# Soil erosion and sediment yield in the Upper Yangtze River basin

#### DAI DINGZHONG & TAN YING

International Research and Training Centre on Erosion and Sedimentation (IRTCES), PO Box 366, Beijing 100044, China

Abstract The Upper Yangtze basin is the principal area of sediment production in the Yangtze basin. The important Three Gorges Project is located just at the outlet of the Upper Yangtze River. Soil erosion control in the Upper Yangtze basin will be of vital importance for decreasing the sediment load of the Yangtze and mitigating the impact of sediment on the Three Gorges Project. Therefore a wide ranging investigation of soil erosion and sediment yield in the basin has been undertaken since 1980. This article briefly addresses some important results of the investigation, including the patterns of erosion, the factors influencing erosion, the magnitude and distribution of soil erosion and sediment yield, and temporal trends in sediment yield from the Upper Yangtze basin.

#### INTRODUCTION

The Yangtze River, the largest river in China, flows from west to east through the middle part of the country, covering a drainage area of  $1.8 \times 10^6$  km<sup>2</sup>, or about 19% of the total territory of China (Fig. 1). However, the population and Gross National Product (GNP) of the Yangtze River basin account respectively for 35% and 40% of the national totals. The total length of the Yangtze River is 6300 km, which may be roughly divided into three courses according to the morphological characteristics as follows: the upper course, from the source to Yichang; the middle course, from Yichang to Hukou; and the lower course, from Hukou to the estuary.

The drainage area of the upper course is  $1 \times 10^6$  km<sup>2</sup>, accounting for 55% of the total drainage area. The average annual sediment load from this part of the basin amounts to  $0.52 \times 10^9$  t, which is greater than that of the lower course. Thus the Upper Yangtze basin (UYB) is the main source area of sediment supply to the river.

The important Three Gorges Project is now being constructed near Yichang, at the outlet of the UYB. Erosion control in the UYB will be of vital importance for mitigating the sediment-related problems of the project. Therefore, a wide ranging investigation of soil erosion and sediment yield in the UYB has been undertaken as one of the national key research projects since 1980. The study was conducted using a combination of approaches, including hydrological survey, field observation, experiments, remote sensing, and synthetic analysis applying systems engineering technology, stochastic analogy, fuzzy set and grey theory, etc. To date, a large amount of data has been obtained, and a general assessment of the status and trend of soil erosion and sediment yield has been derived. Some of the important research results are briefly introduced in this paper.



Fig. 1 The water resource regions of China, showing the location of the Yangtze River basin.

## PHYSIOGRAPHY

The Upper Yangtze and its main tributaries, the Jinsha, Minjiang, Tuojiang, Jialing and Wujiang rivers, flow through the Qinghai-Tibet Plateau (with an elevation of 4000 m), the Parallel Ridges and Valleys (2000-4000 m), the Yunan-Guizhou Plateau (1000-2000 m) and the Sichuan Plain (500-1000 m). These areas are located at the geological contact zone between the rising geosynclinal area to the west and the stable plateau to the east. The landscape undulates drastically, river valleys are deeply incised, and intense tectogenesis has resulted in large amounts of folded, fractured and fragmented rocks. These contribute a rich potential source for surface erosion and sediment load.

Climatically, the UYB is situated in a subtropical zone. It can be divided into two climatic sub-areas, reflecting the different topography. The western plateau climate sub-area receives little rain whereas the eastern subtropical monsoon sub-area receives large amounts of rain. Both temporal and spatial distributions of precipitation and runoff are uneven in the basin. The average annual precipitation varies from less than 400 mm in

the Qinghai-Tibet plateau in the west to more than 1200 mm and even 2000 mm, in the Sichuan Plain in the east (Qian, 1994). In most areas, 70% of the annual rainfall takes place in the flood season, especially in July and August. Fifty percent of the annual runoff is concentrated into the period from July to September. In summer, thunderstorms of short duration occur frequently, causing severe land erosion and floods which threaten the safety of the local inhabitants. The maximum peak flood and maximum annual runoff measured at Yichang Hydrometric Station were 70 800 m<sup>3</sup> s<sup>-1</sup> in 1981 and 575  $\times$  10<sup>9</sup> m<sup>3</sup> in 1954 respectively.

## PATTERNS OF EROSION

The UYB covers a vast area, and in consequence has a variety of physiographic features in its different parts and is characterized by diversity of erosion patterns. In general, the basic patterns of surface erosion involve water erosion, gravitational erosion and a combination of the two in most regions, except in the Qinghai-Tibet plateau with its higher elevation and severe cold climate, where glacial and freeze-thaw processes dominate.

Water erosion, including sheet erosion and gully erosion, is the main type of surface erosion in the basin. It is a form of progressive erosion, which takes place slowly and continues for a long time. Sheet erosion is the most important contributor to soil loss from the basin. It occurs over the widespread cultivated slope land, and on rotation land and wasteland, which constitute a large proportion of the farmland in the basin. In the Upper Jialing basin, 70% of farmland is found on slopes of  $20-30^{\circ}$ . In the mountain and hill areas of the Lower Jinsha basin, cultivated slope land accounts for 50-90% of the total farmland, and one third of the cultivated land has slopes of over  $25^{\circ}$ . When heavy rainfall occurs over the area, the topsoil, being characterized by steep slopes, thin soil layers and sparse vegetation in many places, is easily eroded by rainsplash and overland flow. The maximum rate of erosion is as high as 9000-36000 t km<sup>-2</sup> year<sup>-1</sup> in some places. Gully erosion occurs primarily on ancient alluvial fans, diluvial formations and terraces composed of loose deposits formed during the Quaternary period and distributed over the wide alluvial reaches.

Gravitational erosion, mainly comprising avalanches, landslides and debris slides, reflects both gravitational force as the major exogenic agent and interaction with water. It is commonly an instantaneous form of erosion, lasting for only a short duration, but producing major hazards. In many parts of the basin optimum conditions for gravitational erosion exist. These conditions include steep unstable slopes and banks, large amounts of erodible material or deposits, and triggering factors such as thunderstorms and earthquakes. This type of erosion again occurs frequently. For example, in the Upper Jialing basin alone there are about  $10 \times 10^3$  landslide sites. Another example is the Xintan landslide which occurred on the north bank of the main stem of the Yangtze on 12 June 1985. This brought about  $2 \times 10^6$  m<sup>3</sup> of soil and rock into the river and blocked one third of the river width.

Combined erosion is a term used to refer to erosion processes that reflect the joint effects of gravity and rainfall. Debris flows result from combined erosion. Both the Upper Jialing basin and Lower Jinsha basin are areas where debris flows occur frequently. There are 3000 debris flow valleys in the Upper Jialing basin. In some places

debris flows may even occur when the rainfall intensity is as low as 15-20 mm h<sup>-1</sup>. In the basin of the Xiaojiang River, which has a total length of 133 km and is a tributary of the Jinsha river, there are 107 debris flow valleys, and each year debris flows contribute about  $30-40 \times 10^6$  t of sediment to the Xiaojiang River and about  $6 \times 10^6$  t to the Jinsha River.

## FACTORS INFLUENCING EROSION

Factors influencing erosion processes and sediment yield can be grouped into two types, representing natural conditions, including climate, geology, morphology, soil type, vegetation, etc., and human activities. Natural factors are commonly viewed as influencing the basic occurrence and development of erosion. Human activities primarily act to accelerate or mitigate erosion processes.

Rainfall, as the driving force for surface erosion, is the most important climatic factor. It is obvious that the amount of erosion will depend on rainfall depth and intensity and antecedent precipitation, etc. The spatial distribution of rainfall is also a key factor influencing sediment yield. In the 1980s both the duration of rainfall and the annual precipitation in the Lower Jinsha River basin were less than the average values for the past thirty years, but the sediment load in the river was larger than average. This is attributed primarily to the fact that a zone of high rainfall coincided with the area of high susceptibility to soil loss in those years.

Surface slope is the major morphological element influencing erosion. Field experiments undertaken in three typical small basins of the UYB indicated that the erosion rate may increase by 2.3-3.5 times when slope increases from 5° to 25° under the same percentage of vegetation cover (50%) (Fig. 2).

Vegetation cover is a component of crucial importance for the erosion resistance of surface soil. A field experiment to investigate the effect of different vegetation conditions on erosion in south Gansu Province showed that the ratio of rates of erosion on forest land and grassland, shrub land, sparse woodland, wasteland and cut areas with approximately the same slope was 1:2.5:3:3.3:5.0 respectively. Figure 3 illustrates the



Fig. 2 The effect of slope on erosion (under the same degree of vegetation cover -50%).



Fig. 3 The variation of erosion rate with degree of vegetation cover.

variation of erosion rates with the degree of vegetation cover in the Three Gorges zone. When the degree of cover decreases from 90% to less than 30%, the rate of erosion increases from  $< 500 \text{ t km}^{-2} \text{ year}^{-1}$  to 8000-13000 t km<sup>-2</sup> year<sup>-1</sup>.

Human activities introduce important complications and may have dual effects in both accelerating and mitigating soil erosion. The expansion of cultivated slope land (especially steep land), deforestation for land reclamation under the pressure of increasing population, large scale mining, road building, rock quarrying and other industrial and civil construction activities, etc. may greatly increase the supply of loose erodible material and reduce the erosion resistance of the surface soil and the stability of the mountain side and lead to severe soil loss. For instance, in Sichuan Province, industrial waste alone amounts to  $57 \times 10^6$  t per year, of which 90% reaches the rivers without any treatment. However, afforestation, restrictions on forest cutting, improved tillage practices and engineering measures such as reservoirs, ponds, check dams, etc. can prevent or control erosion progress and reduce sediment yield.

The effects of soil conservation works are generally relatively obvious for small watersheds. A reduction of soil loss within some small watersheds in the basin of up to 30-70% has been recorded over several years as a result of erosion control practices. For large watersheds, the processes of erosion, transport and deposition are more complicated. The effect of soil conservation works may be indiscernible in the short term. To date, about  $12 \times 10^3$  reservoirs have been constructed in the UYB, with a total capacity of  $18.9 \times 10^9$  m<sup>3</sup>. The amount of sediment trapped in these reservoirs was estimated to be about 10.5% of the total annual soil loss, but the corresponding reduction in sediment load at Yichang was only 3-4% of the average load. This was attributed partly to the fact that most of the reservoirs were built upstream of the areas of strong and severe erosion.

## THE MAGNITUDE AND DISTRIBUTION OF EROSION

An extensive investigation of soil erosion in the basin was conducted in 1985. The runoff and sediment load at Yichang during this year was close to the average annual value. The amount of erosion for the year could therefore be considered as typical. The investigation indicated (Table 1) that the eroded area amounted to about  $351 \times 10^3$  km<sup>2</sup> and accounted for 35% of the territory of the UYB. The annual total gross erosion was  $1.57 \times 10^9$  t, with a mean erosion rate of 1559 t km<sup>-2</sup> year<sup>-1</sup>, which falls into the class of moderate erosion. Table 1 also shows that the total soil losses that occurred in the Jinsha and Jialing basins were greater than in other basins, being respectively 557  $\times 10^6$ t year<sup>-1</sup> and 397  $\times 10^6$  t year<sup>-1</sup>, and accounting for 35.6% and 25.3% of the gross erosion in the UYB.

According to the type and severity of erosion, the UYB can be divided into four erosion regions as shown in Table 2 and Fig. 4. These are as follows:

**Region I** – slight erosion This includes the Qinghai-Tibet plateau, the high mountainous zone along the Upper Jinsha, the Minjiang and Yalong rivers and the Sichuan Plain. This region accounts for 47.2% of the total area of the UYB, but the soil

Tributary	Basin area	Gross erosion	Eroded region:	Rate of erosion	
			Area	Erosion	
	$(\times 10^3 \text{ km}^2)$	$(\times 10^6 \text{ t year}^{-1})$	$(\times 10^3 \text{ km}^2)$	$(\times 10^6 \text{ t year}^{-1})$	(t km <sup>-2</sup> year <sup>-1</sup> )
Jinsha	500	557	135	466	1114
Minjiang	133	215	49	194	1616
Tuojiang	28	84	16	81	3000
Jialing	160	397	92	380	2481
Wujiang	72*	95	15	81	1319
Others	112	219	44	202	1938
Total	1005	1567	351	1404	1559

Table 1 Gross erosion in tributary basins of the Upper Yangtze.

\* A small part of the basin area has been included in "Others" in the statistics.

Region	Area		Erosion		Rate of erosion	
	$(\times 10^3 \text{ km})$	m <sup>2</sup> ) (%)	$(\times 10^6 t ye)$	ear <sup>-1</sup> ) (%)	(t km <sup>-2</sup> year <sup>-1</sup> )	
I. Slight erosion	474	47.2	205	13.1	432	
II. Moderate erosion	176	17.5	209	13.3	1187	
III. Strong erosion	243	24.2	770	49.1	3169	
IV. Severe erosion	112	11.1	383	24.5	3420	
Total	1005	100	1567	100	1559	

Table 2 Erosion regionalization in the UYB.

loss accounts for only 13.1% of the total. The average rate of erosion is about  $432 \text{ km}^{-2} \text{ year}^{-1}$ .

**Region II** – moderate erosion This includes the Wujiang River basin and the northeastern and northwestern zones of the Sichuan Plain. Its area and soil loss account for 17.5% and 13.3% of the total values respectively. The rate of erosion is  $1187 \text{ t km}^{-2} \text{ year}^{-1}$ .

**Region III** – strong erosion This includes the mountain and hill zone covering Sichuan, Yunnan and Guizhou Provinces and the Three Gorges zone. The principle type of erosion occurring in this region is sheet erosion resulting from human activities, such as cultivation of steep slopes and barren hills with a thin topsoil layer. In some parts of the region, landslides and debris flows also occur. The area and soil loss account for 24.2% and 49.1% of the totals respectively, and the rate of erosion is  $3169 \text{ t km}^{-2} \text{ year}^{-1}$ .

**Region IV** – severe erosion This consists of the high mountain and deep canyon zone along the Lower Jinsha River and the earth-rock hill zone along the Upper Jialing River. In this region, landslides, avalanches, debris flows and gully erosion occur extensively, and the rate of erosion is up to  $3420 \text{ t km}^{-2} \text{ year}^{-1}$ . Its area only accounts for 11.1% of the total value, but it contributes 24.5% of the soil loss.

It is obvious that regions III and IV are the major source area of sediment supply to the Upper Yangtze River basin.



Fig. 4 The erosion regions of the UYB.

## SEDIMENT YIELD

The sediment yield measured for a river is an important indication of erosion severity in the basin, although the processes of sediment conveyance interposed between on-site erosion and downstream sediment yield are complex and involve considerable uncertainty, and generally only a fraction of the soil eroded in the basin can find its way to the basin outlet. Furthermore, because hydrometric records of temporal and spatial variations in sediment yield of rivers are commonly more readily available and more reliable than those of soil erosion in a basin, they can be used to study the erosion history and to predict its future development. There are many hydrometric stations in the UYB. Some of them, for example that at Yichang, have measured sediment load for over 40 years. Table 3 lists the mean annual runoff and suspended sediment yield measured on the main tributaries in the UYB. The suspended load is much greater than bed load (for instance, at Yichang the ratio between them is about 56:1), and the suspended load approximates the total sediment yield. Table 3 indicates that the average annual runoff and sediment yield of the UYB (at Yichang) are  $439 \times 10^9$  m<sup>3</sup> and  $523 \times 10^6$  t respectively. The runoff comes primarily from the Jinsha, Minjiang and Jialing Rivers, accounting for 32.6%, 20.0% and 16.0% respectively, but the corresponding sediment loads are 46.8%, 9.9% and 26.0%. This means that the Jinsha and Jialing rivers are a major source of sediment, contributing 72.8% of the sediment with only 48.6% of the runoff. The distribution of sediment yield within both these basins is also uneven. In fact, the predominant areas for sediment supply are concentrated in the Upper Jialing and the Lower Jinsha basins. In the Upper Jialing basin the area with a modulus of sediment yield (*Ms*) larger than 3000 t km<sup>-2</sup> year<sup>-1</sup> covers  $9.3 \times 10^3$  km<sup>2</sup> (0.9% of the UYB), and contributes an annual sediment load of  $35 \times 10^6$  t (6.7%) and an annual runoff of  $2.36 \times 10^9$  m<sup>3</sup> (0.5%). In the Lower Jinsha basin the corresponding figures are  $34.5 \times 10^3$  km<sup>2</sup> (3.4%),  $131.4 \times 10^6$  t (25.1%) and  $81 \times 10^9$  m<sup>3</sup> (18.5%) respectively. Based on the sediment data collected at 178 hydrometric stations in the UYB, a spatial distribution of the modulus of sediment yield Ms was drawn (Fig. 5). The region of low sediment yields with Ms < 200 t km<sup>-2</sup> year<sup>-1</sup> occupies 42.6% of the territory, but only contributes 5.4% of the sediment yield. On the contrary, for the region of high sediment yield with Ms > 2000 t km<sup>-2</sup> year<sup>-1</sup>, the above figures are 4.6%

River	Station	Basin area	Runoff	Sediment yield	Modulus of sediment yield	Concen- tration	Median diameter
		(10 <sup>3</sup> km <sup>2</sup> )	(10 <sup>9</sup> m <sup>3</sup> )	(10 <sup>6</sup> t)	(t km <sup>-2</sup> year <sup>-1</sup> )	(kg m <sup>-3</sup> )	(mm)
Yangtze	Yichang	1005	439	523	520	1.19	0.032
Jinsha	Pinshan	485	143	245	505	1.71	0.048
Minjiang	Gaochang	133	88	52	391	0.59	0.048
Tuojiang	Lijiawan	23	12.5	12	522	0.94	0.027
Jialing	Beipei	156	70	136	872	1.94	0.025
Wujiang	Wulong	83	49	30	361	0.62	0.030

Table 3 Average annual runoff and suspended sediment yield for selected gauging stations in the UYB.



Fig. 5 The distribution of specific sediment yield within the UYB.

and 32.8% respectively. Other regions with 200 < Ms < 2000 t km<sup>-2</sup> year<sup>-1</sup> account for 52.8% of the area and 61.8 of the sediment yield.

The sediment yield at a basin outlet and the soil erosion in the basin can be related through their ratio, which is termed the sediment delivery ratio (SDR). The SDR is essentially a measurement of reduction of the mass of eroded sediment by deposition as it moves from the point of erosion to any designated downstream location. The magnitude of the SDR varies with geomorphological factors and human-induced effects, and exhibits various values in different areas. Fourteen typical small watersheds in the basin were selected to estimate the SDR. Using a remote sensing map of soil erosion with the scale 1:500 000, the extent of areas with various erosion intensities could be identified and used to calculate their annual gross erosion after some calibration based on field observations. The sediment load at the outlet of each basin was obtained from the measured data for the adjacent hydrometric station. Thus the SDR values can be derived. The SDR estimates obtained ranged from 0.14 to 0.61, but were mostly between 0.14 and 0.48 (Liu & Zhang, 1995). In general, they exhibit a trend of increase with decrease of basin area and eroded particle size, and they increase when the underlying lithology changes from granite - limestone - purple sandstone - shale - Quaternary loess. The average SDR of the entire UYB was about 0.34.

In order to understand the mechanism of sediment yield in the main areas of sediment supply and to explore the relationship between sediment yield and controlling factors, a grey theory analysis has been used to study the sediment yield process for a typical watershed of 3439  $\text{km}^2$  in the Upper Jialing basin (Hydrometric Research

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Institute, the Changjiang Water Resources Commission, 1993). The average annual hydrological parameters for the basin are as follows: precipitation 551 mm, runoff 360  $\times 10^6$  m<sup>3</sup>, sediment yield  $10.9 \times 10^6$  t and specific sediment yield 3300 t km<sup>-2</sup> year<sup>-1</sup>. In the analysis, sediment yield was selected as the major index of behaviour, and the controlling factors included six variables, namely annual and flood-period runoff, annual and flood-period precipitation, days when rainfall was greater than 20 mm day<sup>-1</sup> and the corresponding rainfall total. Using grey cognate analysis, it was found that the grey cognate degrees (*GCD*) of all six factors mentioned above are higher (*GCD* > 0.681-0.725), and that the strongest factor is annual runoff (*GCD* = 0.863-0.820) The second most important factors are annual precipitation and flood-period runoff. Based on the analysis, a grey system model was successfully established to predict the sediment load.

# **TEMPORAL TRENDS OF SEDIMENT YIELD**

The temporal behaviour of sediment yields depends to a great extent on the space and time scales employed for considering the problem. As far as long-term changes of sediment yield in the entire UYB are concerned, it seems that there is no clear tendency for yields to increase or decrease, based on the following evidence:

(a) The variation of measured annual sediment yield over four decades at Yichang (Fig. 6) demonstrates a random fluctuation without sustained increase or decrease. This was also confirmed by statistical testing of data randomness in terms of kick point analysis and of data trends using Kendall rank correlation. Periods with heavy



Fig. 6 Records of annual runoff, sediment yield and concentration for Yichang.

sediment loads and with lower sediment loads appeared to occur alternately. Each period continued for about 5-6 years.

- (b) Both the plots of annual runoff, sediment yield and mean concentration (Fig. 6) and the relationship of accumulated runoff and sediment yield (Fig. 7) indicate that variations in sediment yield were synchronous with those of runoff. As mentioned above, the grey cognate analysis indicated that annual runoff is the strongest factor influencing sediment yield. The runoff in the UYB varies stochastically with time, as has been confirmed by statistical analysis, and, as a result, the sediment yield at Yichang must also vary in a random manner. For a random series the average value for a large number of samples collected during a long period should be stable. Table 4 lists the standard error of the mean annual runoff and sediment yield for different durations (Lin, 1992). It can be seen that the average values calculated over 30 years have already approached the expected long-term value with only small deviation.
- (c) The average sediment delivery ratio (SDR) in the UYB is about 0.34, and the SDRs in many tributary basins are much less than 1. These values imply that the basin has an enormous capability for storing and regulating the transport of eroded soil. An abrupt increase of sediment supply at one location during a certain period may be compensated by a decline at other places or during other days, and vice versa. A relatively stable natural condition can thereby exist. Of course, this will occur only under the prerequisite that the meteorological conditions and the natural environment remain basically stable without extra-catastrophes or macro-scale disturbance by human activities.



Fig. 7 Plot of cumulative sediment yield vs cumulative runoff for Yichang.

Standard error	Duration (years):					
· · · · · · · · · · · · · · · · · · ·	10	20	30	37		
Runoff	4%	3%	2%	2%		
Sediment yield	8%	6%	5%	4%		

Table 4 Standard error of mean runoff and sediment yield values

Turning to the variation of sediment yield over a shorter time scale or in a local area, the situation may be completely different. For example, if the trend of sediment yield from 1960 to 1968 and 1976 to 1981 is taken as an example (Fig. 6), the conclusion is, undoubtedly, that sediment yield increased through time. However, if attention is directed to the periods from 1954 to 1960, 1968 to 1972 and 1981 to 1986, the situation is diametrically opposed — sediment yield declined through time.

Regarding the variation in local areas, in some tributary watersheds sediment yields may have increased through time over a relatively long period. For example, the sediment yield of the Xiangxi River, a small tributary of the Yangtze River, increased from  $0.87 \times 10^6$  t in 1956 to  $1.26 \times 10^6$  t in 1980 due to deforestation since 1970. However in some other watersheds the opposite trend was evident. For instance, for the 53 km<sup>2</sup> basin of the Daqiao River, a secondary tributary of the Yangtze, the annual amount of soil loss decreased from  $200 \times 10^3$  m<sup>3</sup> prior to 1976, to less than  $20 \times 10^3$  m<sup>3</sup> in the late 1980s, as a result of comprehensive soil erosion control.

In considering the effects of human activities on the trend of sediment yield in the basin, attention must be given to large-scale activities. One such activity, for example, is the resettlement of people due to inundation of the Three Gorges reservoir. It is estimated that about one million people will migrate from the inundated region to higher mountainous areas, and that newly-reclaimed farmland extending to  $80-133 \times 10^3$  ha will be required to offset the inundated fertile cultivated land. This, according to preliminary estimates, may increase soil erosion by  $4-7 \times 10^6$  t annually (Shi *et al.*, 1992). In addition, the destruction of vegetation due to road construction, house building, domestic fuel demand etc. will add about  $100 \times 10^3$  ha of new land exposed to soil erosion, and consequently *ca.*  $5 \times 10^6$  t of soil loss. As a result, an additional  $10-12 \times 10^6$  t of soil erosion may occur in this region each year. Large-scale and continued soil erosion control will clearly be important to prevent soil loss and to reduce sediment supply to rivers.

Based on the current status and distribution of soil erosion, an overall strategy for soil and water conservation in the UYB has been formulated. The stress is laid on comprehensive control of soil erosion in watersheds, taking into account both the principle of ecological protection and the features of socio-economic development, and combining the reduction of soil loss with improving environmental quality and increasing the income of the local people. The plan will be implemented progressively and hierarchically within the basin. At the national level, the State Council decided in 1988 to include four regions consisting of 61 counties in the UYB, namely the Lower Jinsha basin, the Upper and Middle Jialing basin, the South Gansu and Shaanxi Provinces, and the Three Gorges zone, as the national key areas for priority control of soil loss with special funds provided by the state. The four regions are located in the strong and severe erosion areas and have a total area of  $120 \times 10^3$  km<sup>2</sup>, within which there is an area of extremely strong erosion extending to  $73 \times 10^3$  km<sup>2</sup> with an annual soil loss of about  $325 \times 10^6$  t. By the year 2000 the controlled area will extend to  $48 \times 10^3$  km<sup>2</sup>, and the completed erosion control works will include: bench terracing of sloping farmland ( $8.2 \times 10^3$  km<sup>2</sup>), afforestation on waste sloping land ( $24.7 \times 10^3$  km<sup>2</sup>), grassed areas ( $5.4 \times 10^3$  km<sup>2</sup>), and a great number of engineering works such as check dams, grid dams, retaining walls, slide-resistant piles, horizontal screens for debris flow breaking, diversion works etc. At the provincial and local levels, comprehensive improvement of small watersheds will be implemented extensively, and it is estimated that the controlled area will extend to about  $120 \times 10^3$  km<sup>2</sup> by 2000. Thus, the total controlled area at all levels will be up to about  $168 \times 10^3$  km<sup>2</sup> in the UYB before 2000, and the reduction in soil erosion is expected to be 546  $\times 10^6$  t.

#### CONCLUSION

- (a) Under the influence of its special physiographic condition and extensive human activity, the primary patterns of surface erosion in the Upper Yangtze basin (UYB) are water erosion, gravitational erosion and combined erosion. The eroded area amounts to about  $351 \times 10^3$  km<sup>2</sup>, accounting for 35% of the territory of the UYB, which has an annual gross erosion of  $1.57 \times 10^9$  t and an average rate of erosion of 1559 t km<sup>-2</sup> year<sup>-1</sup>. Soil loss occurs primarily in the Jinsha and Jialing basins, and especially in the Lower Jinsha and Upper Jialing basins.
- (b) According to the available hydrometric data, the mean annual runoff and suspended sediment yield of the UYB are  $439 \times 10^9$  m<sup>3</sup> and  $523 \times 10^6$  t respectively. The Jinsha and Jialing rivers are the major source of sediment, contributing 72.8% of the sediment but only 48.6% of the runoff. The high sediment yield region with Ms > 2000 t km<sup>-2</sup> year<sup>-1</sup> occupies only 4.6% of the territory, but contributes 32.8% of the sediment load. The sediment delivery ratios of tributary watersheds lie in the range 0.4-0.61, and the average value for the entire UYB is about 0.34.
- (c) The variation of measured annual sediment yields over four decades, and both statistical and qualitative analyses, indicate that the sediment yield in the UYB fluctuates in a random way with no clear tendency to increase or decrease during a long period. Soil erosion control and sediment yield reduction within the entire UYB will only be effective through sustainable, large scale and long-term soil and water conservation works.

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