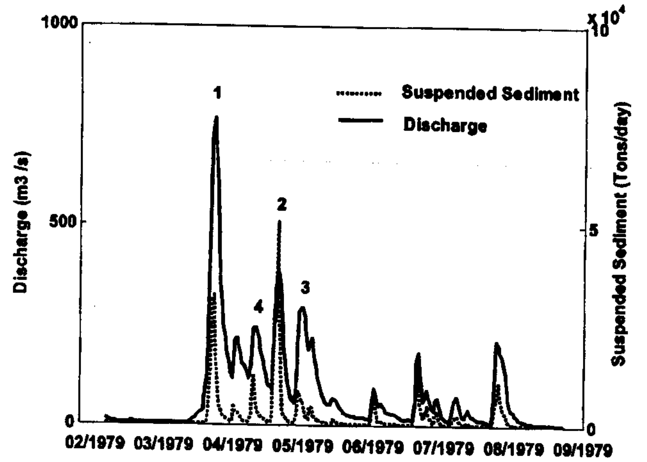

Fig. 1. Four highest flood peaks observed in Water Year 1979, Iroquois River near Chebanse, Ill.

or not the regression lines can be statistically regarded as the same.

The annual sediment load of a stream generally is determined either from direct measurements of the sediment load throughout the year (Steegen et al. 2000) or from any of the many sediment transport equations (Allen 1981; Vanoni 1984). The direct measurement of the sediment load in a stream is very expensive and thus is not done for as many streams as the measurement of water discharge. Most sediment transport equations require detailed information on the flow and sediment characteristics, and their results generally do not agree, making it difficult to choose the best equation for a given stream. Because of these problems, researchers and practitioners always are looking for simple and easy ways to use relationships between sediment load and water discharge or drainage area of the stream.

A stream transports large portions of the annual sediment load from a watershed during a small number of floods that occur over a relatively short time period in a year (Bhowmik et al. 1980; Demissie et al. 1983). For example, 4 years of data from four gaging stations in the Kankakee River basin in Illinois showed that 50% of the annual sediment load was transported over

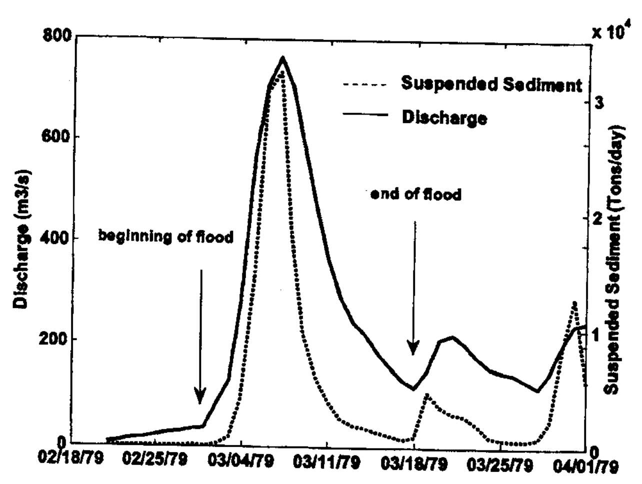

Fig. 2. Beginning and end of highest flood observed in Water Year 1979, Iroquois River near Chebanse, Ill.

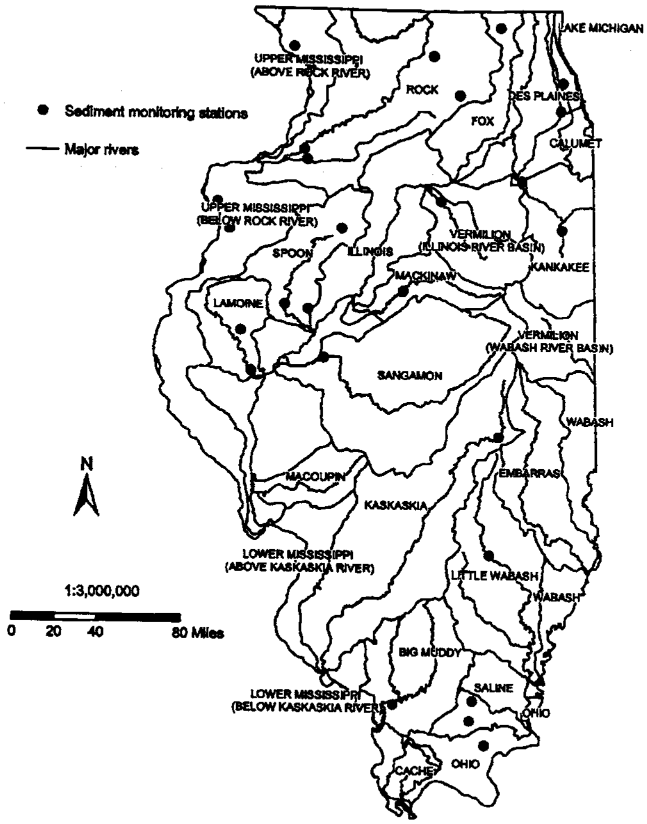

Fig. 3. Stations used in this study

4–53 days of the year (Demissie 1996). Other studies have shown that a large percentage of the annual sediment load is generated by a few storms every year. In a similar study, Wischmeier (1982) estimated that 75% of the soil loss from a small watershed was caused by an average of four storms per year. Piest (1963) analyzed data from 72 small watersheds in 17 states and concluded that 3–46% of the annual sediment load occurred during large storms, 3–22% during medium storms, and 34–92% during small storms. Storms were defined as follows: large storms (>2 year return period), medium storms (1–2 year return period), and small storms (<1 year return period). Dickinson et al. (1975) reported that about 50% of the annual sediment load for streams in southern Ontario, Canada, was transported in March and April. In the Atlantic region of the United States, Meade (1982) found that 85–90% of the annual sediment load was discharged in 10% of the time.

Methods

The annual (water year) hydrograph was examined to identify the highest, second highest, third highest, and fourth highest floods in any particular year, as shown in Fig. 1. The total sediment discharge during those floods was calculated by summing the daily sediment discharges during the flood periods (Fig. 2). Potential problems included the subjective definition of the beginning and end of the flood, as well as a subjective decision whether or not multiple peaks should be considered as multiple floods or just as one large flood. The uncertainty of the beginning and end dates resulted in insignificant error, as both dates are generally during low flows when the sediment transport is not significant. Multiple

Table 1. Twenty Seven Gaging Stations in Illinois Used in This Study

Station number	Station name	Drainage area (km^2)	Period of record
05419000	Apple River near Hanover, Ill.	632	1995–1997
05570370	Big Creek near Bryant, Ill.	105	1977–1987
05599500	Big Muddy River at Murphysboro, Ill.	5,553	1980–1997
03382170	Brushy Creek near Harco, Ill.	34	1980–1981
05532500	Des Plaines River at Riverside, Ill.	1,613	1979–1982
05466500	Edwards River near New Boston, Ill.	1,139	1979–1981
05447500	Green River near Geneseo, Ill.	2,568	1978–1981
05584685	Grindstone Creek near Birmingham, Ill.	116	1981
05469000	Henderson Creek near Oquawka, Ill.	1,106	1978–1981
05568800	Indian Creek near Wyoming, Ill.	161	1981
05526000	Iroquois River near Chebanse, Ill.	5,353	1979–1981; 1993–1996
05527500	Kankakee River near Wilmington, Ill.	13,184	1979–1982; 1993–1996
05591200	Kaskaskia River at Cooks Mills, Ill.	1,211	1979–1997
05440000	Kishwaukee River near Perryville, Ill.	2,813	1979–1981
05585000	La Moine River at Ripley, Ill.	3,310	1981; 1995–1997
03378900	Little Wabash River at Louisville, Ill.	1,907	1977–1981
03384450	Lusk Creek near Eddyville, Ill.	110	1980–1981
05567510	Mackinaw River below Congerville, Ill.	1,964	1983–1986
05548105	Nippersink Creek above Wonder Lake, Ill.	216	1994–1997; 1999–2001
05536000	North Branch Chicago River at Niles, Ill.	256	1985–1986
05420100	Plum River at Savanna, Ill.	699	1995–1997
05446500	Rock River near Joslin, Ill.	24,445	1980–1982; 1999
05583000	Sangamon River near Oakford, Ill.	13,038	1981; 1983–1986; 1995–1997
05439000	South Branch Kishwaukee River at Dekalb, Ill.	199	1980–1981
03382100	South Fork Saline River near Carrier Mills, Ill.	376	1980–1981
05570000	Spoon River at Seville, Ill.	4,188	1981; 1995–1997
05555300	Vermilion River near Leonore, Ill.	3,203	1980–1981

peaks were considered one storm if the discharge did not fall below one third of the larger peak in every two consecutive storms. As the number of multiple floods was much smaller than the number of single-peak floods, it was deemed appropriate to assume that different definitions of flood events in a multiple-peak situation would not significantly affect the general results of this study.

Annual sediment loads and loads during the highest floods have a high correlation, and thus annual sediment loads can be predicted based on the sediment loads during the floods. Such relations were developed for various periods and streams and also for one, two, three, and four major floods in any single year. The following equation describes the two loads

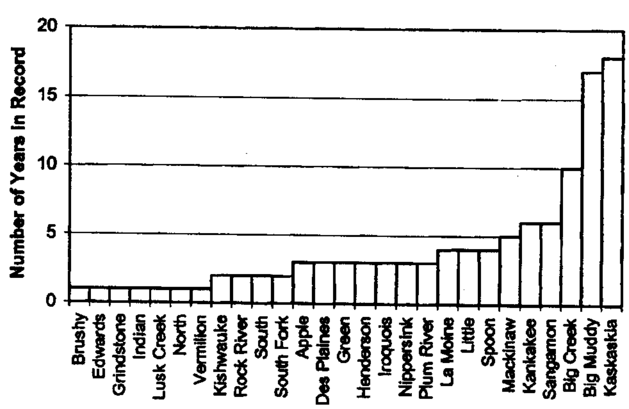

Fig. 4. Number of water years having complete daily records (discharge and suspended sediment loads) for each station within period of record (Harris et al. 2002)

$$\log(S_A) = a + b\,\log(S_N) \tag{1}$$

where a,b=regression parameters; S_N=sediment load during N highest floods (tons) (N=1, 2, 3, or 4); and S_A=annual sediment load (tons).

The ANCOVA compares the following regression lines to determine whether or not they can be statistically regarded as the same

$$Y_{1,j} = \alpha_1 + \beta_1 X_{1,j} + \varepsilon_{1,j} \tag{2}$$

and

$$Y_{2,j} = \alpha_2 + \beta_2 X_{2,j} + \varepsilon_{2,j} \tag{3}$$

Table 2. Contribution Percent of 1–4 Major Floods to Annual Suspended Sediment Loads

Parameter	One flood	Two floods	Three floods	Four floods
Maximum	73.39	88.99	93.68	94.09
Minimum	3.97	10.53	23.84	37.28
Average	32.13	49.45	60.77	68.50
SD	16.35	16.67	15.58	14.39

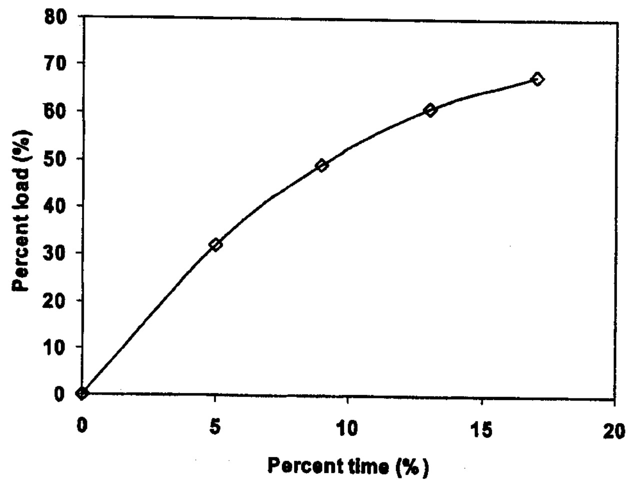

Fig. 5. Average percent time for one, two, three, and four floods in 1 year and corresponding percent load

In Eqs. (2) and (3), X=independent variable; Y=dependent variable; α and β=regression parameters; j represents a particular observation; and ε=residuals. The approach compares the residual variances, the slopes and the intercepts based on the F test. If any of the comparisons detects a statistically significant difference, the regression lines are regarded as different. For details, see Snedecor and Cochran (1980, pp. 385–388).

Data

Twenty seven gaging stations (Fig. 3) in Illinois for which complete daily discharge and suspended sediment data for at least one water year were available were used to develop the relationship between the sediment load during big floods and annual load. The data were collected by the U.S. Geological Survey (USGS) (Harris et al. 2002). The drainage area (Table 1) for the stations used in this analysis ranged from 34 to 24,445 km^2 and did not include the largest rivers, such as the Mississippi River and the Illinois River, or the streams with drainage area smaller than 25.6 km^2. The period of record used in this study was 1977–2000, with 110 records, having approximately 4 years of record per station (Fig. 4). The longest records were for the Kaskaskia River (18 years) and the Big Muddy River (17 years). On the other extreme, seven stations had only 1 year of record, and four stations had 2 years of record.

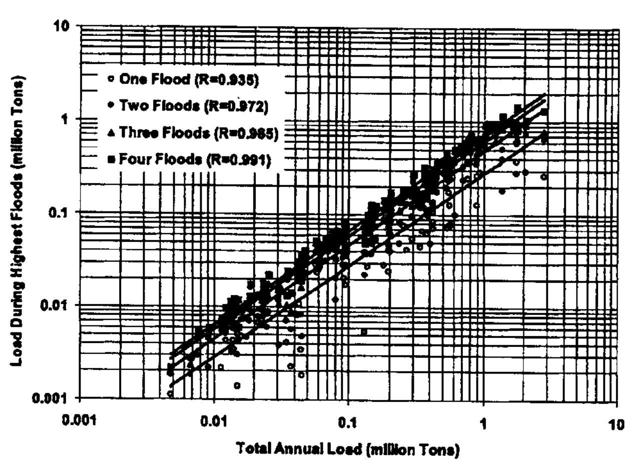

Fig. 6. Regression lines between suspended sediment loads during one and four highest floods and total annual loads for 27 available stations during 1977–2000 for Illinois streams

Table 3. Correlation Coefficient between Loads during Largest Floods and Annual Load (in Log Domain) for Various Data Periods

Period of record	Streams	Years	One flood	Two floods	Three floods	Four floods
1980	11	1	0.923	0.949	0.974	0.986
1981	22	1	0.936	0.979	0.985	0.990
1980–1981	22	2	0.920	0.968	0.980	0.989
1979–1982	22	4	0.933	0.973	0.983	0.990
1995–1997	10	3	0.972	0.988	0.994	0.996
1977–2000	27	22	0.935	0.972	0.985	0.991

Results

Total Data Set

This analysis used all the available data. It was found that, on average, the single highest flood in a year lasts about 17 days (5%) and carries approximately 32% of the annual sediment load with a standard deviation (SD) of 16%. The minimum contribution of the single highest flood was 4.0%, while the maximum contribution was 74%. Similarly, the two, three, and four highest floods in a year, on average, transport 49, 61, and 68% of the annual load, respectively (Table 2). The two, three, and four highest floods in a year on average last 33 days (9%), 47 days (13%), and 61 days (17%), respectively (Fig. 5). The minimum contribution of the four highest floods was 37%, and the maximum contribution was 94%. Generally, the flood duration was longer for larger watersheds. However, there were significant departures from this general trend. For example, the largest flood in 1981 lasted 31 days on the Kaskaskia River (1,211 km^2), and 26 days on the Rock River (24,445 km^2). The largest flood in 1997 lasted 17 days on the Kaskaskia River but only 9 days at the La Moine River (3,310 km^2).

The regression lines given by Eq. (1) between the sediment load during the highest annual floods and the annual sediment load for all the stations are shown (Fig. 6). As also shown in Table 3, there is a very good correlation, 0.935, between the load during the highest floods and the annual sediment loads. The standard error of regression for this prediction is 0.258 log cycles (Table 4, last row). The regression equation is

$$\log(S_A) = 0.5558 + 1.0007 \log(S_1) \tag{4}$$

Table 4. Standard Error for Annual Load Estimation Based on Loads during Largest Floods (in Log Domain) for Kaskaskia River, Big Muddy River, and for Entire Available Data Set in Illinois (1977–2000)

Dataset	Streams	Years	One flood	Two floods	Three floods	Four floods
Kaskaskia	1	18	0.249	0.187	0.087	0.076
Big Muddy	1	17	0.150	0.115	0.098	0.079
All stations (1977–2000)	27	22	0.258	0.166	0.119	0.094

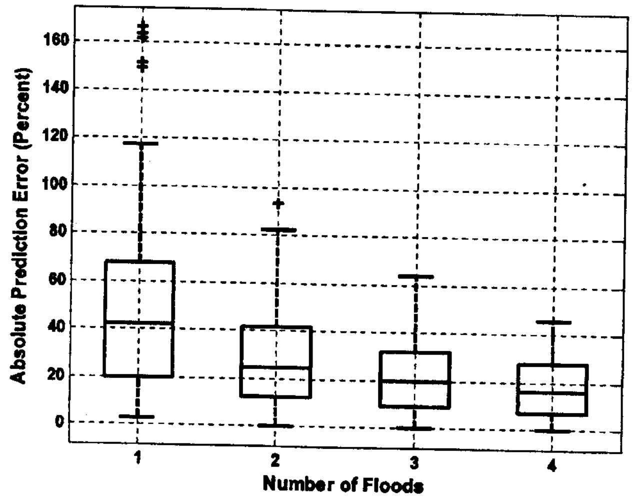

Fig. 7. Box-and-whisker plot of annual load prediction absolute error for one, two, three, and four highest floods, showing minimum, quartiles, and maximum

Similarly, for the four highest floods, the equation is

$$\log(S_A) = 0.2881 + 0.9770\log(S_4) \tag{5}$$

The correlation coefficient between the sediment load during the four highest floods and the annual load is 0.991, and the standard error is 0.094 log cycles.

To better understand the meaning of the log cycles, the results in the log scale were back-transformed to a linear scale. The distribution of prediction errors for one, two, three, and four highest floods is presented (Fig. 7). The median prediction error was equal to 41.7% for the single highest flood, 24.5% for the two highest floods, 19.5% for the three highest floods, and 16.0% for the four highest floods. The mean error was equal to 54.6% for the single highest flood, 29.2% for the two highest floods, 23.9% for the three highest floods, and 17.9% for the four highest floods.

Relations for Different Time Periods

The same calculations for different time periods were performed to examine the sensitivity of the results. Table 5 shows the standard error of prediction for 1980, 1981, 1980–1981, 1979–1982, 1995–1997, and the entire period of record, 1977–2000. The periods were selected to separate times with more monitoring data, such as 1995–1997 and 1979–1982. In addition, the years 1980 and 1981, separately and jointly, as used in Demissie (1996), were also used as periods for the calculation of regression lines. Standard errors for the single highest flood range from 0.159 log cycles, for the period of 1995–1997, to 0.301 log cycles, for the period of 1980–1981. Standard errors steadily decrease with the increased number of floods per year. Standard errors for the four highest floods in a year range from 0.060 log cycles, for the period 1995–1997 to 0.111 log cycles for the period 1980–1981. Table 3 shows the correlation coefficient (R) for the same periods, which ranges from 0.920 for the single highest flood, for the period 1980–1981, to 0.972 for the period 1995–1997. Correlation coefficients steadily increase with the increased number of floods per year. The correlation coefficient for the four highest floods in a year ranges from 0.986 for 1980 to 0.996 for 1995–1997.

Results for the various periods, as well as the results for the entire data range were fairly similar, except for the period 1995–1997, which had more accurate predictions, smaller standard error and higher correlation. On the other hand, the predictions for the year 1980 seem slightly less accurate than others.

Table 5. Standard Error for Annual Load Estimation Based on Loads during Largest Floods (in Log Domain) for Various Data Periods

Period of record	Streams	Years	One flood	Two floods	Three floods	Four floods
1980	11	1	0.258	0.207	0.145	0.107
1981	22	1	0.274	0.151	0.128	0.102
1980–1981	22	2	0.301	0.186	0.143	0.111
1979–1982	22	4	0.274	0.167	0.131	0.100
1995–1997	10	3	0.159	0.101	0.074	0.060
1977–2000	27	22	0.258	0.166	0.119	0.094

Table 6. Correlation Coefficient Between Loads During Largest Floods and Annual Load (in Log Domain) for Kaskaskia River, Big Muddy River, and for Entire Available Data Set in Illinois (1977–2000)

Dataset	Streams	Years	One flood	Two floods	Three floods	Four floods
Kaskaskia	1	18	0.728	0.816	0.950	0.961
Big Muddy	1	17	0.764	0.839	0.875	0.913
All stations (1977–2000)	27	22	0.935	0.972	0.985	0.991

Table 7. Average Water Year Precipitation (cm) in Illinois (Source: Personal communication with James Angel, Illinois State Water Survey, Champaign, Ill.)

Water year	Average precipitation (cm)	Rank (1896–2002)	Wet/Average/Dry
1977	93.35	67	A
1978	93.17	69	A
1979	101.14	38	A
1980	90.60	77	D
1981	103.51	29	W
1982	99.09	42	A
1983	106.43	22	W
1984	107.80	19	W
1985	109.83	14	W
1986	112.29	12	W
1987	83.82	89	D
1988	75.01	103	D
1989	98.55	43	A
1990	102.51	32	W
1991	97.38	50	A
1992	93.47	65	A
1993	135.81	1	W
1994	86.64	84	D
1995	105.61	24	W
1996	97.99	46	A
1997	91.62	74	D
1998	108.23	17	W
1999	98.45	45	A
2000	95.45	58	A

Source: Midwestern Regional Climate Center, Champaign, Ill.

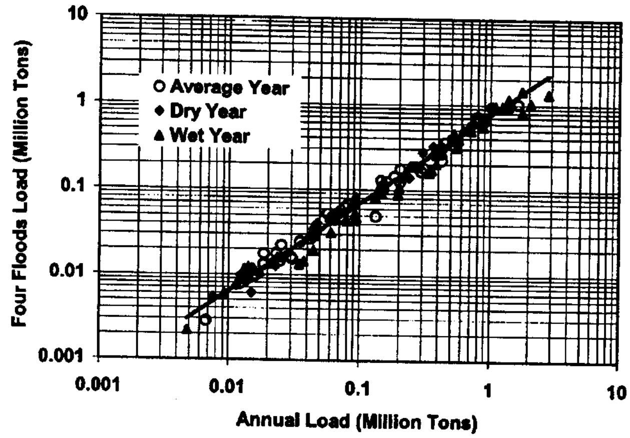

Fig. 8. Regression lines between suspended sediment loads during four highest floods and total annual loads for dry and wet water years and average years

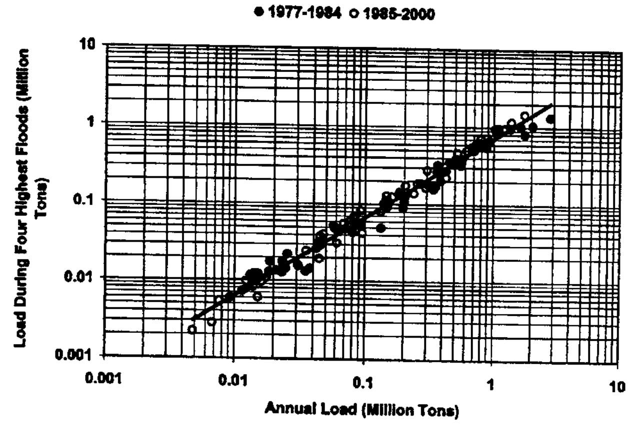

Fig. 9. Regression lines between suspended sediment loads during four highest floods and total annual loads for periods of 1977–1984 and 1985–2000

Relations for Different Locations

The results for the Kaskaskia River and the Big Muddy River, the watersheds with the longest records, were computed separately. Regressions for single sites having a long record were compared with regressions for lumped data for all stations and years of observation, and the standard errors of prediction are presented in Table 4. The Big Muddy River had relatively smaller standard errors than other two cases for the one and two highest floods. Similarly, the Kaskaskia River had relatively smaller standard errors than other two cases for the three and four highest floods. Correlation coefficients for the three regressions are presented in Table 6. In all cases, site-specific regressions had a lower correlation coefficient, than the lumped regression. Larger ranges of lumped data compared to the site-specific data contributed to the higher correlations of the lumped model.

ANCOVA

A sensitivity analysis was performed to test separately dry, average, and wet water years. The list of water years between 1977 and 2000 along with the statewide rainfall amounts and their ranks is presented in Table 7. The years also were categorized based on their rank in the series for the period 1896–2002. Years ranking in the upper third were denoted as wet years (W), the middle third represented average (A), and those in the bottom third were denoted as dry years (D). The separate regression lines between loads during four major floods and annual loads, for the wet and dry years are shown in Fig. 8, as are the average years. ANCOVA for four major floods demonstrated that the change in slope between wet and dry years ($F=6.486$) was significant for $\alpha=0.05$, and for $\alpha=0.025$, but insignificant for $\alpha=0.01$. More importantly, none of the separate regression lines for wet, dry, or average years had statistically different parameters than the regression line for all the periods lumped.

The change in slope between the period of 1977–1984, containing the first half of the available station years, and the remaining period of 1985–2000 was also significant for $\alpha=0.05$, but not significant for $\alpha=0.025$ and $\alpha=0.01$ (Fig. 9). In both analyses wet/dry and earlier/later, the changes in the residual variance and intercept were not significant. When compared with the lumped regression (1977–2000), both regression lines for earlier and later periods did not exhibit statistically different parameters.

The difference between the earlier and later periods could potentially indicate long-term shifts or trends in the regression coefficients. However, the earlier years of this record (1977–1984) were much wetter than the remaining years (1985–2000), as shown in Fig. 10. The effects of dry and wet years can be masked by the earlier and later periods.

Although both wet–dry and earlier–later analyses offer a path towards refinement of the lumped regressions, the improvement in the accuracy was not significant. For example, the correlation coefficient between the annual loads and loads during four major floods for the lumped model ($R=0.991$) was very similar with the correlation coefficients for the dry ($R=0.989$) and wet ($R=0.990$) periods, and also comparable with the correlations for different observation periods, 1977–1984 ($R=0.991$) and 1985–2000 ($R=0.993$).

Practical Aspects of Proposed Approach

On the basis of this study, sediment monitoring programs can be designed to monitor sediment loads primarily during flood events. Annual loads can be calculated using regression equations developed based on detailed monitoring data, such as those presented in this study.

A monitoring "trigger" level for each monitoring station would be defined using the past records, or a duration curve (Fig. 11).

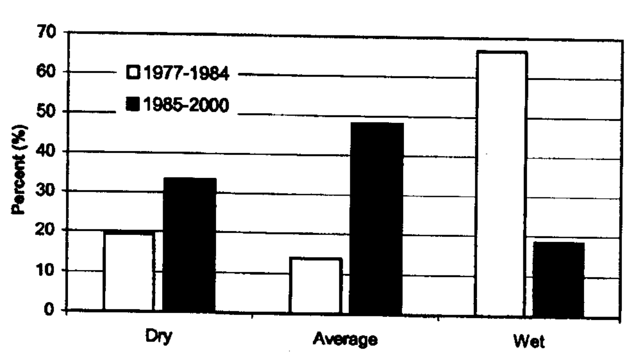

Fig. 10. Percentage of dry, average, and wet years for each station year 1977–1984 and 1985–2000 for each station year

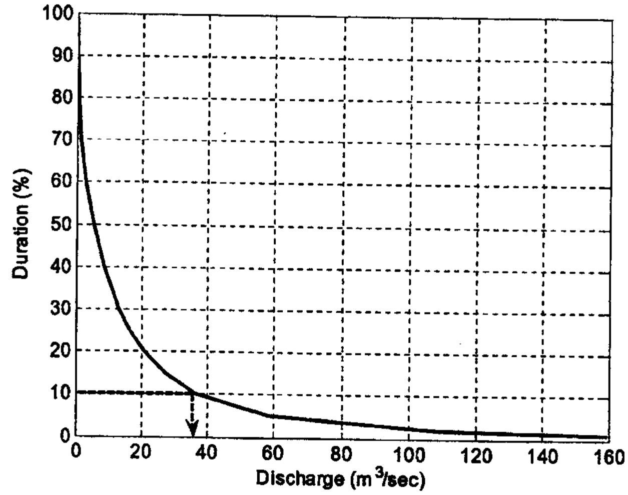

Fig. 11. Example of discharge duration curve for Mackinaw River near Congerville, USGS station number 05567500, showing discharge corresponding to 10% duration (36.6 m^3/s)

The monitoring trigger could be the average flow or the 5% exceedance probability flow. Data then would be collected only during the flood events, with flows exceeding the trigger level. If the number of floods in a year was less than four, an appropriate regression would be based on three floods, or less. If the number of floods was greater than four, then the highest four would be used for annual load estimation. Similar regression lines also can be developed for five or more highest floods. However the incremental benefit in improving the annual load estimate for including the fifth highest flood does not appear significant. The correlation coefficients between annual suspended sediment loads and the loads during the four and five highest floods are $R=0.991$ and $R=0.993$, respectively. The gain in correlation coefficient is 0.002, which is smaller than the gain between three and four floods (0.006), the gain between two and three floods (0.013), or the gain between one and two floods (0.037).

To examine the number of expected flood events for various trigger levels, and the influence of watershed size of the contribution of floods to the annual sediment load calculation, an analysis of the number of floods per year for various watershed sizes was performed. Fig. 12 shows the number of floods per year

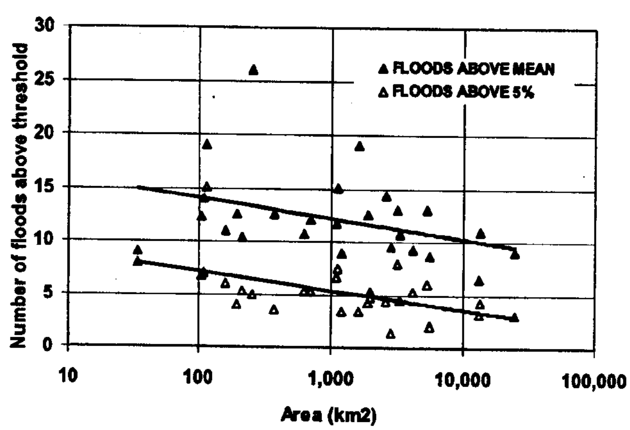

Fig. 12. Average number of peaks per year above mean and above 5% exceedance probability

exceeding two arbitrarily chosen trigger levels (mean flow and the flow with 5% exceedance probability) as a function of watershed size. It appears that the mean and the 5% exceedance probability thresholds are more frequently exceeded on small streams than on the large rivers. It also appears that this trend is more pronounced with the 5% exceedance threshold, and less significant with the threshold equal to the mean discharge. None of the suspected trends could be easily statistically quantified, because of the data heterogeneity. Each point in Fig. 12 represents a different time period and different record length, ranging from 1 to more than 15 years. Although this figure might suggest that the results of this study could be refined by developing different relations for different watershed size classes, for the purpose of this study, the results were lumped for all available watershed sizes. More homogeneous data sets collected in the future will permit more meaningful scale analyses.

The results presented in Fig. 12 also show that in Illinois up to 12 flood events per year might be monitored if the sampling trigger is set at the mean flow level and up to five events if the trigger is set at the 5% exceedance level. The number of events that need to be sampled, however, may decrease as the drainage area increases.

In summary, the relations developed in this study can be used for estimating, with uncertainty bounds, annual sediment loads based on sediment loads during the flood events. A monitoring program based on the approach proposed here will result in an accurate estimate of the annual sediment load at a much reduced cost.

Summary and Conclusions

Most of the annual suspended sediment load is transported during a few floods in a year. The annual load can be predicted using the load observed during largest storms. In Illinois streams, on average, the single highest flood, two highest floods, three highest floods, and four highest floods in a year, transport 32, 49, 61, and 68% of the annual load, respectively. The median absolute prediction error ranged from 41.7% for the single highest flood to 16.0% for the four highest floods. The mean prediction error ranged from 54.6% for the single highest flood to 17.9% for the four highest floods. Equations calculating the annual load based on loads during the highest floods can provide guidelines for sediment monitoring programs and also a simple procedure for estimating annual sediment loads.

Suspended sediment data for 27 stations in Illinois operated between 1977 and 2000 were used to assess the spatial and temporal variability of relationships between annual loads and loads during major floods. The results were validated using the correlation coefficient and standard error of estimate. The relationships for various spatial and temporal data subsets were compared with the lumped relations for the entire data set to demonstrate the sensitivity of the results. The lumped regression, for the period 1977–2000, performed similarly with other regressions for different periods. Site-specific regressions had a smaller standard error of prediction than the lumped regression. This may indicate that different regions have different regression equations, particularly the regions with significant land-use changes and/or climatic variability. However, to refine the lumped results of this study, more complete datasets would be required.

Using ANCOVA to compare the regression lines based on earlier and later periods, as well as wet and dry periods, did not provide sufficient evidence for the regression lines to be statistically regarded as different.

A monitoring program with a targeted sampling during flood events could potentially provide an accurate estimate of annual sediment loads of streams at reasonable cost. As a result, it may be possible to expand sediment monitoring programs to include a larger number of monitoring stations for the same level of funding that is used for intensive sampling of a small number of stations.

These conclusions also may be applicable to similar geographic regions, primarily in the Midwestern United States. Similar studies also should be conducted to examine the regressions for river basins of various sizes in other geographic regions.

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References

Allen, P. B. (1981). "Measurement and prediction of erosion and sediment yield." *Agricultural reviews and manuals*, Vol. S-15, USDA, New Orleans.

Bhowmik, N. G., Bonini, A. P., Bogner, W. C., and Byrene, R. P. (1980). "Hydraulics of flow and sediment transport in the Kankakee River in Illinois." *Rep. of Investigation No. 98*, Illinois State Water Survey, Champaign, Ill.

Demissie, M. (1996). "Sediment load during flood events for Illinois streams." *Water Int.*, 21, 131–137.

Demissie, M., Bhowmik, N. G., and Adams, J. R. (1983). "Hydrology, hydraulics and sediment transport, Kankakee and Iroquois Rivers." *Rep. of Investigation 103*, Illinois State Water Survey, Champaign, Ill.

Dickinson, W. T., Scott, A., and Wall, G. (1975). "Fluvial sedimentation in Southern Ontario." *Can. J. Earth Sci.*, 12(11), 1813–1819.

Guo, Y., Markus, M., and Demissie, M. (2002). "Uncertainty of nitrate-N load computations for agricultural watersheds." *Water Resour. Res.*, 38(10), 3-1-3-12.

Harris, M. L., Draper, P. J., and Schrader, D. L. (2002). "Water resources data, Illinois, water year 2001." *U.S. Geological Survey Water-Data Rep. No. IL-01*, Illinois District, Urbana, Ill.

Meade, R. H. (1982). "Sources, sinks, and storage of river sediment in the Atlantic drainage of the United States." *J. Geol.*, 90(3), 235–252.

Piest, R. F. (1965). "The role of the large storm as a sediment contributor." *Proc., 1963 Conf. of the Federal Inter-Agency Sediment*, Jackson, Miss., USDA Misc. Publ. 970,98–108.

Prosser, I. P., and Rustomji, P. (2000). "Sediment transport capacity relations for overland flow." *Prog. Phys. Geogr.*, 24(2), 179–193.

Snedecor, G. W., and Cochran, W. G. (1980). *Statistical methods*, 7th ed., The Iowa State University Press, Ames, Iowa.

Steegen, A., Govers, G., Nachtergaele, J., Takken, I., Beuselinck, L., and Poesen, J. (2000). "Sediment export by water from an agricultural catchment in the loam belt of central Belgium." *Geomorphology*, 33, 25–36.

Vanoni, V. A. (1984). "Fifty years of sedimentation." *J. Hydraul. Eng.*, 110(8), 1022–1057.

Wischmeier, W. H. (1982). "Storms and soil conservation." *J. Soil Water Conservat.*, 17, 55–59.

Öztürk, F., Apaydin, H., and Walling, D. E. (2001). "Suspended sediment loads through flood events for streams of Sakarya River Basin." *Turk. J. Eng. Environ. Sci.*, 25, 643–650.