Suspended Sediment Yield from the Ansager Å river basin, Denmark

Bent Hasholt & Marek Madeyski

Abstract

Water samples have been collected since 1969, at the Lavborg Bridge gauging station,on the river Ansager Å in South-West Jutland. Different regression equations of concentration versus discharge have been tested. The regression equations are used together with daily discharges to compute the daily suspended loads. Comparisons between measured and computedloads for different periods when water samples were taken twice a day suggest that the 25 computed annual load values have an uncertainty of less than ±10%. The variation in annual loads shown is therefore significant and probably caused by increased rainfall in the eigthies. The average total suspended sediment yield for the 25 year period was 7 t/km²/year, of which the organic load contributed 3.2 t/km²/year.

Keywords:

Sediment yield, concentration of suspended sediment, South West Jutland, Denmark.

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The record of suspended sediment transport by a river will reflect the combined effect of climatic change and changes induced by man. As both climatic change and changes in agricultural practice are expected in the near future, it is important to monitor the existing effects of such changes, and long-term records of sediment discharge are therefore important. The need for long-term measurements is also emphasised e.g. by Walling and Webb (1981) and Gretener (1994).

Sediment transport measurements were initiated in a number of Danish streams in 1969, (Hasholt 1971). Ansager Å was one of the watercourses where measurements were initiated and where they have been continued. The aim of this investigation is to derive a long-term record of suspended sediment yield for this river for the period from 1969 to 1993, using all the available data. Changes in the methodology used over the period are considered and a number of computation procedures are evaluated.

Study area and methods

The study watercourse, Ansager Å, is situated in Jutland see fig. 1. At the gauging station, Lavborg Bro, the area of the drainage basin is 131 km^2. The watercourse has its source area in an old morainic landscape from the Saale glaciation and its lower course runs through an outwash plain developed during the Weichsel glaciation. The slope of the river is gentle, 1-5 ‰. The soils are mainly sandy Spodosols. In the recent river valley peat is often present. Most of the area is cultivated (70%), although shelter belts and conifer plantations (23%) are found on the poor sandy soils. The remainder of the area is occupied by heath (5%), lakes (less than 0.5%) and settlement areas (villages 2%). The mean annual corrected precipitation is 850-900 mm. Due to the high infiltration rates the river floods are not flashy. The river is considered typical of western Jutland.

Continuous recording of the water level at Lavborg Bro and computation of the discharge started in 1975. Before 1975 discharge records only existed for the adjacent river Sneum Å. In the period 1969-1975 the discharge record for the Lavborg gauging station therefore has been synthesised from the records for the Sneum Å river using a regression approach. This procedure is acceptable because the two catchments receive approximately the same amounts of precipitation, and because of their similar situation,size and morphology, the same response time is to be expected.

Sampling of suspended sediment concentrations has

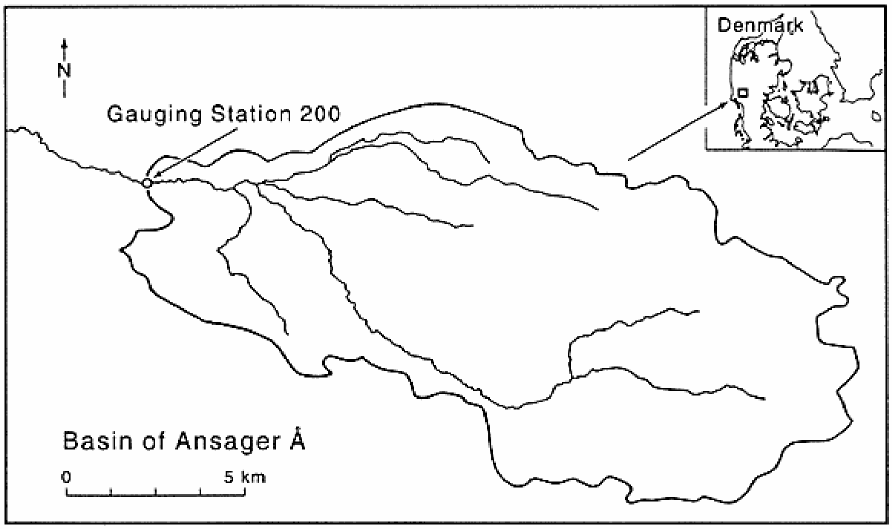

Figure 1: Location of Ansager Å and gauging station.

been carried out since 1969.Water samples have been collected using a depth-integrating water sampler, Nilsson (1969). From 1969 until 1976, monthly sampling was carried out by taking 5–10 depth integrated samples in a cross-section. The mean concentration has been computed and used in this investigation. The variation within the cross-section was found to be small, and therefore from 1976 the monthly sampling was reduced to a collection of three samples, from the middle of the cross-section. Two of these samples were depth- integrated while the third was taken 8 cm below the surface, thus representing the wash load. The 8 cm depth represents the distance between the intake tube and the air exhaust tube of the sampler. In order to provide information for peak discharge situations, additional sampling was carried out when possible. From 1987, more frequent sampling was periodically carried out using an ISCO peristaltic automatic pump sampler. To check the representativity of the ISCO samples, sediment concentrations were also recorded indirectly by use of a Partech IR transmissiometer every 2 min. The intake of the automatic sampler was situated ca. 50 cm above the river bed, in a tube that could pivot away from drifting weeds. During the periods April-June 1991, May-December 1992 and January-June 1993 water samples were collected twice a day using an ISCO Automatic Water Sampler.

From 1969 until 1974 the water samples were filtered through Munktell OOH paper filters, but from 1975 47 diameter Whatman GF/F filters were used. The filters were dried at 65°C and then weighed. Then the filters were heated to 550°C. The increase in filter weight after sampling and after drying at 65°C provides the total suspended sediment concentration (mg/l). The difference between the weight of the filter dried at 65°C and at 550°C is used as a measure of the organic component of the suspended sediment. The difference between the total suspended load and the organic load gives the inorganic load. The concentrations obtained for the samples taken from the fixed level of 8 cm below the water surface provide values for the wash load (total, organic and inorganic).

All the values of suspended sediment concentration (total, organic and inorganic) and the related discharges at the gauging station (cross-section) were used to establish a relationship between suspended sediment concentration and discharge.

A total of 1179 values of suspended sediment concentration (total, organic and inorganic) and 270 values of wash load concentration (total, organic and inorganic) was available.

A sediment rating curve represents the relationship between sediment concentration or sediment load and water discharge. This relationship is often determined by regression analysis. When a relationship is established, it can be used to estimate sediment transport for unsampled periods or to reconstruct the long-term record of sediment transport. Assumption of bivariate relationship between sediment concentration and water discharge is a purely statistical approach and is a considerable simplification of the real situation. Because the precise functional relationship between suspended sediment concentration and water discharge is not known, different models may be applied in the regression analysis. Multiplicative, exponential and polynomial functions are possible models to be selected. Walling and Webb (1981) have critically reviewed the reliability of the different procedures for determining the suspended load. These procedures are commonly based on the formula :

$$C = aQ^b \tag{1}$$

where C- concentration of suspension mg*l^{-1}

Q- discharge of water l*s^{-1}

a,b- local coefficients characterizing the watersheds

The simple linear regression on all data gave a very low correlation coefficient r (0.54 and 0.59 respectively). In some investigations the division of data into seasons with separate rating relationships has produced better correlations than a single rating curve (Nilsson 1971, Walling 1977).

Because of seasonal variation in sediment transport conditions, the data have been divided into two periods- a winter period (Nov.1st–Mar.15th) where the response to rainfall is relatively rapid, due to high antecedent moisture conditions and a summer – autumn period (Mar.16th–Oct.31st) where the response is slower, because the unsaturated zone has to be replenished.

All the data have been divided into the two periods mentioned above. Such a division provided 750 values of suspended sediment concentration and discharge for the summer period and 429 for the winter period. However, this division did not improve the correlation coefficient associated with linear regression relationship between suspended sediment concentration and discharge. Therefore the approach of Jansson (1985) has been employed as described below: The values of water discharge which ranged from 800 to 3000 l/s during the summer period and from 1000 to 6000 l/s during the winter period were divided into 22 (in summer) and 50 (in winter) classes representing 100 l/s increments.

The mean sediment concentration associated with every discharge class has been calculated and these values have been used to establish rating relationships. The values of coefficient a and b in Eq. 1 have been calculated and also the significance level according to the Student t-test and Fischer-Snedecor F-test. Two different versions of the calculations have been performed:

Version 1 – relationship between log (mean concentration) and log (mean discharge)

Version 2 – power function relationship between mean concentration and mean discharge

The power regression, based on an iterative determination of a and b, produced an estimate closest to the measured load, when this was based on frequent sampling. The daily values of suspended sediment concentration were calculated for the period 1969–1993, based on the two relationships. It was assumed that the concentration of suspended sediment was constant during the day and that the suspended load could therefore be estimated as the product of concentration and daily discharge. The wash load has also been calculated using the same procedure. However, a smaller data base was available (160 samples for the summer period and 105 for the winter period).

As mentioned above measurements were made periodically using the ISCO Automatic Sampler, which collected samples twice a day. The suspended sediment load for these days was computed by summing the product of measured concentration and discharge for each 12 hours. To verify the concentration values estimated using the empirical relationships, these values were compared with the results obtained from the frequent samples collected using the ISCO Automatic Water Sampler.

Results

The relationship between discharge in Ansager Å and in Sneum Å surprisingly proved not to be linear, Hasholt & Madeyski(1997). The following two equations gave the best fit of daily discharge at Lavborg (Q_{Ans}) as a function of daily discharge from Sneum Å (Q_{Sn}):

For Q_{Sn} up to 6000 l/s:

$Q_{ans} = \exp(2.29831 + 0.6583 * \ln(Q_{Sn}))$

Correlation coefficient r = 0.909, standard error of estimate 0.093.

For Q_{Sn} larger than 6000 l/s:

$Q_{ans} = \exp(3.5764 + 0.5060 * \ln(Q_{Sn}))$

Correlation coefficient r = 0.952, standard error of estimate 0.032

According to Jansson's procedure the relationships for total, organic and inorganic suspension, for the two periods, expressed in the logarithmic form have been defined as follows:

$$\log C_{total,organic,inorganic} = a + b \log Q \tag{3}$$

and expressed in the power function form defined as follows:

$$C_{total,organic,inorganic} = a\,Q^{b} \tag{4}$$

***Table 1:** The parameters of the equations.*

Version 1 - logarithmic form			
Summer period			
	total	***organic***	***inorganic***
a	-3,654	-3,631	-5,595
b	1,436	1,325	1,951
corr. coef.	0,94	0,94	0,93
st. err.	0,079	0,074	0,114
Winter period			
a	-1,633	-1,978	-1,786
b	0,839	0,835	0,800
corr. coef.	0,74	0,685	0,681
st. err.	0,140	0,156	0,145

Version 2 - power function form			
Summer period			
	total	***organic***	***inorganic***
a	0,000038	0,000226	0,00000253
b	1,671	1,329	1,951
corr. coef.	0,94	0,93	0,93
st. err.	0,211	0,168	0,261
Winter period			
a	0,0262	0,0106	0,0163
b	0,821	0,834	0,801
corr. coef.	0,72	0,685	0,68
st. err.	0,307	0,156	0,332

corr. coef. - correlation coefficient
st. err. - standard error of estimation

In Table 1 the values of the coefficients a and b are given for the two periods and the two different computation procedures for total,inorganic and organic suspended sediment concentration. Values are not given for wash-load concentration, because the correlation was not significant.

To validate the use of the rating curves presented above above to estimate sediment concentration, the concentrations were estimated for periods when the ISCO Sampler had taken two daily samples. The estimated concentration values were multiplied by the discharge to compute the load and these load estimates were compared with load based on the ISCO Sampler. The results are shown in Table 2. Both over- and underestimation are seen, the largest discrepansies are related to shorter periods, predominantly during the summer period. The power function (version 2) performs slightly better than the log regression (version 1). It is therefore selected for the subsequent calculations.

The power functions representing the suspended sediment concentration as a function of discharge e.g. (C_{total} vs Q) for the summer and winter periods are presented in Fig. 2 and 3. Using the above equations, the daily values of sediment concentration can be estimated, and the daily suspended load in the years 1969/93 has been calculated. The daily load values are summed for each year, and divided by the area of the drainage basin to give the annual sediment yields. The results are presented in Table 3. The mean,median, maximum and minimum for the 25 year period are also given in Table 3.

To illustrate better the variation through time, the values from Table 3b are shown in fig.4.

Discussion and conclusions

The transport of suspended sediment is dependent on many different time-variant factors including the erosivity of rainfall and runoff, the location and availability of sediment sources and not least, on human activities. Describing suspended sediment transport by the use of a power function relating concentration to discharge is therefore a very simplistic approach. However, use of such a method is essential where only infrequent samples are available. With this simple method a degree of uncertainty in the result is to be expected and before drawing any conclusion this uncertainty should be assessed.

Computation of sediment loads using the equations for

Table 2: Measured and calculated total suspended load.

Time of Measurements	*Measured value*	*Calculation acc. to the*	*3/2*	*Calculation acc. to the*	*5/2*
	(t)	(t)		(t)	
	2	3	4	5	6
11.04–22.04. 1991	22.990	24.110	1.05	23.520	1.02
04.06–17.07. 1991	25.102	37.980	1.51	36.630	1.45
30.07–30.08. 1991	14.390	19.690	1.36	18.810	1.30
10.09–25.09. 1991	6.210	8.700	1.39	8.320	1.32
18.05–26.05. 1992	16.570	11.250	0.68	10.830	0.65
09.06–02.07. 1992	13.220	10.590	0.79	10.230	0.77
08.07–26.07. 1992	7.640	8.930	1.17	8.540	1.10
28.08–17.09. 1992	18.249	23.860	1.30	23.610	1.29
04.11–27.11. 1992	46.850	56.640	1.21	56.230	1.20
09.12–31.12. 1992	46.340	45.980	0.99	45.310	0.98
07.01–27.05. 1993	379.900	381.560	1.00	381.000	1.00

two seasons was preferred because there is a significant difference in discharge response to rainfall in winter and summer in Denmark. The procedure reccommended by Jansson was used to establish the rating relationship because of the need to correct for log-log transformation bias. However, there seems be a difference of only about 1 % between the results obtained using the log regression and the power function. The approach does not work for wash-load and this could be due to the fact that wash load concentrations respond more rapidly rainfall, than discharge. For improved prediction of wash-load concentrations, a rainfall parameter should possibly be included together with the discharge, but it is not obvious how this can be done.

Single day values of estimated concentration may over- or underestimate the true(measured) concentration by more than a 100%. In Table 2 a comparison is made between the sediment load computed by use of the two types of rating curve and the actual measured transport based on frequent sampling. The comparison relates to the periods when the ISCO sampler was installed and functioning. Malfunctioning was sometimes caused by freezing during the winter.

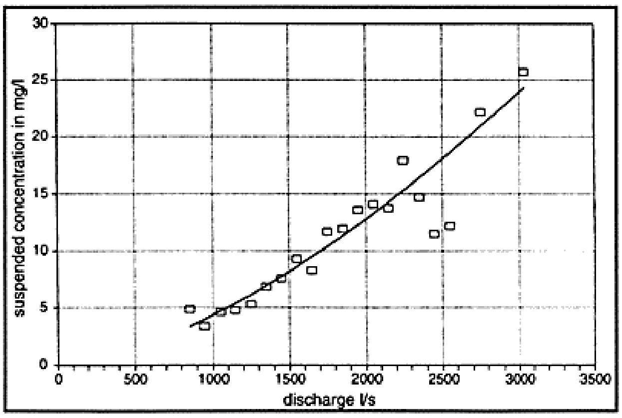

Figure 2: Version 2 summer.

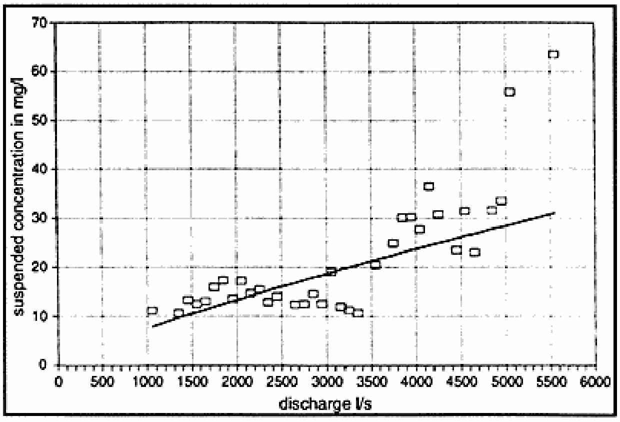

Figure 3: Version 2 winter.

Table 3: Annual suspended sediment yield computed according to logaritmic regression (version 1) and power function (version 2).

	First version			*Second Version*		
Year	*Total* t/km^2/year	*Inorgan.* t/km^2/year	*Organ.* t/km^2/year	*Total* t/km^2/year	*Inorgan.* t/km^2/year	*Organ.* t/km^2/year
1969	4.642	2.336	2.157	4.502	2.385	2.204
1970	7.987	5.169	3.009	8.811	5.225	2.825
1971	3.994	2.030	1.791	3.860	1.996	1.812
1972	3.412	1.740	1.522	3.315	1.735	1.514
1973	3.522	1.723	1.573	3.332	1.713	1.569
1974	6.345	3.220	2.897	6.135	3.172	2.799
1975	5.206	2.680	2.402	5.091	2.691	2.346
1976	3.318	1.632	1.462	3.210	1.611	1.455
1977	4.702	2.413	2.132	4.641	2.398	2.106
1978	6.216	3.427	2.544	6.183	3.403	2.529
1979	7.964	4.226	3.718	7.805	4.191	3.621
1980	10.702	5.814	4.805	10.427	5.766	6.662
1981	12.204	6.976	5.302	12.119	6.896.	5.276
1982	8.539	4.495	3.742	8.371	4.385	3.861
1983	11.986	7.194	4.808	12.103	7.113	4.796
1984	9.214	4.938	4.098	9.032	4.918	4.117
1985	7.289	3.902	3.147	7.121	3.887	3.035
1986	7.135	3.811	3.077	6.971	3.749	3.191
1987	7.641	4.193	3.296	7.508	4.115	3.212
1988	14.996	8.849	6.073	14.861	8.811	5.979
1989	5.987	3.382	2.542	5.946	3.326	2.511
1990	7.435	4.054	3.197	7.310	4.012	3.134
1991	5.512	2.856	2.554	5.394	2.841	2.466
1992	6.426	3.407	2.863	6.302	3.357	2.784
1993	7.552	4.028	3.507	7.394	4.011	3.204
Mean	7.199	3.940	3.130	7.109	3.900	3.160
Median	7.289	3.811	3.009	6.971	3.749	2.825
Maximum	14.996	8.849	6.073	14.861	8.811	5.979
Minimum	3.318	1.632	1.462	3.210	1.611	1.455

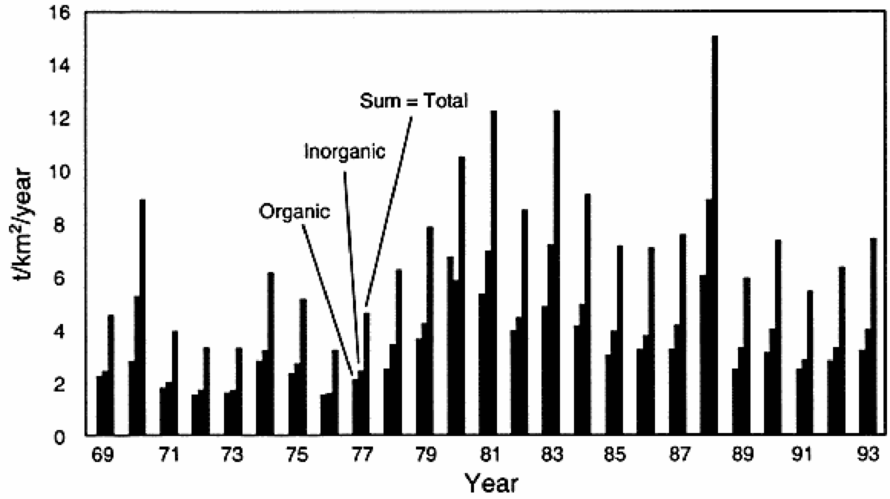

Figure 4: Annual suspended sediment yield, inorganic, organic and total in t/km^2/year.

For the period lengths of 9 to 32 days, the difference between the estimated and measured loads varied between 2 to 36%. For one period of 44 days the difference was 45%. There is a slight tendency in the estimated values to overestimate the load. Winter periods seem to give a better fit. For the 141 day period the difference was zero. If all periods are summed together for the three years, providing a total of 365 days, a difference of 7% was found. This indicates that for period lengths of about a half year or more the effect of the variation around the regression lines tends to even out the short term variations, so that the annual values have an uncertainty of less than +- 10%. This is in close agreement with the earlier findings of Hasholt (1981). It is therefore acceptable to compare the load values for individual years in the time series.

The results from this investigation can also be compared with the results from earlier investigations undertaken in the Ansager Å basin. In Hasholt (1971) the mean annual load was computed use of the log-log regression between load and discharge and of the duration curve. The thus computed mean annual sediment yield was 9.5 t/km^2/year. In Hasholt (1986) the transport was computed for the years 1975 to 1984 using 10 years of monthly data and a log-transformed bias corrected regression as recommended by Jansson (1985) and Ferguson (1986). The mean annual yield for this period was 12.7 t/km^2/year. Both of the earlier investigations gave higher values than the average for this 25 year period, 7.0 t/km^2/year. For the same 10 years the difference between the results obtained in this investigation and in the 1986 study was 40%.

The annual yields in this investigation are computed from a drainage basin area of 138 km^2 in accordance with the older investigations, taking the newly corrected basin area (131 km^2) into account, the yields should be muliplied by 1.053. As the earlier investigations are based on fewer observations, their regression equations will be relatively more sensitive to single outliers than those in the present study. In adition there are a few older data to prove any significant changes in the coefficients a and b over time. This indicates that it is important to have a wide range of concentration and discharge values as a basis for establishing the concentration versus discharge relationship, if, as in the case here, it is used for a long time series with the basic assumption that the relationship is constant through the 25 year period. To validate this assumption, however, frequent sampling is needed, so that changes in coefficients a and b are statistically significant. This will, however, partly contradict the reason for application of the rating curve method.

Bearing the reservations about the assumption above in mind, it is concluded that the present investigation gives the best estimate of the mean annual sediment yield from the Ansager basin. The mean yield of total suspended sediment was 7 t/km^2, whereas that for the organic component was 3.2 t/km^2.

From Table 3 and from fig. 4, it can be seen that there has been a significant variation of the suspended yield through time. As the rating curve is assumed constant over the period, high yield values must be due to high discharge values alone. This is a limitation for the rating curve metod to investigate long-term trends in sediment yield. Changes in land use might have changed the a and b values over time, although it is believed that the actual changes are too modest to cause changes. The high values in the eighties were therefore in fact due to the higher runoff values caused by the increasing amount of rainfall in this period.

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