DIFFERENT CHARACTERISTICS OF SUSPENDED SEDIMENT TRANSPORT IN DRY AND WET YEARS REVISITED

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Abstract Sediment yield is defined as the total volume of sediment that leaves a drainage basin in a given time period (usually a year). Many factors, including the size and texture of the erodible material, climate, land use, local environment, and physiographic position, affect the sediment yield. Based on data collected from streams, the sediment load transported in a stream during a period of dry climate is different from that during a period of wet climate. This means that the climate might play an important role in the sediment transport process. A case study was conducted on the Skunk River at Augusta, Iowa, with daily water discharge data of 94 years and daily sediment load data of 33 years. The purpose of this study is to investigate effects of the climate on the suspended sediment transport and to explore the difference of the suspended sediment transport in dry years and wet years.

INTRODUCTION

Sediment yield is defined as the total volume of sediment that leaves a drainage basin in a given time period (usually a year). The coarse sediment is transported by streams as the bed load, and the fine sediment is transported as the suspended load. Many factors, such as the size and texture of the erodible material, climate, land use, local environment, and physiographic position, affect the sediment yield.

Based on data collected from streams, the sediment load transported in a stream during a period of dry climate is different from that during a period of wet climate. This is because that the soil moisture and soil structure on the surface are different under the dry or wet condition. This is also because the number, intensity, and duration of precipitations are different during the dry or wet climate. For the dry climate, dry soils with little or no vegetation cover are highly erodible and consequently the sediment load might increase. For the wet climate, sediment load is more related to the variations of precipitation. The wetter the weather, the more the sediment transported. The heavy precipitations generally erode higher amount of soil from the land surface and consequently the sediment load might increase. These indicate that the climate might play an important role in the sediment transport process.

Spreafico and Lehmann (1994) observed suspended sediment transport in Switzerland. They concluded that the annual and long time variations of sediment transport depend on climate. During summer which is relatively wet, high water discharges occur, and a large amount of suspended sediment is transported.

Yu and Neil (1994) examined 20 streamgauging stations in the Snowy Mountains region, Australia, and evaluated the temporal and spatial variation of sediment yield. They stated that the sediment concentration is generally higher in wet summer than in dry winter.

Zhou and Xiang (1994) investigated sediment transport in the Yangtze River basin, China, and concluded that the distribution of suspended sediment concentration throughout one year is closely related to the variations of precipitation. The more the precipitation, the wetter the weather, then the more the sediment transported.

Lawler and Wright (1996) studied impacts of the climate change on the sediment yield in southern Iceland and found that the decline of suspended sediment yield is closely related with the climate change.

Currently, many studies indicated that the climate change has a greater impact on the sediment load, such as Cobon et al. (2007) for the Nogoa River basin, Australia, and Kettner et al. (2008) for the Waipaoa River basin, New Zealand.

This paper addresses two issues: the first is an investigation of the effects of the climate on the suspended sediment transport using daily water discharge and daily sediment load data collected from the Skunk River at Augusta, Iowa. The second is an exploration of the difference of the suspended sediment transport in dry years and wet years.

DATA SELECTION

One gage station, USGS 05474000 Skunk River at Augusta, Iowa, with a drainage area of 4,312 mi^2, was used in this study. The area map around this gage is shown in Figure 1.

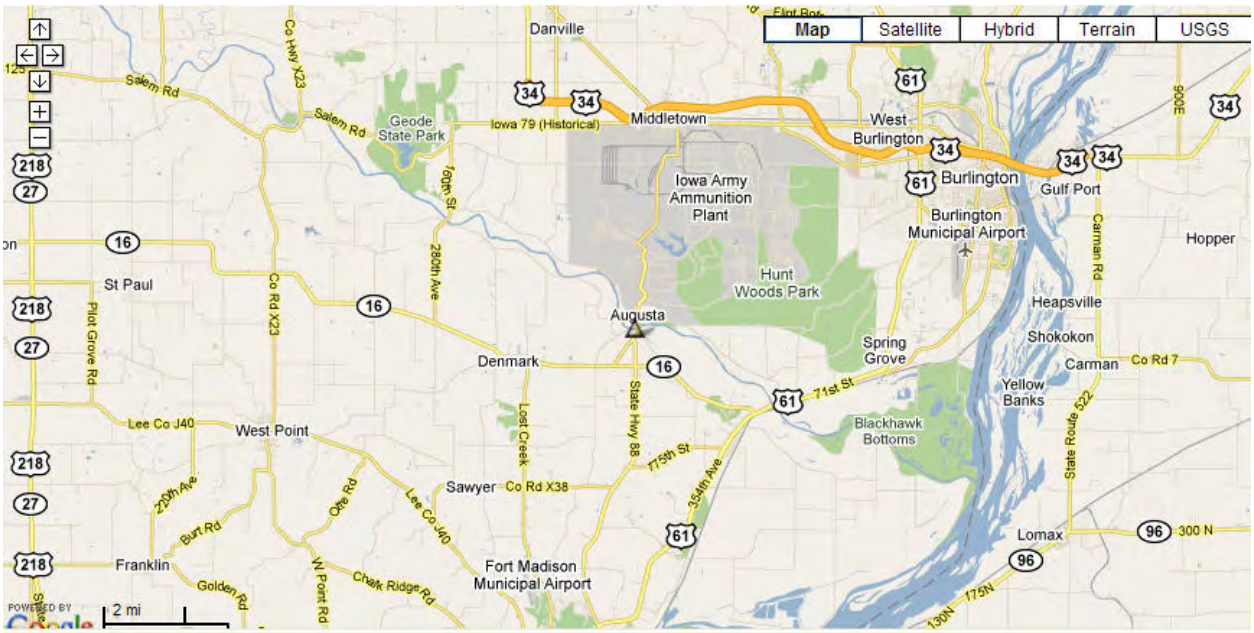

Figure 1 Area Map for USGS 05474000 Skunk River at Augusta.

The Skunk River flows into the Mississippi River about five miles south of the city of Burlington, Iowa. The reason selecting this station is that it provides a long period of records for the water discharge and for the suspended sediment load.

The Skunk River at Augusta has provided the daily water discharge data since October 1, 1914 and the daily suspended sediment load data since October 1, 1975. Based on the records of the water discharge and sediment load, the mean annual water discharge Q_{MW} and the mean annual suspended sediment load Q_{MS} for the station were calculated and shown in Table 1.

Table 1 Mean Annual Water Discharge and Suspended Sediment Load.

Station name	Record of daily discharge (year)	Mean annual discharge, Q_{MW} (cfs)	Record of daily sediment load (year)	Mean annual sediment load, Q_{MS} (tons)
Skunk River at Augusta	79	934,338	18	2,734,541
	94	953,276	33	2,531,169
Change (%)		2.03		-7.44

The author did an analysis in 1993 for the mean annual water discharge Q_{MW} and the mean annual sediment load Q_{MS}. Comparing the average of 79 years with the average of 94 years for Q_{MW} shows an increase of 2.03 %. Comparing the average of 18 years with the average of 33 years for Q_{MS} shows a decrease of 7.44 %. This indicates that the analysis result is changed with the study period investigated.

ANALYSIS OF SUSPENDED SEDIMENT TRANSPORT IN DRY OR WET YEAR

In this study, a water year with its annual water discharge less (or more) than the long-term mean annual water discharge Q_{MW} is considered as a dry (or wet) year. Thus, comparing the annual water discharge of a certain year with the mean annual water discharge Q_{MW}, one can easily identify this year as dry or wet. Different types of water year for the Skunk River from 1976 to 2008 are shown in Table 2.

In Table 2 Q_W and Q_S represent the annual water discharge and the annual suspended sediment load, respectively, and $(Q_W - Q_{MW})/Q_{MW}$ is used as a parameter to identify the type of the water year. If $(Q_W - Q_{MW})/Q_{MW}$ is positive, the water year is wet. In contrast, if $(Q_W - Q_{MW})/Q_{MW}$ is negative, the water year is dry. In addition, $(Q_W - Q_{MW})/Q_{MW}$ can be used to judge that the dry (or wet) water year is how dry (or wet). For example, $(Q_W - Q_{MW})/Q_{MW}$ for 2006 is equal to -59.9 and $(Q_W - Q_{MW})/Q_{MW}$ for 2004 is equal to -4.4. This means that the water year 2006 is dryer than the water year 2004.

A ratio of Q_S/Q_W is introduced as a parameter to express how many tons of sediment is delivered by one cubic feet per second of water discharge. The higher the ratio, the more the suspended sediment transported by the flow. This ratio of Q_S/Q_W can be used to compare the sediment transport among different years. Table 2 shows the ratio of Q_S/Q_W during water years from 1976 to 2008 for the river basin investigated.

Table 2 Comparison of Suspended Sediment Transport between Dry and Wet Years.

water year	*Skunk River at Augusta*					
	Annual Q_W (cfs)	$\frac{Q_w - Q_{Mw}}{Q_{Mw}}$ (%)	*type of water year	Annual Q_S (tons)	Ratio of Q_S/Q_W dry year	wet year
1976	823,264	-13.6	d	3,048,733	3.7	
1977	242,901	-74.5	d	481,186	2.0	
1978	1,359,392	42.6	w	5,354,167		3.9
1979	1,467,150	53.9	w	3,290,788		2.2
1980	585,105	-38.6	d	2,056,738	3.5	
1981	528,249	-44.6	d	2,647,534	5.0	
1982	1,594,128	67.2	w	5,071,197		3.2
1983	1,657,911	73.9	w	3,034,885		1.8
1984	1,782,499	87.0	w	3,820,230		2.1
1985	842,858	-11.6	d	2,299,042	2.7	
1986	1,454,601	52.6	w	3,817,846		2.6
1987	1,201,780	26.1	w	1,668,825		1.4
1988	413,839	-56.6	d	244,765	0.6	
1989	172,908	-81.9	d	426,737	2.5	
1990	1,349,728	41.6	w	3,103,668		2.3
1991	1,107,359	16.2	w	2,152,097		1.9
1992	1,110,817	16.5	w	2,168,690		2.0
1993	3,722,602	290.5	w	4,534,610		1.2
1994	707,709	-25.8	d	629,884	0.9	
1995	1,139,937	19.6	w	3,316,846		2.9
1996	1,017,622	6.7	w	4,237,564		4.2
1997	719,734	-24.5	d	2,396,951	3.3	
1998	1,790,723	87.8	w	5,365,424		3.0
1999	1,322,371	38.7	w	2,741,452		2.1
2000	407,351	-57.3	d	786,636	1.9	
2001	1,361,287	42.8	w	3,271,798		2.4
2002	675,106	-29.2	d	1,709,570	2.5	
2003	448,710	-52.9	d	866,243	1.9	
2004	911,638	-4.4	d	1,743,596	1.9	
2005	730,868	-23.3	d	1,022,766	1.4	
2006	381,802	-59.9	d	489,360	1.3	
2007	1,614,965	69.4	w	2,518,237		1.6
2008	2,565,398	169.1	w	3,210,499		1.3
Average of 18 years (1976 – 1993)					2.86	2.24
Average of 33 years (1976 – 2008)					2.34	2.34

* d = dry water year and w = wet water year.

Table 2 shows that the water year 1989 was the driest year with $(Q_W - Q_{MW})/Q_{MW}$ equal to -81.9 and the water year 1993 was the wettest year with $(Q_W - Q_{MW})/Q_{MW}$ equal to 290.5 for the Skunk River at Augusta during the time period investigated.

Table 2 shows that in general, for continuous dry years such as 2002 – 2006, the ratio of Q_S/Q_W is decreased while for continuous wet years such as 1982 – 1984 and 1990 – 1993, the ratio of Q_S/Q_W is also decreased. The first dry (or wet) year in the dry (or wet) year series has a largest ratio. This means that more suspended sediment is transported in the first dry (or wet) year, then less sediment is transported in the following dry (or wet) years.

Table 2 also shows some exceptions such as for dry year series of 1980 – 1981 or 1988 – 1989 and for wet year series of 1995 – 1996, the ratio of Q_S/Q_W is increased, i.e., the ratio of Q_S/Q_W for the second dry (or wet) year is greater that that for the first dry (or wet) year.

From Table 2, it is demonstrated that characteristics of suspended sediment transport in dry years are different from that in wet years, i.e., the climate has some effects on the suspended sediment transport process.

In Table 2, the last two rows show that during the period of 18 years from 1976 to 1993, the averaged ratio of Q_S/Q_W for the total of 7 dry years is 2.86 higher than the averaged ratio of Q_S/Q_W equal to 2.24 for the total of 11 wet years. It was concluded that the suspended sediment transported in dry years was higher than that in wet years. This indicates that the river flow carries more sediment in dry years than in wet years.

However, using the period of 33 years from 1976 to 2008, the averaged ratio of Q_S/Q_W for the total of 15 dry years is 2.34 same as the averaged ratio of Q_S/Q_W for the total of 18 wet years. It was concluded that the suspended sediment transported in dry years was same as that in wet years. This conclusion indicates that the analysis result could be changed based on the study period of investigation.

ANALYSIS OF SUSPENDED SEDIMENT TRANSPORT RATIO

The last two columns in the Table 2 were reorganized based on the order of the magnitude of $(Q_W - Q_{MW})/Q_{MW}$, and shown in Table 3.

Table 3 shows that the wettest year is 1993 with $(Q_W - Q_{MW})/Q_{MW}$ equal to 290.5, but the ratio of Q_S/Q_W is only 1.2. The largest ratio of Q_S/Q_W is equal to 4.2 corresponding to year 1996, but 1996 is only a little wet year. This means that for the wettest year, it is not certain that more suspended sediment is transported.

Table 3 shows that the driest year is 1989 with $(Q_W - Q_{MW})/Q_{MW}$ equal to -81.9 and the ratio of Q_S/Q_W is equal to 2.5. The largest ratio of Q_S/Q_W is equal to 5.0 corresponding to year 1981, but 1981 is only a medium dry year with $(Q_W - Q_{MW})/Q_{MW}$ equal to -44.6. This means that for the driest year, it is also not certain that more suspended sediment is transported.

In another word, the suspended sediment transport is affected by many factors, and the climate is just one factor. The relationship between the suspended sediment transport and the climate might be complicated.

Table 3 Suspended Sediment Transport Ratio of Q_S/Q_W in Dry and Wet Years.

Wet			Dry		
Year	$\frac{Q_w - Q_{Mw}}{Q_{Mw}}$ (%)	Ratio of Q_S/Q_W	Year	$\frac{Q_w - Q_{Mw}}{Q_{Mw}}$ (%)	Ratio of Q_S/Q_W
1993	290.5	1.2	1989	-81.9	2.5
2008	169.1	1.3	1977	-74.5	2.0
1998	87.8	3.0	2006	-59.9	1.3
1984	87.0	2.1	2000	-57.3	1.9
1983	73.9	1.8	1988	-56.6	0.6
2007	69.4	1.6	2003	-52.9	1.9
1982	67.2	3.2	1981	-44.6	5.0
1979	53.9	2.2	1980	-38.6	3.5
1986	52.6	2.6	2002	-29.2	2.5
2001	42.8	2.4	1994	-25.8	0.9
1978	42.6	3.9	1997	-24.5	3.3
1990	41.6	2.3	2005	-23.3	1.4
1999	38.7	2.1	1976	-13.6	3.7
1987	26.1	1.4	1985	-11.6	2.7
1995	19.6	2.9	2004	-4.4	1.9
1992	16.5	2.0			
1991	16.2	1.9			
1996	6.7	4.2			

CONCLUSIONS

The climate might play an important role on the erosion and sediment transport process. However, the relationship between them is complicated. Based on this study, the following primary conclusions can be made:

(1) In general, the first dry (or wet) year in a dry (or wet) year series has a largest ratio of Q_S/Q_W. This implies that the river flow in the first dry (or wet) year carries more suspended sediment than the flow in the following dry (or wet) years.
(2) It is not certain that the river flow in the driest (or wettest) year carries more suspended sediment than the flow in the general dry (or wet) years.
(3) The relationship between the suspended sediment transport and the climate is complicated. This is because that the suspended sediment transport is affected by many factors, and the climate is just one factor.

DISCLAIMER

The views expressed in this article are those of the author and do not reflect the official policy or position of the Department of the Army, Department of Defense, or the U.S. Government.

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