Changes in Runoff and Sediment Load in the Pearl River Basin and Its Causes

IRTCES Report-2008-2-01

INTERNATIONAL RESEARCH AND TRAINING CENTER ON EROSION AND SEDIMENTATION

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CONTENTS

Changes in Runoff and Sediment Load in the Pearl River Basin and Its Causes

1. Description of Pearl River Basin

1.1 Physical geography

1.1.1 River system

The Pearl River is one of the largest rivers in the south and among the seven major rivers of the Yangtze, the Yellow, the Huaihe, the Haihe, the Songhua and the Liaohe Rivers in China. The Pearl River Basin is located between 102°14′~115°53′ of east longitude and 21°31′~26°49′ of north latitude. It flows through six provinces and autonomous regions, Yunna, Guizhou, Guanxi, Guandong, HunanXiang, Jiangxi Gan and northeast part of Vietnam, involving west part of Hong Kong Special Administration Region and Macao Special Administration Region, with a catchment area of 453700km^2, among which an area of 442100 km^2 lies in China.

The Pearl River is composed of the West, the North, the East Rivers and the Pearl River Delta. Converging in the Pearl River Delta, the West, the North and the East Rivers are interlaced into a waterway network system with water channels totaling 1740 km in length and an area of 100000 km^2, and then empty into the South China Sea through eight outlets namely Humen, Jiaomen, Hongqimen, Hengmen, Modaomen, Jitimen, Hutiaomen and Yamen Outlets.

The West River, the main stem of the Pearl River, rises from the Maxiong Mountain in Qujing City, Yunnan Province. It is located between 102°14′~114°50′ of east longitude and 21°31′~26°49′ of north latitude. From the source it goes under the name of the Nanpan River, Hongshui River, Qianjiang River, Xunjiang River and the West River in succession, running through Yunnan, Guizhou, Guangxi and Guangdong Provinces (autonomous region). After connecting the North River at Sixianjiao in Sanshui County of Guangdong Province, the West River flows to the delta waterway network with its main course emptying into the South China Sea through the Modaomen outlet in Zhuhai City. The length of the West River is 2,274 km and its catchment area is 353,100 km^2, making up 78% of the basin's total. There exist many tributaries in the West River system, among which the Beipan River, Liujiang River, Yujiang River, Guijiang River and Hejiang River, etc. are the first-grade tributaries with a catchment area larger than 10000 km^2.

Pictures 1 ~3 are satellite images of the Pearl River in 2008, 2005 and 2004, respectively. Pictures 4 and 5 show the source and the mainstream of the Pearl River, respectively.

Picture 1 Satellite image of Pearl River Delta (2008) (www.geocarto.composter)

Picture 2 Satellite image of Pearl River Delta (2005) (www.geocarto.composter)

Picture 3 Satellite image of Pearl River Delta (2004) (www.geocarto.composter)

Picture 4 Source of Pearl River

Picture 5 Pearl River (http:hi.baidu.com)

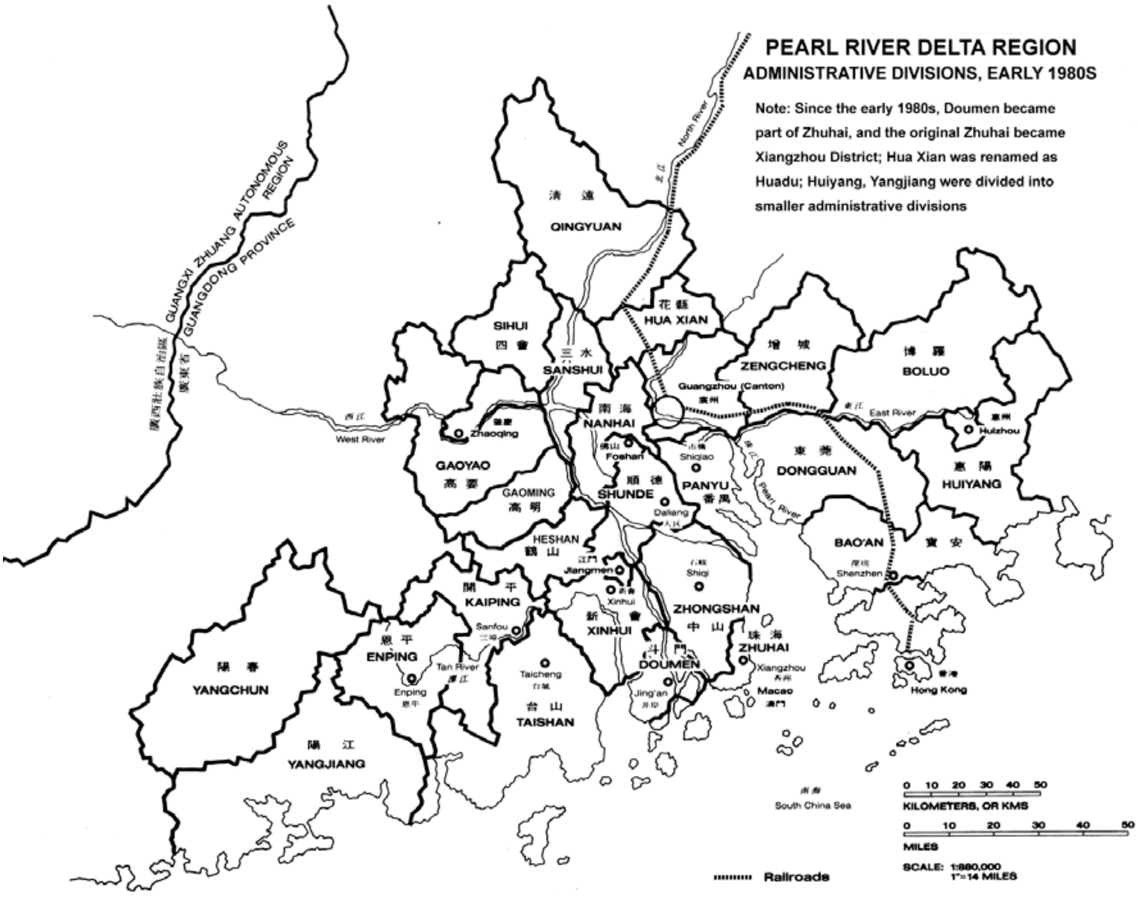


Fig. 1.1 Plan view of Pearl River Basin (www.c-c-c.orgprogramsroots)

The North River is the second largest river system of the Pearl River Basin, located between 111°55′~114°50′ of east longitude and 23°10′~25°31′ of north latitude. The Zhenshui Creek of its main stem originates from Shijiedamaokeng of Xinfeng County, Jiangxi Province. The North River system runs through Hunan，Jiangxi and Guangdong Provinces, after connecting the West River at Sixianjiao, it flows to the Pearl River Delta. The total length of the North River is 468 km, its average slope is 0.26‰, and its catchment area is 46710 km^2. There are large tributaries such as the Wushui, Lianjiang, Yujiang, Qianjiang, Binjiang and Suijiang Rivers etc. in the North River.

The East River is the third largest river system of the Pearl River Basin, located between 113°52′~115°53′ of east longitude and 22°33′~25°14′ of north latitude. The main stem of the East River rises from Xunwu County, Jiangxi Province, it flows to the Pearl River Delta from north to south at Shilong Town of Dongguan City, Guangdong Province. The total length of the East River is 520 km, its average slope is 0.39‰，its catchment area 27040 km^2. Large tributaries of the East River include the Anyuan, Xinfeng and Xizhi Rivers, etc.

The plan view of the Pearl River Basin is shown in Fig.1.1. The characteristics of channel reach of Pearl River Basin system are listed in Table 1.1.

Table 1.1 Characteristics of the Pearl River channel

Name of river systems and channel reach		Catchment area (km^2)	River length (km)	Slope (‰)
West River system		353120	2075	0.580
Upper river	Nanpan River	56880	914	1.740
	Hongshui River	138340	659	0.366
Middle river	Qianjiang River	198820	122	0.065
	Xunjiang River	309260	172	0.097
Lower river	West River	353120	208	0.086
North River system		46710	468	0.260
Upper river(Zhenshui)		7554	212	0.590
Middle river		34302	173	0.250
Lower river		46710	83	0.082
East River system		27040	520	0.388
Upper river(Xunwushui)			138	2.210
Middle river			232	0.311
Lower river			150	0.173
Delta river system		26820		
River outlet of West River			139	0.048
River outlet of North River			105	0.053
River outlet of East River			42	0.0005
Pearl River Basin		453690	2214	0.453

1.1.2 Topography and morphology

The Pearl River Basin is located in the subtropical zone with the Wuling Mountain to the north, the South China Sea to the south, the Yunnan-Guizhou Plateau in the west, the Guangxi hilly land and basins in the centre and the delta in the southeast. Topographically, it is high in northwest and low in southeast. It can be classified into highland, hilly land and plain. The mountainous area in the watershed accounts for over 60％ of the total catchment, mainly at an elevation of 1000m～1500 m above sea level. The trend of most mountains is northeast and northeast-east. The mountains are mainly folded mountains, among them the Nanling Mountain is the maximum, extending from the Wuyi Mountain in the east to the Bashilinan Mountain in the west. The Nanling Mountain extends 600 km from east to west and 200 km from north to south, which is the watershed divide of the Changjiang River and the Pearl River.

Picture 6 Scenery in Zuojiang River (Longzhou sighting platform)

The hilly land is mainly located in the southeast part of the watershed, which are piedmonts and along the boundary of basins, accounting for over 20% of the total watershed area. There are several typical hilly lands in the Yujiang and Youjiang River basins, and Danxia hilly land and granite hilly land. The Yujiang River hilly land includes the lower reaches of the Zuojiang (See Picture 6) and Youjiang Rivers and Nanning Basin, its total area is about 5000 km^2 and its top elevation is below 300 m. It is the largest hilly land in the Pearl River Basin. The Youjiang River hilly land is located between the mountainous area and the plain of the Youjiang River Valley, extending several hundred kilometers from the Baise Basin. It is the typical hilly land in the river valley. Its elevation is 200 m to 250 m. The Danxia hilly land is not widely distributed, with its representative in the Upper North River. The granite hilly land is mainly located in northern Guangzhou, Lower East River and at Deqing of the West River.

Picture 7 shows the Jiulong Gouge in Heng Couty.

Picture 7 Jiulong Gouge in Heng Couty

The plain of the Pearl River Basin accounts for 5.6% of the total watershed. Small basins are situated in the upper river valleys, such as Zhanyi and Yilan basins in the Nanpan River Valley, Lianxian, Shaoguan, and Yingde basins in the North River. The river plains are in the middle and lower reaches, such as the Lower Liujiang River, Qianjiang River, Yujiang River and Xunjiang River. The delta plain is at the river mouth, which is the most important plain of the watershed. The area of the delta plain accounts for 80% of the delta.

The inclined topography of the watershed from northwest to southeast or from north to south has significant effect on the formation and distribution of storms in the watershed and the features of the flood.

1.1.3 Soil and vegetation

The Pearl River Basin is quite broad with different factors of topography, climate, vegetation cover and soil in various zones. Red soil, yellow soil, calcareous soil, hilly meadow soil are widely distributed. The arable land is mainly paddy field and dry farm.

There are 68.2 million mu (1 ha=15 mu) arable land. The percentage of arable land is lower than the national average, while the percentage of forest is higher than the nationa average. 80% of the arable land and forest concentrate in the lower river valley. The forest is mainly of sub-tropical broad-leaf forest. The forest coverage is 32.7% in Yunnan Province, 30.0% in Guizhou Province, 39.3% in Guanxi Zhuang Autonomous Region and 43% in Guangdong Province. Due to the high forest coverage, the sediment concentration of the Pearl River is low. The average annual sediment concentration of the West, North and East Rivers are 0.342 kg/m^3、0.144 kg/m^3 and 0.123 kg/m^3, respectively.

1.2 Social economy

The Pearl River Basin includes Yunnan, Guizhou, Guangxi, Guangdong, Hunan and Jiangxi Province (Autonomous Region), 49 cities, 202 counties, Hong Kong and Macao Special Administration Regions. Shenzhen and Zhuhai Special Economic Zones are located in the watershed. The total population is 96.64 million, among which 9.24 million in Yunnan, 10.24 million in Guizhou, 37.87 million in Guanxi, 37.90 million in Guangdong, 0.91 million in Hunan, and 0.48 million in Jiangxi. The average density of population is 219 person/km^2, higher than the national average. The distribution of population is uneven, and the maximal density of population is 670 person/km^2 in the delta area. The density of population in the West River Valley is 84 person/km^2, 203 person/km^2 in the North River Valley, and 235 person/km^2 in the East River Valley. It is 156 person/km^2 in Yunnan, 170 person/km^2 in Guizhou, 187 person/km^2 in Guanxi, 341 person/km^2 in Guandong, 179 person/km^2 in Hunan, 134 person/km^2 in Jiangxi. There are many nationalities lived in the watershed, most of them are Han people, and the minorities include Zhuang, Miao, Yao, Buyi, Maonan, Yi, Hani, Yaolao, Shuijia, Li, Man, Hui and Tong.

The total arable land in the watershed is 68 million mu with an average of 0.71 mu per capita. About 76％ of the arable land is in Guangdong and Guangxi, while about 80％ of the waste land are in Guizhou and Guangxi.

Table 1.2 Social economy data of the Pearl River Basin in 2000

Province (Autonomous region)	Area (km^2)	Cropland area (km^2)	Registered population (mil.)	Non-agricultural population (mil.)	Gross domestic product (bil. yuan)	GDP of industry & agriculture (bil. yuan)	GDP of industry (bil. yuan)
Yunnan	59380	806.91	9.2386	1.3626	61.030	76.475	58.617
Guizhou	60360	740.85	10.2367	1.1675	18.234	22.807	13.029
Guangxi	202440	3357.65	37.8672	7.0638	159.438	204.665	144.661
Guangdong	111250	1817.45	37.9053	14.9733	729.229	1426.739	1339.360
Hunan	5110	63.09	0.9157	0.1498	4.23	6.718	4.738
Jiangxi	3560	33.59	0.4776	0.0643	1.312	1.441	0.496
Total	442100	6819.54	96.6411	24.7813	973.473	1738.845	1560.901

In 2000 the GDP of the total watershed were 973.5 billion RMB yuan, in which

1738.9 billion yuan in industry and agriculture (1560.9 billion yuan in industry and 178.0 billion yuan in agriculture), accounting for 11.04% and 15.72% of the nation respectively. However, the development in various regions is different. The eastern region and the lower reaches of the rivers are more developed, while the western region and the upper reaches of the rivers are less developed. The Pearl River Delta is the first economic zone of reform and opening up to the outside world. After 20 year development it has become the most developed area in China. In 2000 the GDP was 578.3 billion RMB yuan and the value of foreign trade was 84.741 billion dollars. Among the seven largest rivers of China the average density of population, GDP of industry and agriculture in the lower reach of the Pearl River are the largest.

Social economy data of the Pearl River Basin is listed in Table 1.2.

1.3 Hydrology and climate

1.3.1 Characteristics of climate

The Pearl River Basin is located in the southern part of China, the tropic of cancer traverses the central part leaning to the south of the river basin, the South China Sea to the south, at a distance from Indochina and look over Bengal bay. The river basin is affected by southeast monsoon, as a whole belongs to subtropical climate, the climate at the edge of the northern part and in the upper river basins of the Yunnan-Guizhou Plateau can be divided into subtropical wetness and full wetness climate area. Climate features of the basin are generally no chilliness in winter, no very hot in summer, rainy in spring and summer, dry in autumn and winter, and frequent influence by tropic cyclones in summer and autumn. It is the most distinct continent monsoon climate and oceanic climate area. In the watershed the radiation from the sun is very strong, and the weather is mild. The average annual temperature is between 14^0C~22^0C, no big yearly variation, the extremely highest temperature in Baise of Guangxi and Shaoguan of Guangdong once reached a record high 42.5℃ and 42.0℃, respectively, the extremely lowest temperature in Luliang of the Nanpan River was -9.8^0C. The average annual relative humidity is between 71％~82％, sometimes 100％ in spring; the average annual precipitation is approximately 1470 mm, decreasing from east to west, more rainfall along the coast than in the hinterland, more rainfall in the mountainous area than in the plain, more rainfall in windward side than leeward side and valleys as well as basins. The average annual precipitation in the middle and lower reaches of the North River and the East River is up to 2000 mm~2500 mm. The maximum average annual precipitation in the watershed is 3158 mm recorded at Changqi Station，and the minimum average annual precipitation 720 mm recorded at Yuguopu Station. The precipitation in the rainy season from April to September accounts for 70％~80％ of the annual total；the average annual surface evaporation on watershed is between 900 mm~1400 mm, generally smaller in the northern area and larger in the southeasten area. The average annual sunlight hours are 1282 h~2243 h, normally longer before June and shorter after July. The average annual wind speed is between 0.7m/s~2.9m/s, relatively stronger in winter and weaker in summer. Over 30m/s wind and stronger than grade twelve wind may occur in the delta and the coast area are directly affected by cyclones.

1.3.2 Characteristics of rainstorms

The Pearl River Basin is situated in the monsoon zone of tropical and subtropical region. The climate is quite complicated. The northern region belongs to humid climate zone of subtropical region and the rest belongs to humid climate zone of tropical zone of South Asia. The main climate systems include frontal surface, trough, barometric minimum, shearing line, tropical cyclone, etc. The main activity of frontal surface occurs from April to June and the rainstorm induced by barometric minimum also takes place in this period. The main activities of barometric minimum and frontal surface happen simultaneously, inducing rainstroms with a short duration and a large amount in small areas, when it happens with others, continuous rainstorms may take place. Tropical cyclones occur from July to September.

In winter the Pearl River Basin is situated at the edge of continental high pressure zone, northeast winds prevail and the weather is dry. Rainstorms are scarce. In spring and summer rainstorms with high intensity are frequent. Autumn is a transitional period, and the intensity and frequency of rainsotms decrease. From April to June rainstorms incudecd by frontal surface and barometric minimum are dominant in the basin, and its frequency accounts for 58% of the annual. From July to September rainstorms induced by typhoons dominate. Scarce rainstorms may occur from April to September, but high-intensity rainstorms mainly occur from April to June.

The duration of a rainstorm lasts generally 7 days, the precipitation in 3 days may account for 80%-85% of the precipitation in 7 days, while the precipitaion in 3 days in the center of rainstrom may account for 90% of the precipitation in 7 days. The rainstorm precipitation in the Pearl River Basin decreases from east to west with high values in mountanous regions and low values on plains. Orographic precipitation is the highest. The Yunkaida Yunwu, Tianlu and Lianhua Mountains are the watershed divide between the Pearl River Basin and the rivers along the southeast coast of China. Those mountains are the first screen of the warm-humid, southeast atmospheric cuurent and southwest atmospheric current. The maximum 3 day precipitation is 500 mm to 800 mm, which is the highest in the Pearl River Basin. In the middle of the basin there are Shiwanda Mountain, Dayao Mountain, Lianhua Mountain and Dongfeng Mountain, where the orographic precipitation is high with maximum 3 day precipitation of 400 mm to 700 mm. The intensity and scope of rainstorms in the west of the basin are smaller than that in the east. The maximum 3 day precipitation is 200 mm to 300 mm in south Guizhou, Luoping of Yunnan and Luodian of Guizhou.

1.3.3 Characteristics of floods

Floods of the Pearl River Basin are caused by rainstorms. As the large area and high intensity of the rainstorm are almost in mountainous areas without storage of lakes, concentration of the runoff is rapid, resulted in high floods with large flood volume and long duration. The characteristics in various tributaries and main stream are different due to different characteristics of rainstorms and geomorphologic characteristics.

(1) The West River

The flood in the West River mainly takes place from May to October. As the area of the watershed is large, the timing of the flood in various tributaries is different. Generally, the flood occurs from April to July in the Guijiang River, it occurs from May to August in the Liujiang River, it occurs from June to September in the Hongshui River, and it occurs from June to October in the Yujiangi River. The flood of the West River is high with long duration and large volume, which is induced by several consecutive rainstorms. The duration of a high flood may last 30 to 40 days, which may have several floods peaks. The largest historical flood discharge at Wuzhou Station was 54500m^3/s (July 1915) and the measured maximum flood discharge was 52900 m^3/s (June 1998).

The large flood of the West River mainly comes from the Qianjiang River in the upper basin. According to statistics the annual maximum flood volume in 30 days at Wuzhou Station was composed of that of the Qianjiang River (64.2% of the total, larger than its area percentage), the Yujiang River at Guigang Station (21.5% of the total, less than its area percentage), the Guijiang River at Majiang Station (6.9%, larger than its area percentage), and the rest (7.4%, less than its areas percentage).

(2) The North River

The large flood of the North River mainly occurs from May to July with peculiarity of a mountainous flood, a high peak and a short duration. One or two flood peaks appear in a flood event, while multi-peaks appear occasionally. The duration of a flood event induced by a 3-5 day consecutive precipitation is about 7-20 days. The flood of the North River mainly comes from the area above Hengshi. As the watershed is not large the whole watershed may be covered by a strong precipitaion event. Due to steep slope and short length of the tributaries, the floods of the tributaries may meet with that of the main stream. The floods of the tributaries below Hengshi occur earlier than that of the main stream. Therefore they meet with each other occasionally. The historical flood peak at Shijiao Station (flood control cross-section) was 22000 m^3/s (July 1915). The measured flood peak was 19000 m^3/s (May 1982). 84% of the maximum 15 day flood volume at Shijiao Station was from the area above Hengshi and the rest (16%) was below Hengshi.

(3) The East River

The flood of the East River mainly occurs from May to October, concentrated in June to August. The duration of a flood event (almost with one peak) lasts 10 days to 20 days. The flood of the East River mainly comes from the catchment above Heyuan. Due to the small catchment area, the flood peaks from the tributaries and the main stream meet with each other frequently. Three dams were built in this catchement, Xinfeng Dam in 1959, Fengshu Dam in 1973 and Baipenzhu Dam in 1985. The watershed controlled by the three dams account for 46.4% of the total (above Boluo Station). Since then, the characteristics of the flood of the East River have been changed significantly. The 1% flood peak discharge at Boluo reduced to 11670 m^3/s~12070m^3/s from 14400 m^3/s, which is almost the 5% flood peak 11200 m^3/s. Consequently, the flood control problem has been basically solved. The measured maximum flood discharge at Boluo was 12800 m^3/s (June, 1959) and 10200 m^3/s (June, 1966), they were 14100 m^3/s and 14300 m^3/s after recovery calculation.

(4) The Pearl River Delta

The Pearl River Delta is affected by the floods from the West, North and East Rivers. The West River and the North River meet at Sixianjiao, Sanshui City, Guandong Province. From there the floods enter the West-North River Delta. The floods of the East River enter the East River Delta at Shilong. The floods of the Pearl River join the South China Sea through 8 outlets.

According to statistics，the timing of the floods of the East River and that of the West and North Rivers is different. Furthermore, there is the Shiziyang between the two deltas. Therefore, the influence of the floods from the two areas is not large.

The floods of the West River often meet with that of the North River at Sixianjiao. The larger the flood, the larger the chance the floods meet. There are 4 occasions. Extraordinary floods of the two rivers meet with, as in 1915 and 1994; a large flood of the West River meets with a common flood of the North River, as in 1949; a common flood of the West River meets with a large flood of the North River, as in 1931; common floods of the two rivers meet with, as in 1947.

1.3.4 Flood disasters

Flood disasters are the most serious disaster in the Pearl River Basin, in which the plains in the lower reaches and the delta are affected most significantly. Due to large watershed and difference in topography and climate flood disasters in various regions are different. Flood disasters may happen in the whole watershed or a part of the watershed. A large rainstorm occurred in a large area of the watershed may induce a devastating flood disaster in the plains in the lower reaches of the river. Local rainstorms in the upper region of the watershed, as Yunnan, Guizhou and Guanxi, may induce local flood disasters, including landslides, debris flows, which have great threat to the local inhabitants.

According to historical records, in 582 years from 1368 to 1949 there were 104 times of flood disasters in large areas and 867 times of flood disasters in small areas in Yunnan, Guizhou, Guangxi and Guangdong. Extraordinary or large disasters were large floods happened in 1464, 1492, 1535, 1571, 1586, 1616, 1701, 1704, 1769, 1773, 1794, 1833, 1856, 1864, 1877, 1885, 1915, 1947, and 1949. Over 10 counties and cities were disaster areas each time. In 35 years from 1915 to 1949 22 times of flood disasters took place, one million mu farmlands were damaged each time.

From 1950 to 2000 the accumulative damaged area by flood disasters were 726.31 million mu, among which 374.96 million mu were destroyed，the average annual area was 14.43 million mu and 7.35 million mu respectively. The total affected population was 494.11 million persons, and the average annual one was 9.68 million persons. The death toll was 25872 persons, and the average annual death toll was 507 persons. 9.21 million houses were collapsed and the average annual was 180 thousands. Although there was no extraordinary flood as in 1915 during this period, large floods happened in 1994, 1998, 1968, 1996, and 1959. The frequency and extent of damage increased obviously. Hydro projects were destroyed frequently. Levees were destroyed 596 km annually.

In 1915, 1947, 1949, 1959, 1968, 1976, 1979, 1982, 1988, 1994, 1996 and 1998 serious flood disasters happened, among which the situation was the worst in 1915.

From June 21 to July 10, 1915 heavy rainstorms occurred in Guangdong, Guanxi, Jiangxi, Hunan and Yunnan, resulted in big floods in the river systems of the Pearl River. An over 0.5% flood peak took place simultaneously in the West River and the North River. A large flood also occurred in the East River. During the flood spring tides took place, resulted in tidal backwater. Thus, a devastating flood disaster took place. The Lower Pearl River and Delta were the most seriously affected regions. Almost all the levees breached and the Guangzhou City was submerged with water depth over 2 m for 7 days. The damaged areas were over 57 counties (cities). Guangdong, Guangxi, Hunan and Jiangxi were the most serious. The devastated arable land in Guangdong and Guangxi were about 14 million mu and the population affected were about 6 million persons, among which the devastated arable land in the Lower Pearl River and Delta were 6.48 million mu and the population affected were 3.78 million persons, including over 100 thousand injured and dead persons. According to the price standard in 2000, the economic loss was 46.2 billion RMB Yuan in Guangzhou.

Waterlogging disasters in the Pearl River Basin were also serious. In Guangdong Province the waterlogging-prone areas were 8.79 million mu, accounting for 25.2％ of the total arable land, mainly in the lower reaches of the river and the delta. In Guangxi Zhuang Autonomous Region the waterlogging-prone areas were 5.23 million mu, accounting for 10％ of the total arable land, mainly in the Lower Yujiang River, Xunjiang River and coastal area in southern Guangxi. In 1964 a devastating waterlogging disaster occurred in the Pearl River Delta, the waterlogging area was 4 million mu.

Pictures 8, 9 and 10 show scenes of big floods in the Pearl River Basin.

Picture 8 Big flood at Wuzhou on West River

Picture 9 Inundating scene at Lishi (2) Hydrologic Station during extraordinary big flood in Wujiang River in July, 2006

Picture 10 Inundating scene at Shaoguan City during extraordinary big flood in Wujiang River in July, 2006

1.4 Geological condition

The Pearl River Basin surrounds by mountains as watershed divides with neighboring river basins. The elevation of the watershed divide is above 700 m, mainly in the range of 1000m～2000m, the highest peak of the Wumeng Mountain is 2853m. The elevation of the Pearl River Delta is lower than 50m.

The Pearl River Basin inclining from northwest to southeast includes four geomorphologic zones. The most western zone is the Yunnan-Guizhou Plateau with three step plantation surfaces, their elevation are 2000m, 1800m and 600m, respectively. The elevations of mountain peaks are in the range of 1800 m to 2500 m. Calcareous rock and karst geomorphy prevail in this zone. The mid-west zone is the Qiangui Plateau, the transitional zone between Yunnan-Guizhou Plateau and Guanxi-Guangdong hilly land. The elevation is 1600m～1800m in the west and 1000m～1200m in the east. Three step plantation surfaces with elevations of 1600m, 1400m and 1200m, respectively. Calcareous rock prevails in this zone. The mid-east zone is Guangxi-Guangdong hilly land, valleys and basins. The elevations of the mountain peaks are 800m～1500m with the highest of 1700m～2141m. Basins are situated in the lower reaches of the rivers. In the southeast is the Pearl River Delta with different geomorphology. The deposit of the delta is of late Pleistocene series of Quaternary system. Plains account for 80％ of the zone and hilly lands with peaks of 200m to 500m account for 20％.

The geology of the Pearl River Basin is complex. The strata are from Sinian period to Quarnary period, mainly from Cambrian period, Devonian period, Carboniferous period, and Triassic period. In the aspect of geological structure, the New Cathaysian system is the main geological structure in the watershed, from the western zone to the east zone, the further the east, the later the time of formation and the stronger the extent of development and activity.

According to (GB18306—2001)《China Earthquake Movement Parameter Zoning Map》, the features of earthquake in various zones of the basin are listed in Table 1.3.

Table 1.3 Features of earthquake in various zones

River	Location	Acceleration (g)	Frequency (s)	Earthquake intensity
Upper West	Yunnan & Guanxi	0.15-0.40	0.35-0.40	VII-X
		0.05 or less		
North River	Above Feilai Valley	0.05 or less	0.35	VI or less
	Below Feilai Valley	0.05	0.35	VI
East River	Heyuan	0.10	0.35	VII
	The rest	0.05	0.35	VI
Delta	West-North River	0.01	0.35	VII
	The rest	0.05	0.35	VI

The areas with acceleration larger than 0.01g are unstable in regional geological structure, unfavorable for building safety. The areas with acceleration less than 0.01g are stable in regional geological structure, favorable for building safety.

2. Variations in Runoff and Sediment Load in Major Rivers of Pearl River Basin

2.1 General situation

The average annual sediment load of the Pearl River Basin including the West River, the North River, the East River and the Pearl River Delta, amounts to 88.72 million tons. Its sediment load mainly comes from the West River, and the average annual sediment load from 1957～2000 at Gaoyao Hydrologic Station on the West River amounts to 71.60 million tons, accounting for 80.7% of the total of the Pearl River Basin. Sediment load at Shijiao Station on the North River and Boluo Station on the East River is 5.636 million tons and 2.569 million tons, respectively, accounting for 6.4 % and 2.9 % of the total, respectively. According to China Gazette of River Sediment, 2005, the Xiaolongtan Station on the Nanpan River, Qianjiang Station on the Hongshui River, Liuzhou Station on the Liujiang River and Nanning Station on the Yujiang River are used as representative stations on the tributary of the Upper West River, Dahuangjiangkou Station on the Xunjiang River, Wuzhou Station and Gaoyao Station used as representative stations on the main stream of the West River, Shijiao Station as the representative station of the North River and Boluo Station as the representative station on the East River, as shown in Fig. 1.2. Table 2.1 lists the average annual runoff and sediment load at those hydrologic stations.

Table 2.1 Average annual runoff and sediment load at main hydrologic stations in the Pearl River Basin

River	Controlling station	Catchment area and its percentage of the total		Average annual runoff & its percentage of total		Average annual sediment load & its percentage of total	
		（km^2）	(%)	($bil.m^3$）	(%)	($bil.m^3$）	(%)
Nanpan River	Xiaolongtan	1.54	11.9	3.826	5.7	49.4	11.8
Hongshui River	Qianjiang	12.89	74.0	6.672	62.7	419	88.9
Liujiang River	Liuzhou	4.54	26.0	39.67	37.3	52.5	11.1
Qianjiang River	Qianjiang+ Liuzhou	17.43	70.6	106.39	73.9	471.5	83.9
Yujiang River	Nanning	7.27	29.4	37.51	26.1	90.4	16.1
Qianjiang River +Yujiang River	Qianjiang+Liuzhou+ Nanning	24.7	70.3	143.9	65.4	561.9	82.6
Xunjiang River	Dahuangjiangkou	28.85	82.1	171.6	78.0	572	84.1
West River	Wuzhou（four）	32.7	93.0	204.3	92.9	636	93.5
West River	Gaoyao	35.15	84.7	220	77.2	680	89.6
North River	Shijiao	3.84	9.2	41.86	14.7	54.1	7.1
East River	Boluo	2.53	6.1	23.08	8.1	24.6	3.2
Pearl River Basin	Gaoyao + Shijiao+ Boluo	41.52	100	284.94	100	758.7	100

Notation：Percentage shown in Table 2.1 refers to ratio of the figure at the station to the one at the next station in the lower reach of the same river or the total figure at several converging stations below.

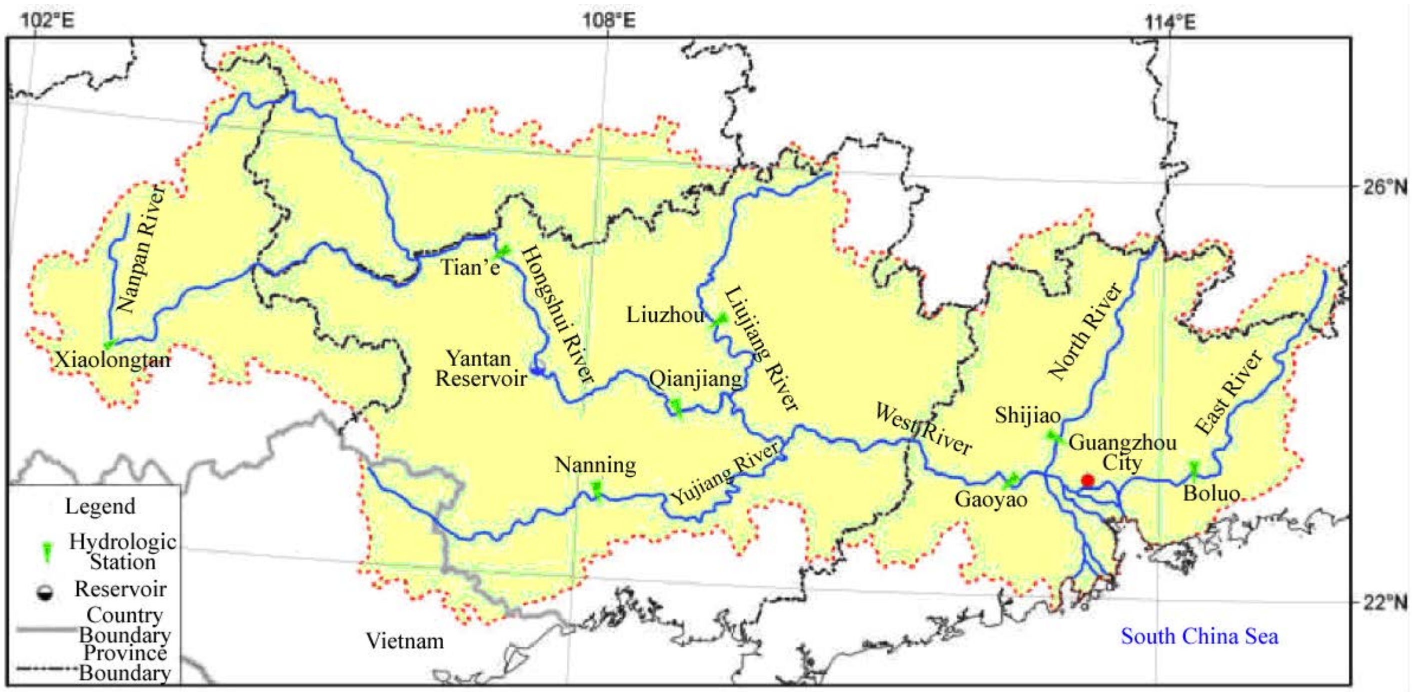


Fig.1.2 Plan view of main hydrologic stations in Pearl River Basin

2.2 Variations in runoff and sediment load in main stem and tributaries of West River

2.2.1 Variations in runoff and sediment load in tributaries of West River

Main tributaries of the West River include the Nanpan River, Hongshui River, Liujiang River as well as Yujiang River, and the average annual runoff and sediment load at hydrologic stations are shown in Table 2.2. Pictures 11, 12 and 13 show those stations.

Picture 11 Xiaolongtan Hydrologic Station

Picture 12 Nanning Hydrologic Station

Picture 13 Liuzhou Hydrologic Station

（1）Nanpan River, Liujiang River and Yujiang River

Fig.2.1 shows changes in runoff and sediment load at hydrologic stations on the Nanpan River, the Liujiang River and the Yujiang River. The average annual runoffs at Xiaolongtan Station on the Nanpan River, Liuzhou Station on the Liujiang River and Nanning Station on the Yujiang River were 3.826 billion m^3, 39.67 billion m^3 and 37.51 billion m^3, respectively, the maximum annual runoff at these stations were 7.452 billion m^3, 64.49 billion m^3 and 60.6 billion m^3, respectively. The ratios of the maximum one to the minimum one were 4.54, 2.96 and 3.0, respectively. From Fig.2.1, it can be seen that the annual runoff at Xiaolongtan Station shows a decreasing trend as a whole, the annual runoff before 1975 was relatively larger, after that it decreased; variations in runoff at Liuzhou Station and Nanning Station showed no obvious trend.

The average annual sediment load at Xiaolongtan Station on the Nanpan River, Liuzhou Station on the Liujiang River and Nanning Station on the Yujiang River were 4.94 million tons, 5.25 million tons and 904 million tons, respectively. The maximum one at these stations were 11.50 million tons, 17.90 million tons and 21.90 million tons, respectively, and the ratios of the maximum one to the minimum one were 11.27, 25.07 and 10.19, respectively. The average annual sediment concentrations at these three stations were 1.273 kg/m^3, 0.132 kg/m^3 and 0.241 kg/m^3， respectively, among which one at Xiaolongtan Station on the Nanpan River was the largest. It is seen from Fig.2.1 that the sediment load at Xiaolongtan Station shows a decresing trend, it reached the maximum of 6.46 million tons in the 1960s, and reached the minimum of 3.95 million tons during 2000~2005; sediment load at Liuzhou Station generally showed an increasing trend; no obvious trend at Nanning Station on the Yujiang River.

Fig.2.2 are the mass-curve of annual runoff and annual sediment load at Xiaolongtan, Liuzhou and Nanning Stations and the double mass-curve of annual runoff~annual sediment load. It can be seen from Fig.2.2 that there exists a turn in

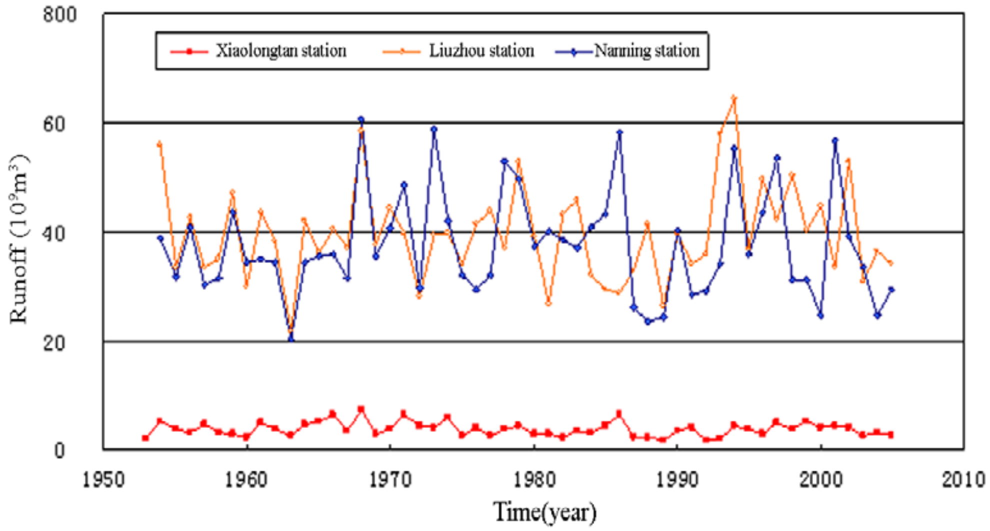
1994 and at this point the double mass-curve of annual runoff and annual sediment load obviously began to deflect to the runoff axis, which reveals that the sediment load decreased from 1994. The main reason for the decrease in sediment load is that in 1992 the middle and upper reaches of the Nanpan and Beipan Rivers were treated as the key prevention area of soil and water conservation.

Table 2.2 Average annual runoff and sediment load at hydrologic stations of the upper West River in different periods

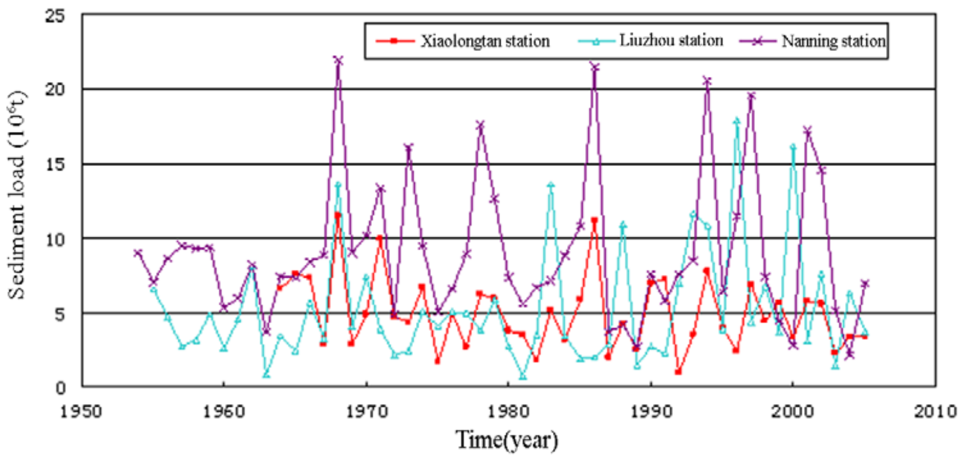
Stations	Time / Item	1954* ~1959	1960 ~1969	1970 ~1979	1980 ~1989	1990 ~1999	2000 ~2005	Average annual
Xiaolongtan, Nanpan River	Runoff (10^9m^3)	3.943	4.452	4.251	3.266	3.639	3.517	3.826
	Sediment load (10^6t)		6.46	5.19	4.32	4.99	3.95	4.94
	Sediment concentration (kg/m^3)		1.45	1.22	1.32	1.37	1.12	1.27
Qianjiang, Hongshui River	Runoff (10^9m^3)	632.0	70.10	71.47	60.97	69.91	60.94	66.72
	Sediment load (10^6t)	33.05	47.81	52.68	59.18	32.64	9.33	41.87
	Sediment concentration (kg/m^3)	0.523	0.682	0.737	0.971	0.467	0.153	0.628
Liuzhou, Liujiang River	Runoff (10^9m^3)	41.25	38.53	40.08	34.57	45.15	38.72	39.67
	Sediment load (10^6t)	4.41	4.85	4.47	4.32	7.09	6.41	5.25
	Sediment concentration (kg/m^3)	0.107	0.126	0.111	0.125	0.157	0.166	0.132
Nanning, Yujiang River	Runoff (10^9m^3)	36.14	35.74	41.62	36.88	38.29	34.73	37.51
	Sediment load (10^6t)	8.82	8.60	10.47	7.84	9.94	8.11	9.04
	Sediment concentration (kg/m^3)	0.244	0.241	0.252	0.213	0.259	0.234	0.241

Notation：Runoff at Xiaolongtan Station was measured from 1953, other stations from 1954; Sediment load at Xiaolongtan Station from 1964, other stations from 1954.

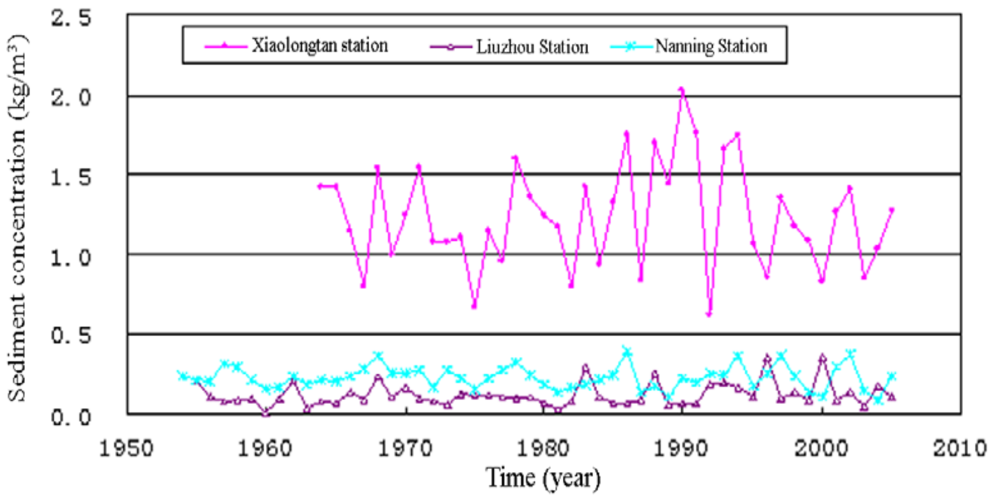
The curve slope of the sediment load at Liuzhou Station after 1992 began to increase, as shown in Fig.2.2, which shows that the sediment load began to increase after 1992. The average annual runoff in 1951~1991 was 38.2 billion m^3, and the sediment load was 4.41 million tons. The average annual runoff in 1992~2005 was 43.6 billion m^3 and the sediment load 7.46 million tons. Compared with that in 1951~1991, the runoff only increased by 13.9%, while the sediment load increased by 68.9%, which shows that the increase in the sediment load is much larger than the runoff.



(a) Annual runoff

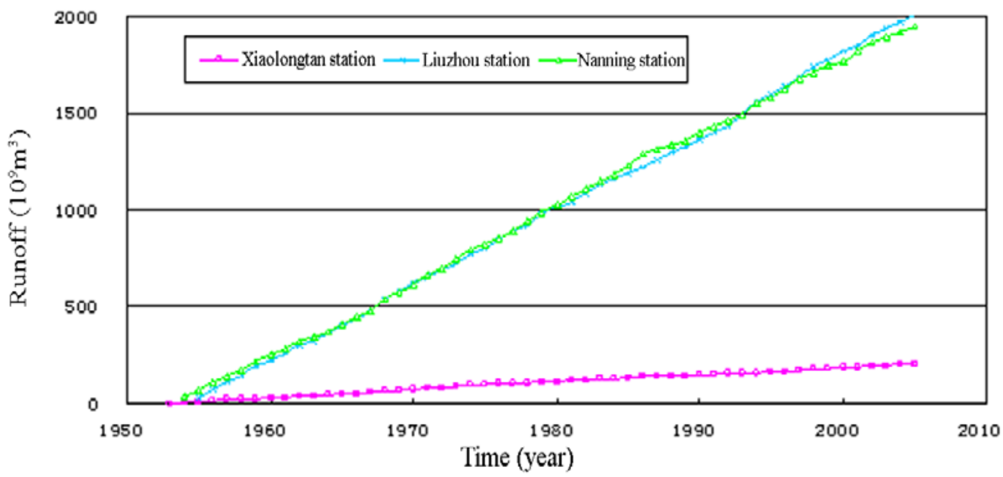


(b) Annual sediment load

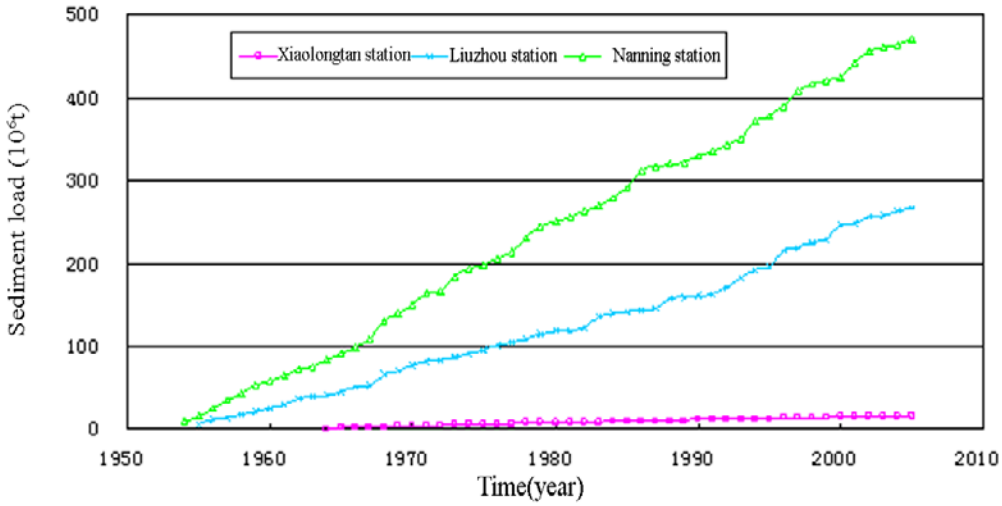


(c) Average annual sediment concentration

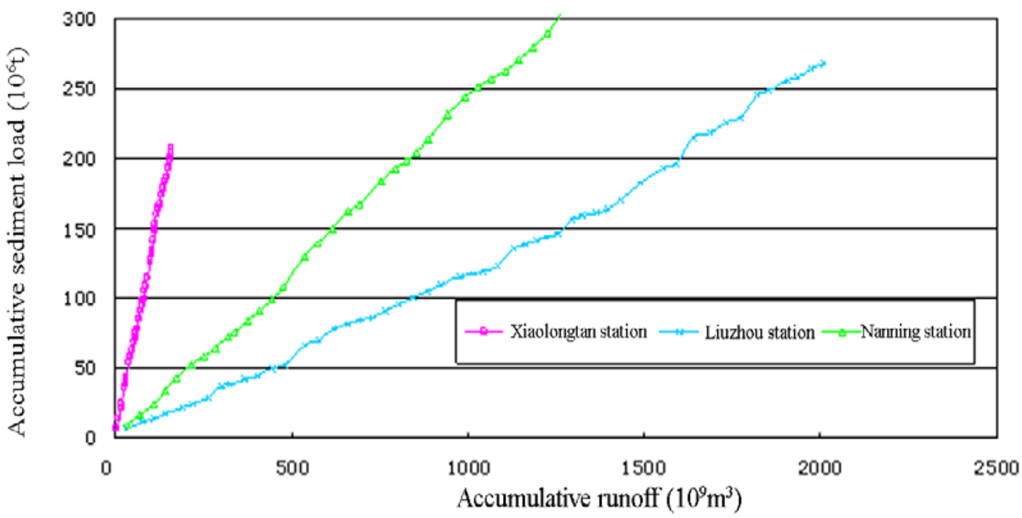
Fig.2.1 Variations in water and sediment load at hydrologic stations on Nanpan and Liujiang as well as Yujiang Rivers



（a）Accumulative annual runoff



（b）Accumulative annual sediment load



（c）Double mass-curve of annual runoff~annual sediment load

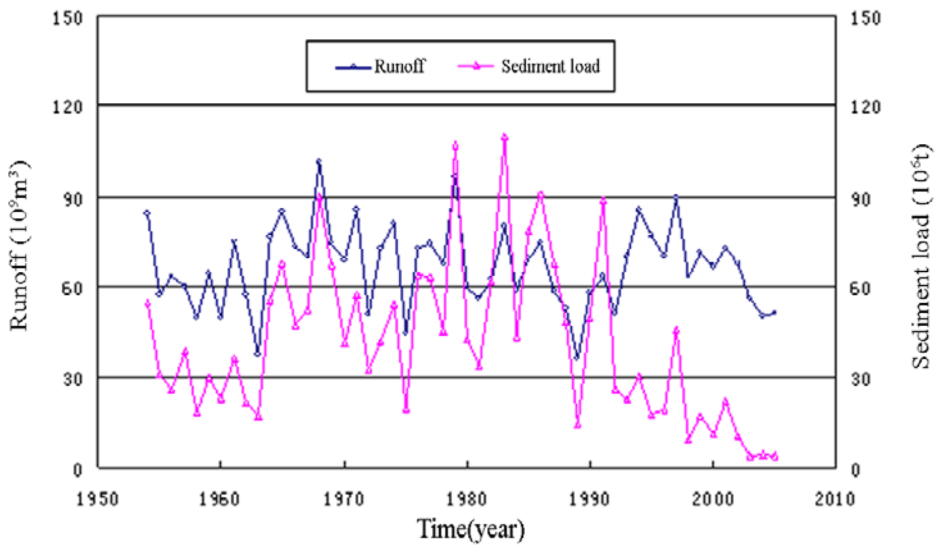
Fig.2.2 Variations in acumulative runoff and acumulative sediment load at hydrologic stations on Nanpan and Liujiang as well as Yujiang Rivers

(2) Hongshui River

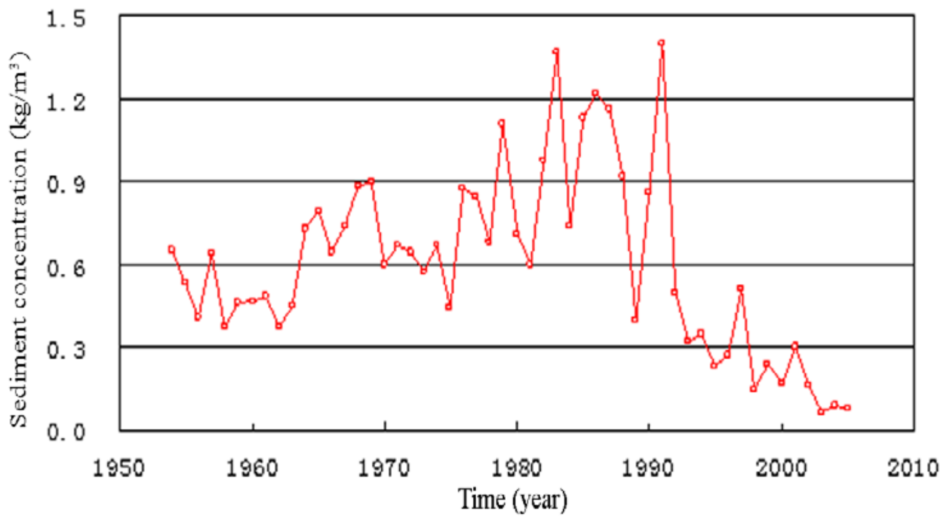
The average annual runoff at Qianjiang Station on the Hongshui River was 66.72 billion m^3, the maximum one was 101.7 billion m^3, and the ratio of the maximum one to the minimum one was 2.79. It can be seen from Fig.2.3 that the annual runoff at Qianjiang Station shows no obvious variation trend.

The average annual sediment load at Qianjiang Station was 41.87 million tons, the maximum one was 110 million tons, and the ratio of the maximum one to the minimum one was 29.41. The annual average sediment concentration was 0.628 m^3/s. Fig.2.3 shows that the sediment load at Qianjiang Station decreased, especially after the construction of Yantan Hydro Project in 1992, the incoming sediment load reduced remarkably.

Fig.2.4 is the accumulative curve and double mass-curve of annual runoff~annual sediment load at Qianjiang Station. The double mass-curve of annual runoff~annual sediment load appeared turns at the year of 1963, 1982, 1991 and 2001, respectively. According to change in curve slope, the curve can be divided into five segments, that is, 1954~1963, 1964~1982, 1983~1991, 1992~2001 and 2002~2005. Table 2.3 lists the average runoff and average sediment load as well as average sediment concentration of the five periods. It can be seen from Table 2.3 that runoff at Qianjiang Station had fluctuating variation, and that after 1992 sediment load decreased greatly.



(a) Annual runoff and annual sediment load

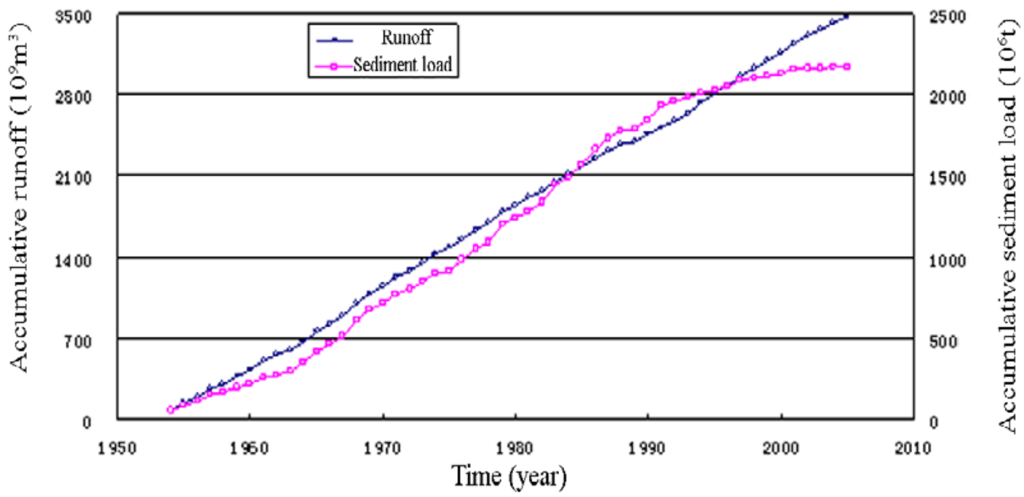


(**b**) Average annual sediment concentration

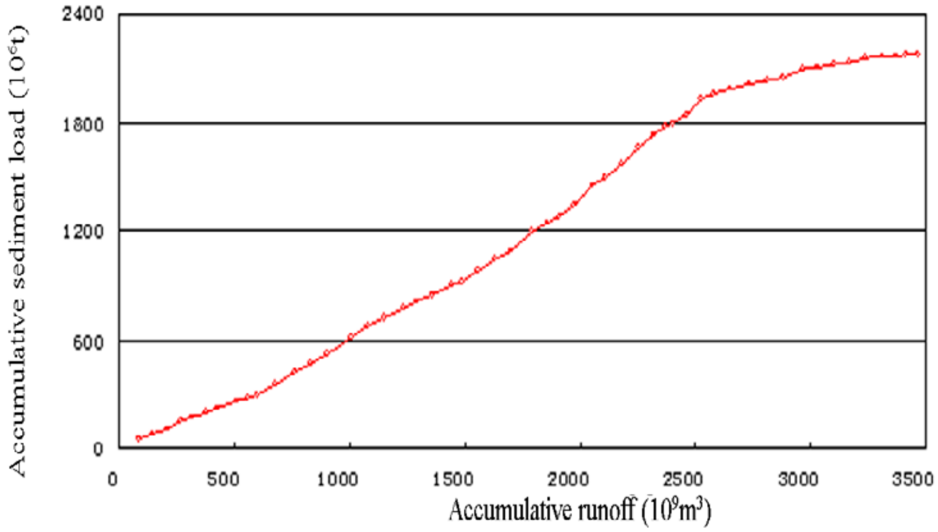
Fig.2.3 Variations in water and sediment at Qianjiang Station on Hongshui River

Table 2.3 Variations in runoff and sediment load as well as sediment concentration at Qianjiang Station

Time	Runoff（bil.m^3）	Change in runoff（%）	Sediment load（mil.t）	Change in sediment load（%）	Sediment concentration（kg/m^3）	Change in sediment concentration（%）
1954-1963	59.9		31.98		0.521	
1964-1982	72.4	20.9	54.95	53.2	0.762	53.2
1983-1991	61.4	-15.2	61.85	37.7	1.025	37.7
1992-2001	71.8	17.0	21.69	-70.3	0.293	-70.3
2002-2005	56.5	-21.2	567	-67.8	0.100	-67.8



（a） Accumulative runoff and accumulative sediment load



（b）Double mass-curve of annual runoff~sediment load

Fig.2.4 Variations in acumulative runoff and acumulative sediment load at Qianjiang Station on Hongshui River

2.2.2 Variations in runoff and sediment load in main stem of the West River

Hydrologic stations along the main stream of the West River are Dahuangjiangkou Station on the Xunjiang River, Wuzhou Station and Gaoyao Station. Runoff and sediment load at these stations are listed in Table 2.4. Fig.2.5 shows variation process of runoff and sediment load at those stations. Pictures 14 and 15 show Wuzhou Station and Night piece of the Pearl River, respectively.

Runoff and sediment load at Dahuangjiangkou Station on the Xunjiang River mainly come from the upper reach of the Hongshui River, the Liujiang River and the Yujiang River. Total runoff at Liuzhou Station on the Liujiang River, Nanning Station on the Yujiang River and Qianjiang Station on the Hongshui River accounts for 83.9% of the runoff at Dahuangjiangkou Station on the Xunjiang River, among which the runoff of the Hongshui River is the largest, accounting for 38.9%, Liujiang River 23.1%, Yujiang River 21.9%. Total sediment load of the Liujiang River and the Yujiang River as well as the Hongshui River accounts for 98.2% of the sediment load at Dahuangjiangkou Station, among which the sediment load from the Hongshui River is the largest, accounting for 73.2%, Yujiang River 15.8%, and Liujiang River 9.2%, as shown in Table 2.5.

Controlling catchment area of Wuzhou Station is 0.327 million km^2, and the one between Wuzhou Station and Dahuangjiangkou Station is 0.0385 million km^2. There are mainly the Mengjiang River on the left bank and the Beiliu River on the right between the two stations. If not considering variations in erosion and scour of the river channel, the water amount and sediment load from the river basin area between two stations accounts for 16% and 10.1% of the amount at Wuzhou Station, respectively. There are mainly the Hejiang River and the Luoding River entering between Wuzhou Station and Gaoyao Station. From Fig.2.5 it can be seen that the variations in runoff and sediment load at Dahuangjiangkou and Wuzhou as well as Gaoyao Stations are very similar. So Gaoyao Station as the last station of the West River entering the Pearl River Delta was chosen as the representative hydrologic station.

Picture 14 Wuzhou Hydrologic Station

Picture 15 Night piece of Pearl River (http：www.uutuu.commemberphoto)

Table 2.4 Characteristics of runoff and sediment load at hydrologic stations on the main stem of the West River

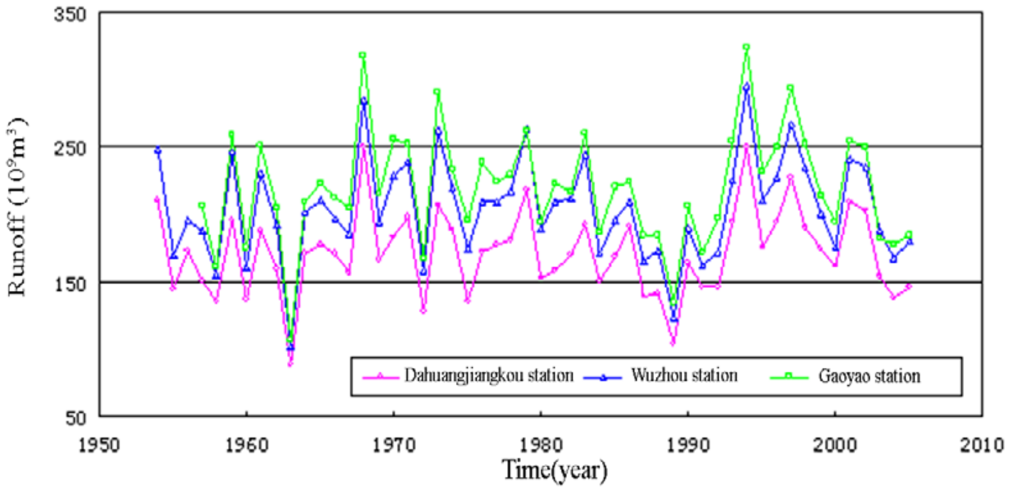
Hydrologic stations	Item	1954* ~1959	1960 ~1969	1970 ~1979	1980 ~1989	1990 ~1999	2000 ~2005	Annual average
Dahuangjiangkou, Xunjiang River	Runoff（10^9m^3）	168.5	166.7	179.2	157.2	186.5	169.1	171.6
	Sediment load（10^6t）	58.28	57.75	64.60	69.92	54.01	26.75	57.17
	Sediment concentration（kg/m^3）	0.346	0.346	0.361	0.445	0.290	0.158	0.333
Wuzhou, West River	Runoff（10^9m^3）	201.2	196.3	218.3	189.6	218.5	198.1	204.3
	Sediment load（10^6t）	68.58	67.03	79.01	75.08	51.52	27.98	63.57
	Sediment concentration（kg/m^3）	0.341	0.341	0.362	0.396	0.236	0.141	0.311
Gaoyao, West River	Runoff（10^9m^3）	209	212.5	235.4	203.3	239.9	207.5	220
	Sediment load（10^6t）	67.77	67.81	75.17	77.74	70.76	35.43	67.97
	Sediment concentration（kg/m^3）	0.324	0.319	0.319	0.382	0.295	0.171	0.309

Notation：Runoff at Gaoyao Station on the West River is from 1957, other stations from 1954；Sediment load at Gaoyao Station is from 1957, other stations from 1954.

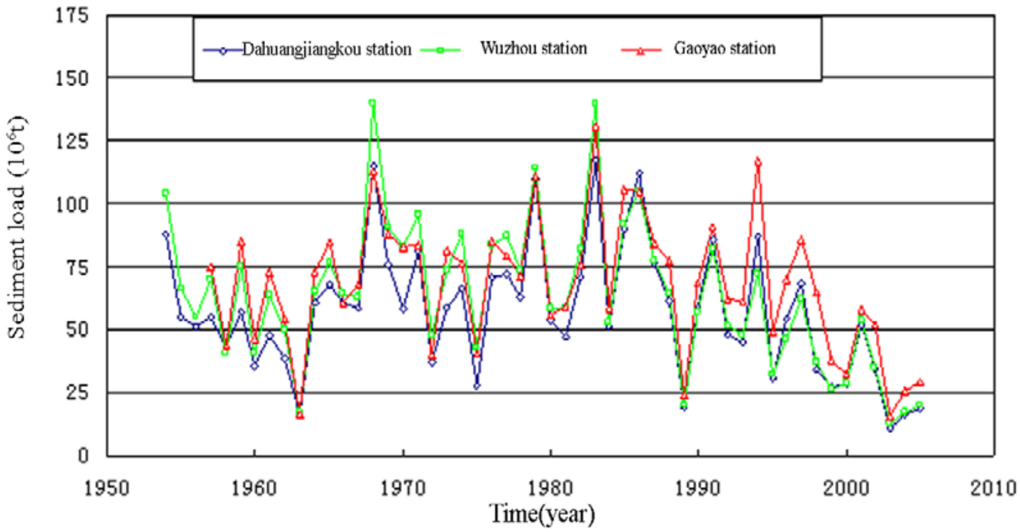
Table 2.5 Runoff and sediment load of main tributaries above Dahuangjiangkou Station on Xunjiang River

Station / Item	Qianjiang	Liuzhou	Nanning	Total	Dahuangjiangkou
Runoff（$bil.m^3$）	66.7	39.7	37.5	143.9	171.6
Percentage（%）	38.9	23.1	21.9	83.9	
Sediment load（mil.t）	41.87	5.25	9.04	56.16	57.17
Percentage（%）	73.2	9.2	15.8	98.2	

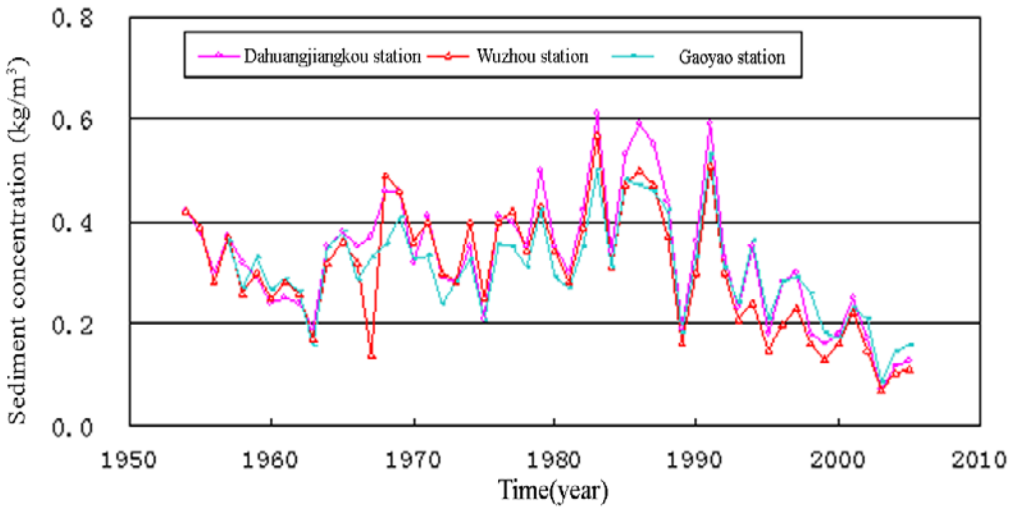
The average annual runoff at Gaoyao Station during the period of 1954~2005 was 220 billion m^3, the maximum runoff was 323.5 billion m^3, and the ratio of maximum one to the minimum was 3.0. The average annual sediment load at Gaoyao Station is 67.97 million tons, the maximum sediment load is 131 million tons（appearing in 1983）, the minimum 15.60 million tons（in 2003）, and the ratio of maximum one to the minimum is 8.40. From 1950s to 1980s, the sediment load gradually increased, reaching the maximum in 1980s, then generally decreased; during the year of 2000~2005 the annual runoff is close to the average annual runoff, but the sediment load is only 52.13% of the average annual runoff. The average annual sediment concentration at Gaoyao Station during the period of 1954~2005 is 0.309 m^3/s.



(a) Annual runoff



(b) Annual sediment load



(c) Average annual sediment concentration

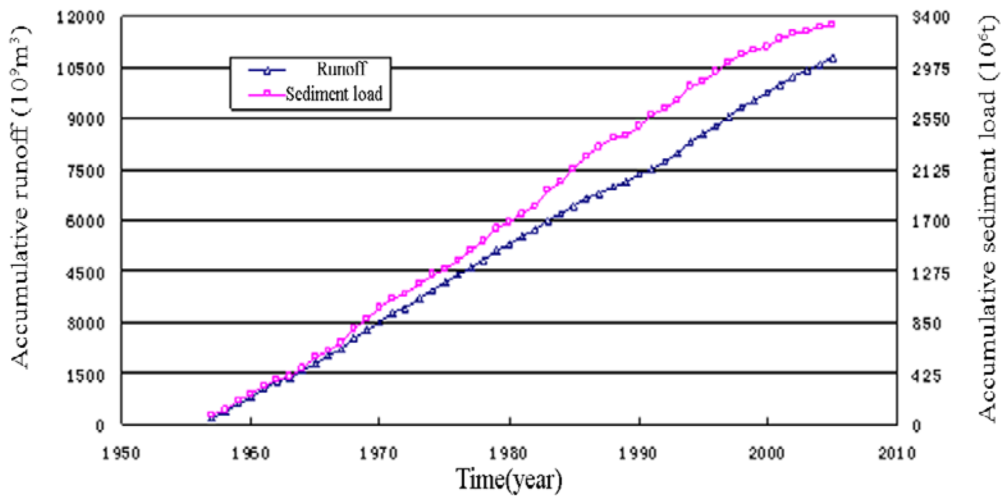
Fig.2.5 Variations in annual runoff and sediment load at hydrologic stations on main stream of West River

Fig.2.5 shows variations in annual runoff and sediment load at hydrologic stations on main stream of the West River. Fig.2.6 shows variations in accumulative annual runoff and accumulative sediment load at Gaoyao Station on the West River. From Fig.2.5 and Fig.2.6（a）, it can be seen that the runoff at Gaoyao Station had no obvious trend, whereas the sediment load after 1990s had obvious decreasing trend. As shown in double mass-curve Fig.2.6(b), variations in water and sediment can be divided into four periods, i.e., 1957~1982, 1983~1992, 1993~1998 and 1999~2005, the four periods' runoff and sediment load as well as sediment concentration are listed in Table 2.6. Their variation percentages in runoff compared with those in the former period are -10.6%, 35.8% and -22.2%, variation percentages in sediment load 15.2% , -7.6% and -52.1%, and variation percentages in sediment concentration 28.9%, -32.0 % and -38.4%, respectively. It is obvious that the sediment load and sediment concentration showed decreaseing trend after 1992. In general, runoff of main stream of the West River has no obvious trend, whereas the sediment load has obvious decreasing trend.

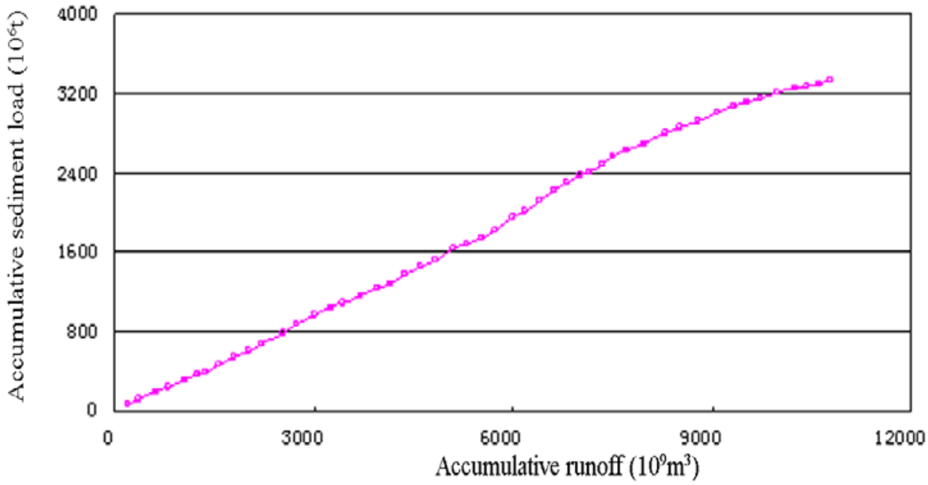
Table 2.6 Runoff and sediment load at Gaoyao Station in different periods

Time	Runoff & its variation		Sediment load & its variation		Sediment concentration & its variation	
	（bil.m^3）	（%）	(mil.t)	（%）	（kg/m^3）	（%）
1957-1982	220.8		70.15		0.318	
1983-1992	197.4	-10.6	80.81	15.2	0.409	28.9
1993-1998	268.1	35.8	74.69	-7.6	0.279	-32.0
1999-2005	208.5	-22.2	35.79	-52.1	0.172	-38.4

Notation： '+' represents increase, '-' represents decrease.



（a）Accumulative annual runoff and accumulative annual sediment load



（b）Double mass-curve annual runoff~annual sediment load

Fig.2.6 Variations in accumulative annual runoff and accumulative annual sediment load at Gaoyao Station on West River

2.3 Variations in runoff and sediment load in North River

The controlling catchment area of Shijiao Station on the North River is 38,400 km^2. Table 2.7 lists the runoff and sediment load at Shijiao Station. The average annual runoff during the periods of 1954~2005 was 41.86 billion m^3, ranging from 16.27~72.17 billion m^3, and the ratio of maximum annual runoff to minimum annual runoff was 4.44. From Fig.2.7, the runoff at Shijiao Station fluctuates, and shows no obvious trend.

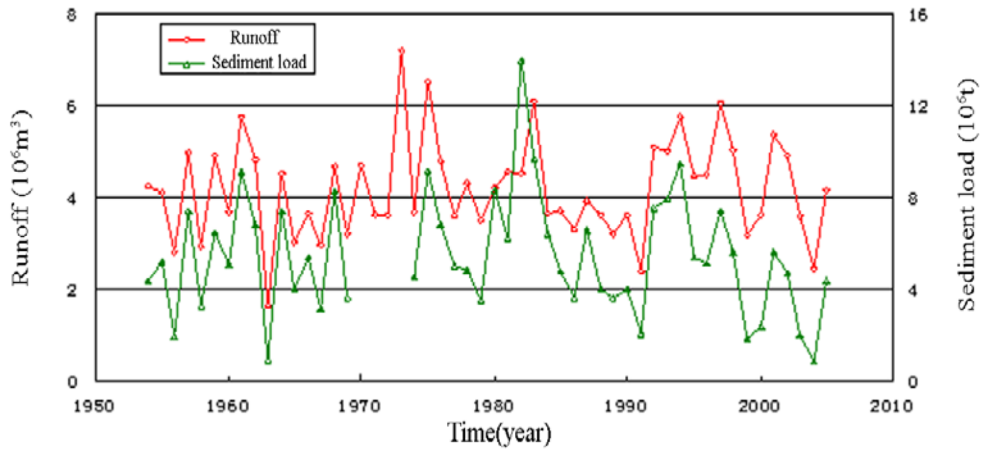
Table 2.7　Runoff and sediment load at Shijiao Station on the North River in different periods

Hydrologic station	Item	Time						
		1954 ~1959	1960 ~1969	1970 ~1979	1980 ~1989	1990 ~1999	2000 ~2005	Average annual
Shijiao Station on North River	Runoff（10^9m^3）	40.05	37.97	45.58	40.81	45.18	40.22	41.86
	Sediment load（10^6t）	4.77	5.38	5.65	6.73	5.63	3.32	5.41
	Average sediment concentration（kg/m^3）	0.119	0.142	0.124	0.165	0.125	0.083	0.129

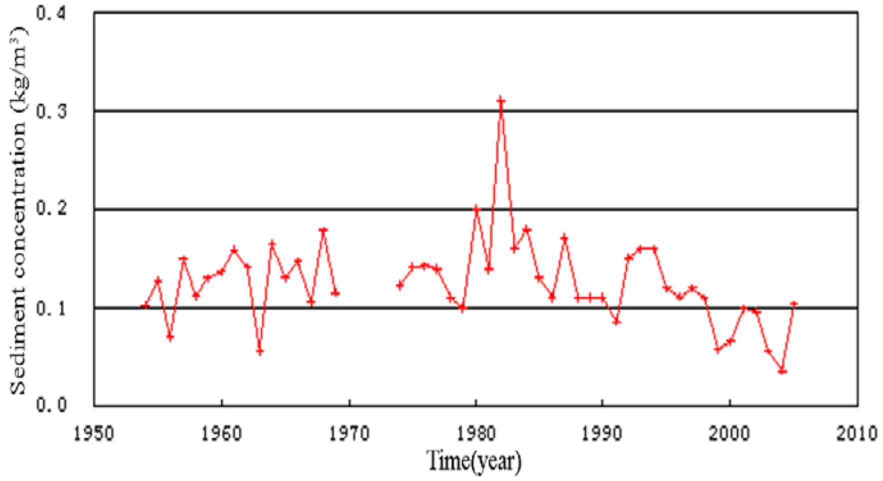
The average annual sediment load at Shijiao Station during the periods of 1954~2005 was 5.41 million tons, the variation extent of annual sediment load was far larger than that of runoff, the maximum annual sediment load was 14.0 million tons（in 1982）, the minimum annual sediment load was 0.869 million tons（in 2004）, and the ratio of the maximum annual sediment load to the minimum annual sediment load was 16.11. From the 1950s to the 1980s, the sediment load showed gradually increasing trend, while after the 1990s it gradually decreased. The runoff in the 1990s increased by 10.71% than that in the 1980s, but the sediment load decreased by 16.30% than that in the 1980s. After 1985 thanks to the implementation of water and soil conservation and the construction of Feilaixia Dam in 1999, the sediment load obviously decreased; the annual runoff during 2000~2005 was close to the average annual runoff during 1954~2005, accounting for 96.1% of the average annual runoff, but the sediment load only accounting for 61.28% of the average annual sediment load. The average sediment concentration at Shijiao Station was 0.129m^3/s, and the annual average sediment concentration was 0.036 ~0.31 m^3/s.

From Fig. 2.7, the runoff at Shijiao Station varied in periodical flunctuation, showing no trend. The sediment load before 1984 showed a slight increasing trend, and after 1984 a decreasing trend.

Fig.2.8 is variations in the accumulative annual water and accumulative sediment at Shijiao Station. The reduction in curve slope in double mass-curve of annual runoff~annual sediment load after 1998 showed that the sediment load decreased.

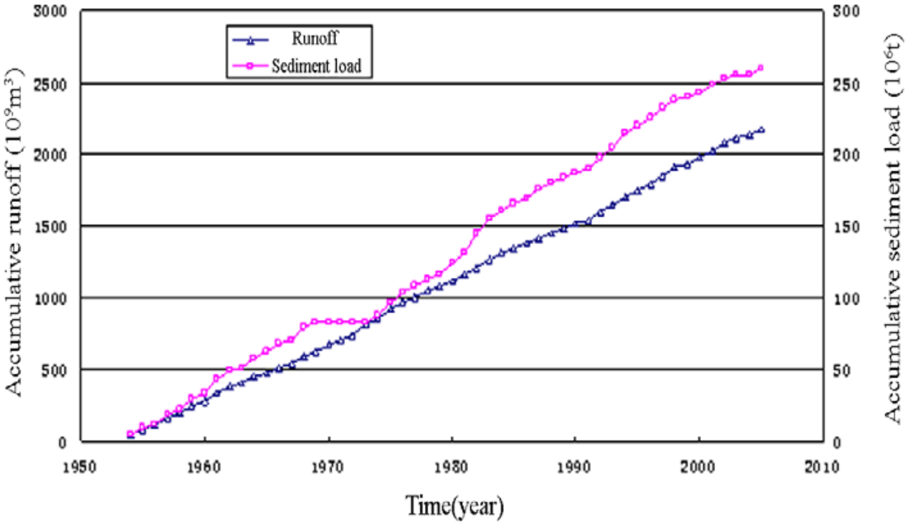


(a) Annual runoff and annual sediment load

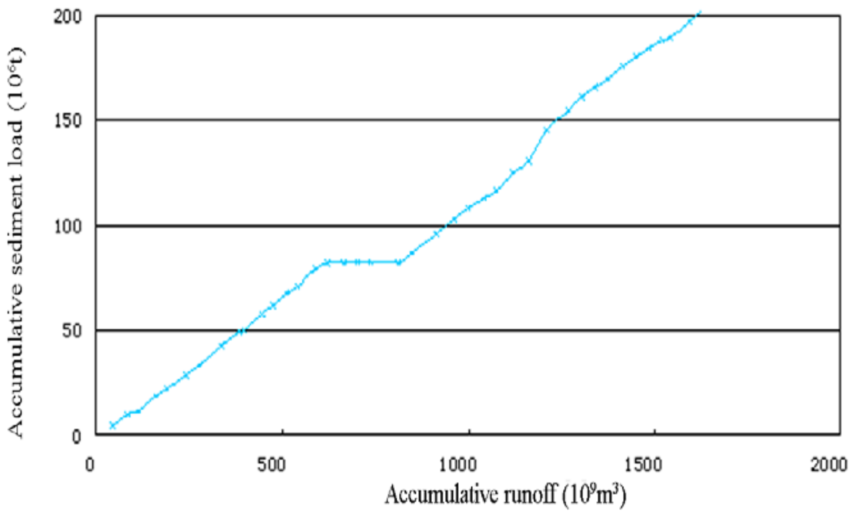


(b) Average annual sediment concentration

Fig.2.7 Variations in water and sediment at Shijiao Station on North River



（a）Accumulative annual runoff and accumulative annual sediment load



（b）Double mass-curve of annual runoff and annual sediment load

Fig.2.8 Accumulative variations in annual water and sediment at Shijiao Station on North River

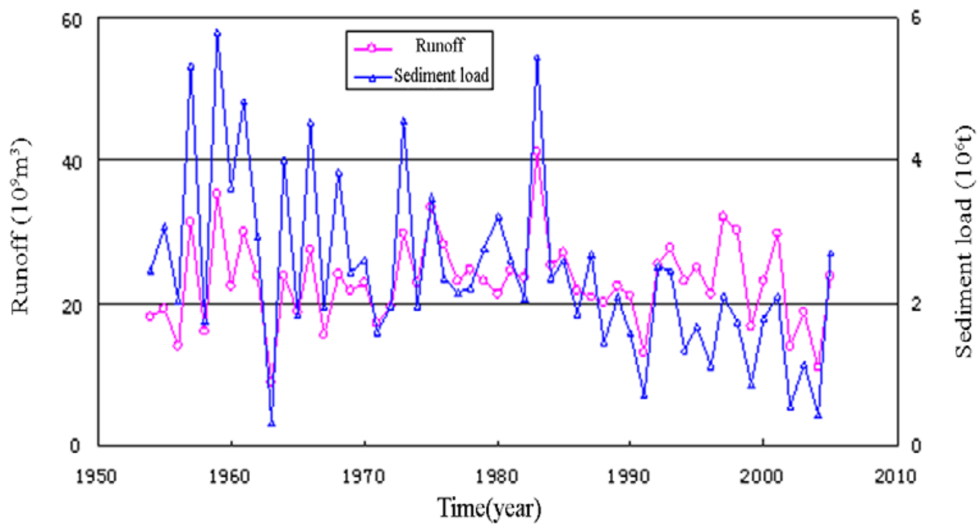
2.4 Variations in runoff and sediment load in East River

The controlling catchment area of Boluo Station on the East River is 0.0253 million km^2. Table 2.8 and Fig.2.9 show characteristic values of the runoff and sediment load as well as variations in water and sediment at Boluo Station, respectively. During 1954~2005, the average annual runoff at Boluo Station was 23.08 billion m^3, the annual runoff varied from 8.937~41.3 billion m^3, and the ratio of maximum runoff to the minimum was 4.62.

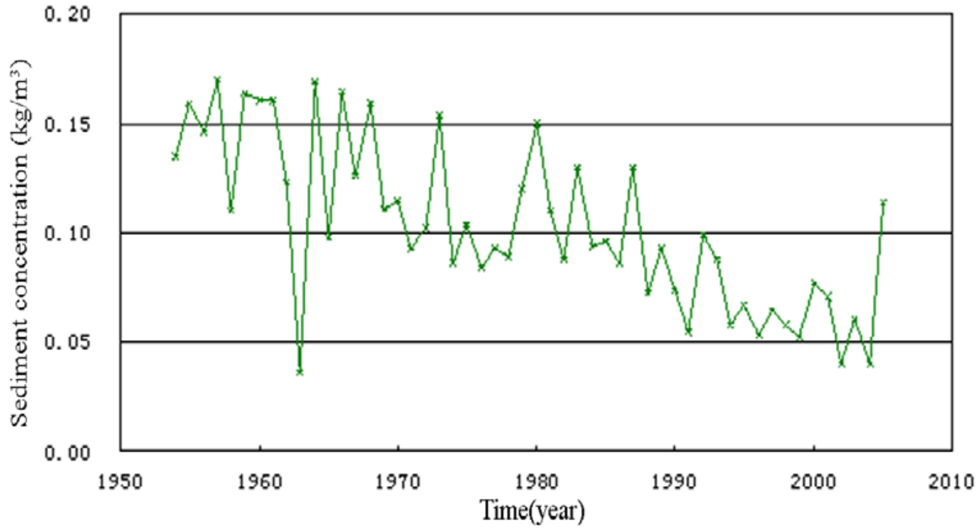
Table 2.8 Characteristic values of annual runoff and sediment load at Boluo Station on East River

Item	Time						
	1954 ~1959	1960 ~1969	1970 ~1979	1980 ~1989	1990 ~1999	2000 ~2005	Average annual
Runoff （10^9m^3）	22.37	21.68	24.50	24.79	23.56	20.09	23.08
Sediment load （10^6t）	341.	3.03	2.57	2.64	1.61	1.45	2.46
Average sediment concentration （kg/m^3）	0.152	0.140	0.105	0.106	0.068	0.072	0.106

The average annual sediment load at Boluo Station during 1954~2005 was 2.46 million tons, yearly changes in sediment load was far larger than that of runoff, the maximum annual sediment load was 5.80 million tons（in 1959）, the minimum sediment load was 0.325 million tons（in 1963）, and the ration of maximum sediment load to minimum one was 17.85. During 1950s ~1970s, the sediment load almost decreased gradually in equal steps, the annual average sediment load during 2000~2005 was 1.45 million tons, which was only 59.22% of the average annual one (2.46 million tons) during 1954~2005. Sediment trapped by the large dams such as Xinfeng River Dam after 1959, Fengshuba Dam after 1973, Baipenzhu Dam after 1985, and the sediment load decreased by soil and water and conservation was the main reason of decrease in sediment load. The average sediment concentration at Boluo Station was 0.106 m^3/s. The average annual sediment concentration varied between 0.036~0.17 m^3/s.



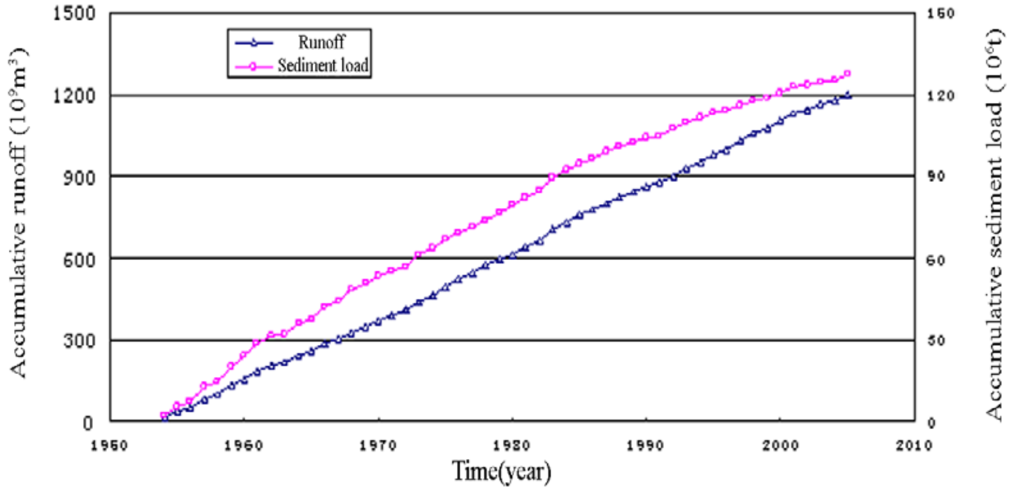
(a) Annual runoff and annual sediment load



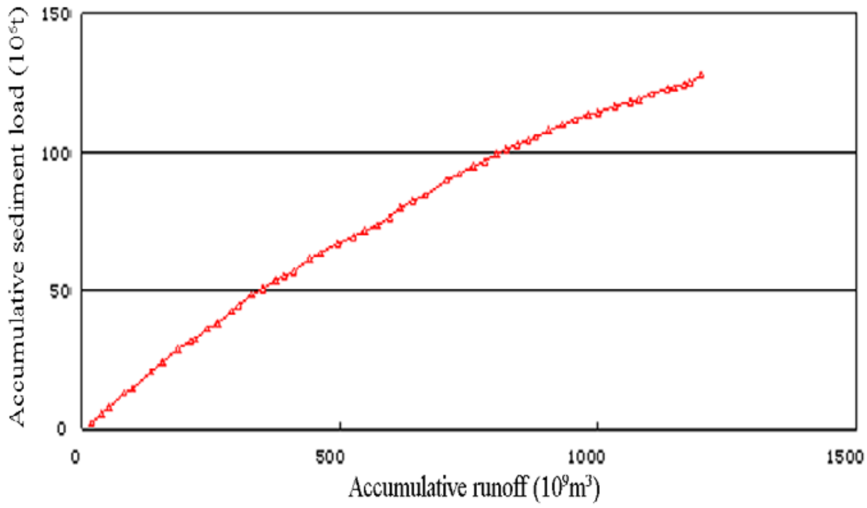
(c) Average annual sediment concentration

Fig.2.9 Variations in water and sediment processes at Boluo Station on East River

Fig.2.10 shows variations in accumulative annual runoff at Boluo Station. There is no big change in the annual runoff at Boluo Station. The double mass-curve of the annual runoff and sediment load can be dvided into three periods, i.e., 1954~1962, 1963~1984 and 1985~2005, the curve slope of the three periods decreased in turn, which was mainly due to the commissioning of Xiangang Dam in July 1963 and Baipenzhu Dam in 1985. Compared with 1954~1962, the annual runoff increased by 1.2%, the sediment load decreased by 22.5%, during 1963~1984; the annual runoff decreased by 4.7%, the sediment load decreased by 52.3%, during 1985~2005. Sediment concentration of the three periods was 0.151 m^3/s, 0.116 m^3/s and 0.076 m^3/s, respectively, which decreased by 23.4% and 49.9%, respectively, compared with 1954~1962.



（a）Accumulative annual runoff and annual sediment load



（b）Double mass-curve of annual runoff~annual sediment load

Fig.2.10 Variations in accumulative annual water and sediment process at Boluo Station on East River

3. Characteristics of Variations in Runoff and Sediment Load in Pearl River Basin

3.1 Distribution of runoff and sediment load in Pearl River Basin

The average annual runoff of the Pearl River Basin, including the West River and the North River as well as the East River, is 284.94 billion m^3, and the average annual sediment load is 75.87 million tons. The runoffs at Gaoyao Station on the West River, Shijiao Station on the North River and Boluo Station on the East River account for 77.2%, 14.7% and 8.1% of the total, respectively; the sediment load 89.6%, 7.1% and 3.2% of the total, respectively. It is obvious that both the runoff and sediment load of the Pearl River Basin mainly come from the West River Basin.

In the West River Basin, the controlling area of Liuzhou Station on the Liujiang River, Nanning Station on the Yujiang River and Qianjiang Station on the Hongshui River accounts for 70.3% of Gaoyao Station, 65.4% in runoff, 82.6% in sediment load. The runoff and sediment load at Qianjiang Station on the Hongshui River accounts for 30.3% and 61.6% of that at Gaoyao Station, respectively. The runoff and sediment load coming from the area between these three stations and Gaoyao Station accounts for 34.6% and 17.4% of that at Gaoyao Station, respectively, which shows that the runoff from the area is relatively large, and the sediment load relatively small. Therefore, the sediment load of the West River Basin mainly comes from the Liujiang River, the Yujiang River and the Hongshui River in its upper reaches, among which the sediment load of the Hongshui River is the largest.

Pictures 16 and 17 show beautiful scenery at Yangshuo County in the Pearl River Basin.

Picture 16 Scenery at Yangshuo County

Picture 17 Water level station at Yangshuo County

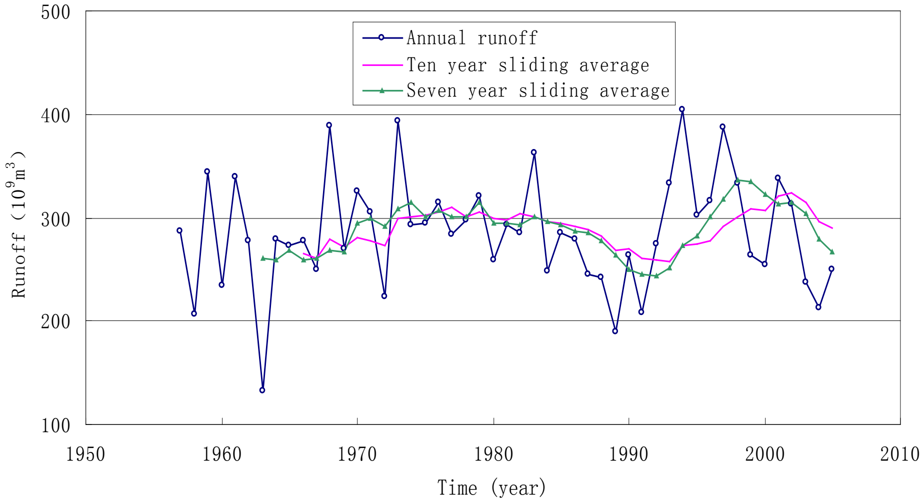
3.2 Trend of variation in runoff and sediment load in Pearl River Basin

Changes in the total amount of runoff and sediment load at Gaoyao Station on the West River, Boluo Station on the East River and Shijiao Station on the North River represent variations in water and sediment of the Pearl River Basin. The average annual runoff of the representative station of the Pearl River Basin is 285 billion m^3, and the sediment load 75.84 million tons. Runoffs in different decades flucuated around the average, showing no big change, varied from 267.8~308.6 billion m^3; the sediment load was 75.95 million tons in 1950s, increased to 87.11 million tons in 1980s, then decreased to 40.21 million tons during 2000~200. From the sliding average curve of annual runoff and sediment load of the Pearl River Basin as shown in Fig.3.1, it can be seen that the runoff periodicaly fluctuated, showing no obvious trend; the sediment load generally increased before 1988, and decreased after 1988.

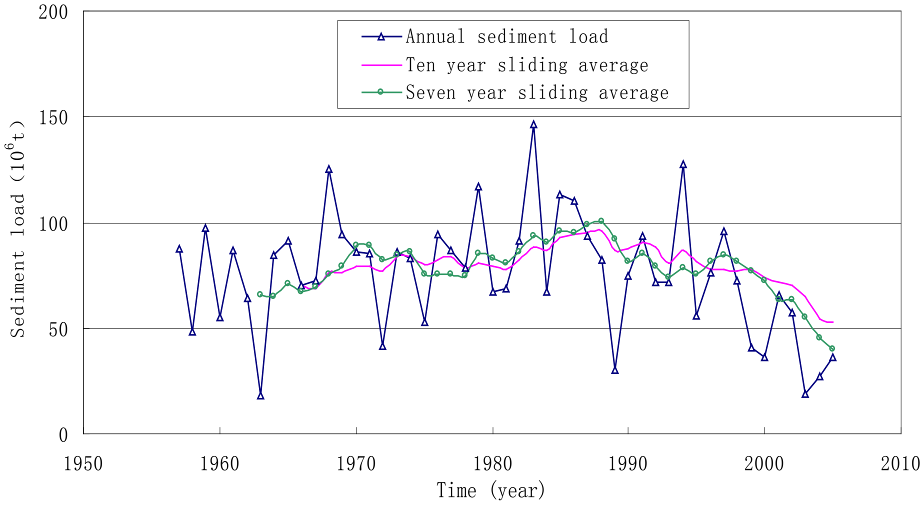
From variations in accumulative runoff and sediment load at the representative station as shown in Fig.3.2, the runoff shows no accumulative trend. From the double mass-curve of the runoff and sediment load at the representative station as shown in Fig.3.2(b), according to the variations in curve slope the curve can be devided into five periods, i.e., 1957-1963, 1964-1982, 1983-1988, 1989-1994 and 1995-2005, in which variations in annual runoff compared with those in the former period was 13.8%, -6.5%, 0.7% and 4.6%, respectively, variation percentatge of annual sediment load was 26.9%, 23.2%, -23.5% and -32.4%, respectively, as listed in Table 3.1. Under the condition that the runoff increased in a small extent after 1988, the sediment load decreased in a great extent, showing obvious decreasing trend. Variations in sediment concentration were 11.5%, 31.8%, -24.0% and -35.4%, respectively, which obviously decreased after 1988. The annual sediment concentration decreased by 50.9% during 1995-2005 in comparison with the maximal sediment concentration during 1983-1988.

Table 3.1 Changes in annual runoff and sediment load at representative station on Pearl River Basin

Time	Runoff & change		Sediment load & change		Sediment concentration & change	
	(bil.m^3)	（%）	(mil.t)	（%）	（kg/m^3）	（%）
1957-1963	260.3		65.37		0.251	
1964-1982	296.3	13.8	82.98	26.9	0.280	11.5
1983-1988	277.0	-6.5	102.25	23.2	0.369	31.8
1989-1994	278.9	0.7	78.26	-23.5	0.281	-24.0
1995-2005	291.7	4.6	52.91	-32.4	0.181	-35.4

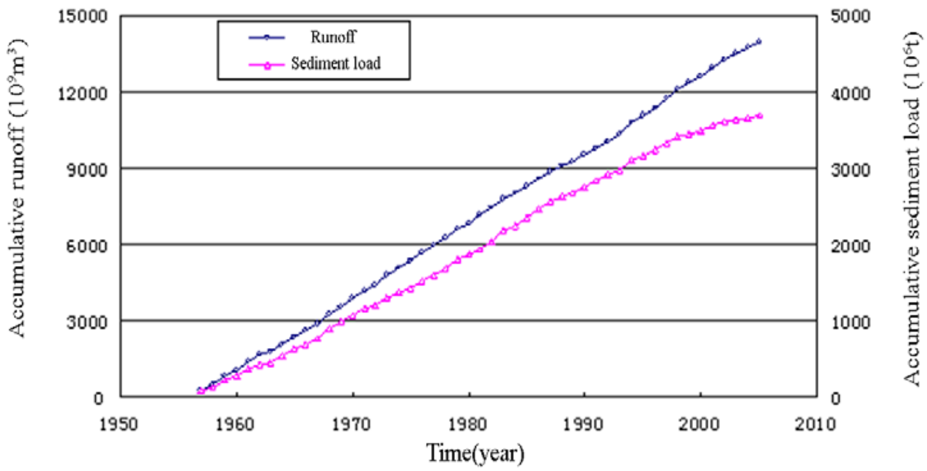


（a） Annual runoff

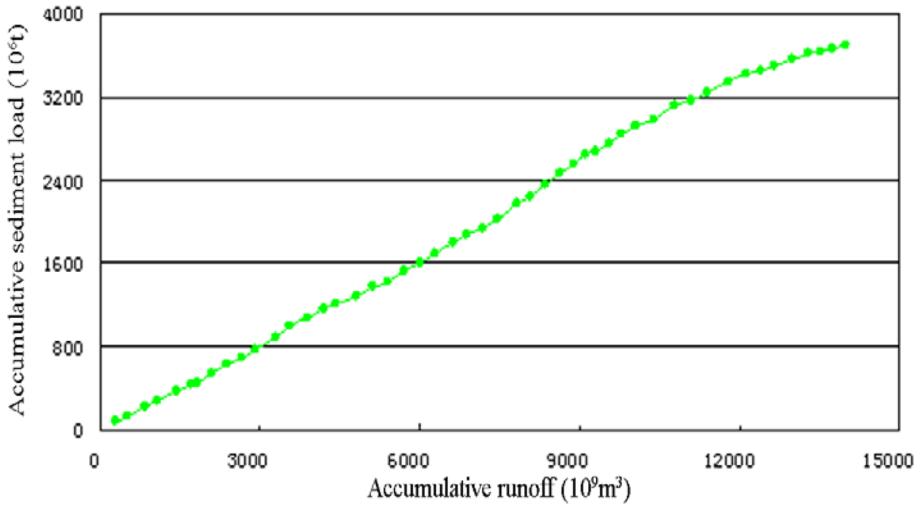


（b） Annual sediment load

Fig.3.1 Sliding average of annual runoff and sediment load at representative station on Pearl River



（a） Accumulative annual runoff and accumulative sediment load



（b）Double mass-curve of annual runoff~annual sediment load

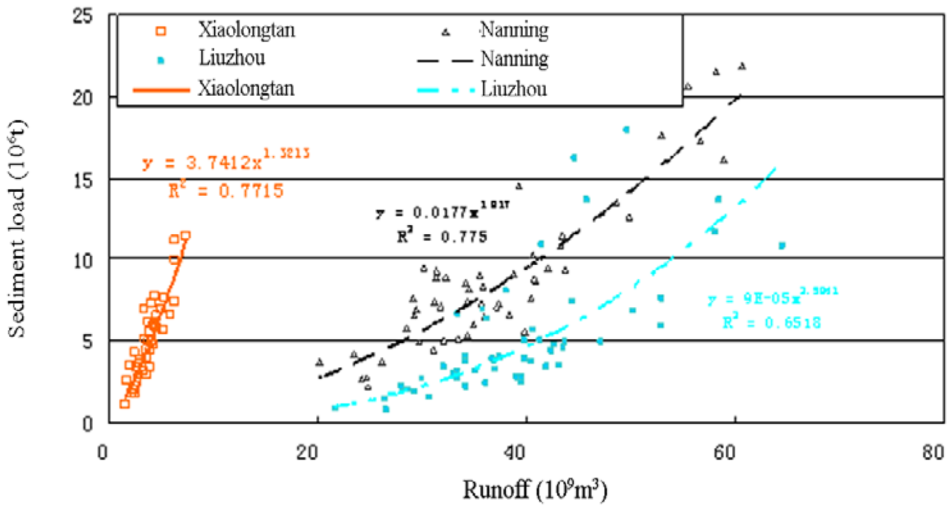
Fig.3.2 Variations in accumulative annual runoff and accumulative annual sediment load at representative station on Pearl River

3.3 Variation relations between runoff and sediment load in Pearl River Basin

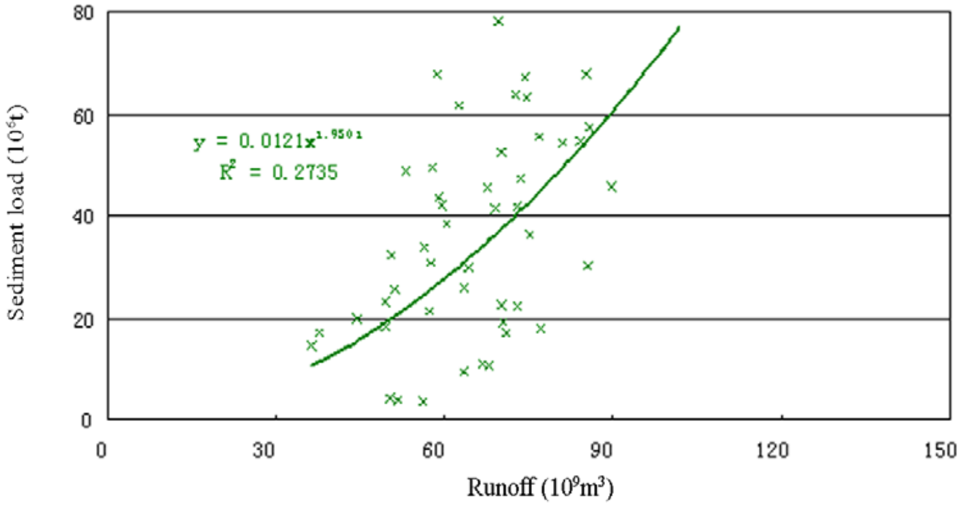
3.3.1 Relations between runoff and sediment load in Pearl River Basin

Fig.3.3 shows relations between the annual runoff and annual sediment load of the Pearl River Basin. From Fig.3.3 it can be seen that at different stations the sediment load is closely related with runoff. Sediment load increases with runoff increase, the relation between sediment load and runoff follows an exponential relation, i.e., $W_s = KW^m$, in which W and W_s are runoff and sediment load, respectively, K is a coefficient, as listed in Table 3.2. Correlations of sediment load and runoff at stations on tributaries of the West River including the Nanpan River and the Liujiang River as well as the Yujiang River, and at Shijiao Station on the North River are better than at Boluo Station on the East River. Correlations of sediment load and runoff at stations on the Hongshui River and the main stream of the West River are comparatively weaker. According to analyses of variations in water and sediment in Chapter 2, sediment load of the Hongshui River and that of the main stream of the West River shows an obvious decreasing trend due to the influence of human activities on transportation of water and sediment, which is also the right reason that greatly weakens the intrinsic relations between runoff and sediment load.

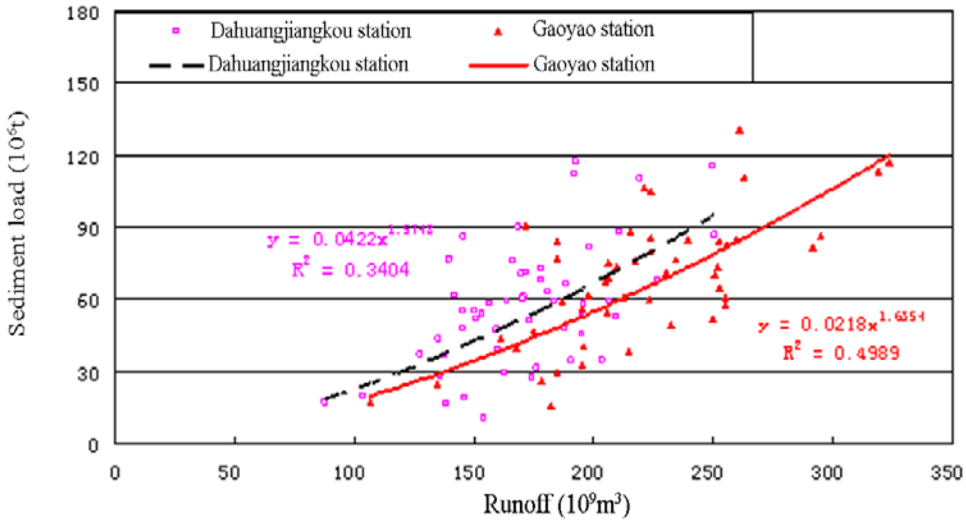
Coefficients of corelation of water and sediment between Gaoyao Station and Qianjiang Station in the upper reaches of the West River are 0.67 and 0.69, respectively, as shown in Fig.3.4. It indicates that water and sediment from the Hongshui River has a big influence on that of the main stream of the West River



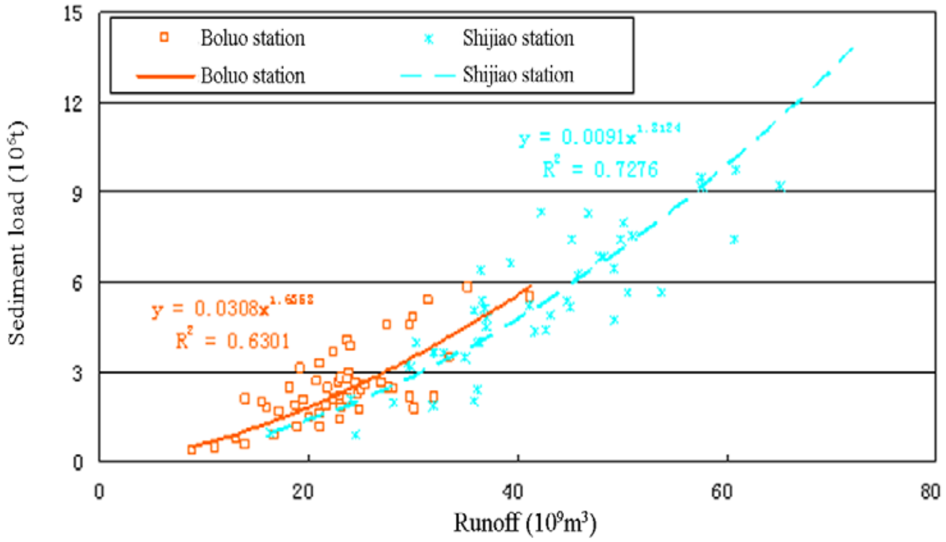
（a）Hydrologic stations on Nanpan, Liujiang and Yujiang Rivers, tributaries of West River



（b）Qianjiang Station on Hongshui River, tributary of West River



（c）Hydrologic stations on main stream of West River



（d）Shijiao Station on North River and Boluo Station on East River

Fig.3.3 Relations between water and sediment at hydrologic stations in Pearl River Basin

Table 3.2 Coefficients of relations between water and sediment at hydrologic stations

Station	Xiaolongtan	Qianjiang	Liuzhou	Nanning	Dahuang-jiangkou	Wuzhou	Gaoyao	Shijiao	Boluo
Coefficient	3.7412	0.0121	0.00009	0.0177	0.0422	0.0516	0.0218	0.0091	0.0308
Exponential	1.3213	1.9301	2.5841	1.817	1.5748	1.526	1.6354	1.8124	1.6358
Coefficient of Correlation	0.7715	0.2735	0.6518	0.775	0.3404	0.3162	0.4989	0.7276	0.6301

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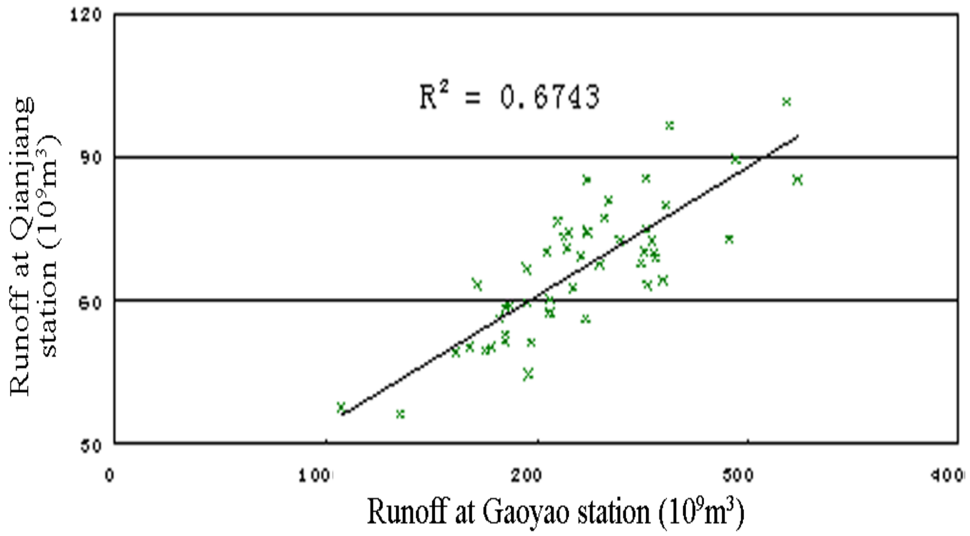
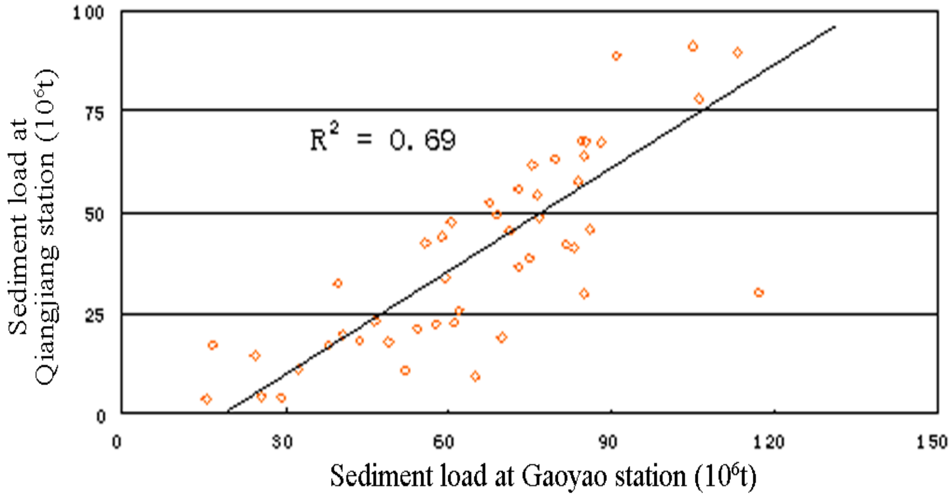


（a）Runoff

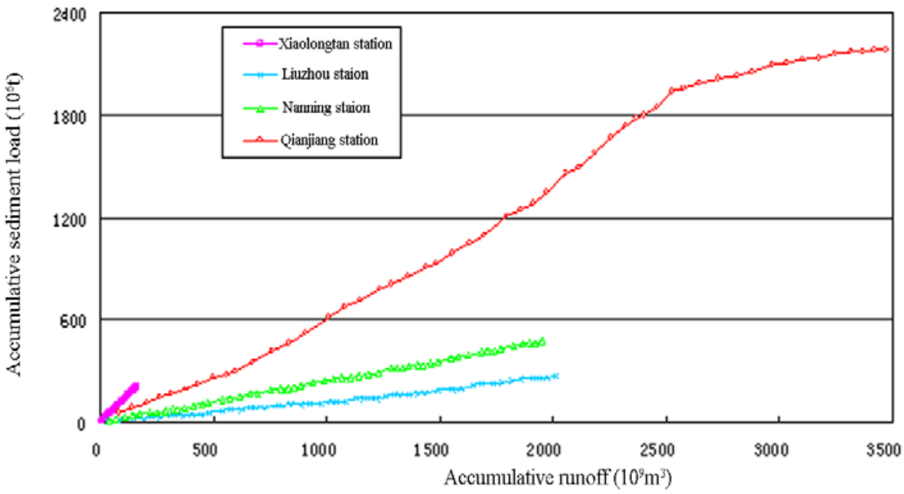


（b）Sediment load

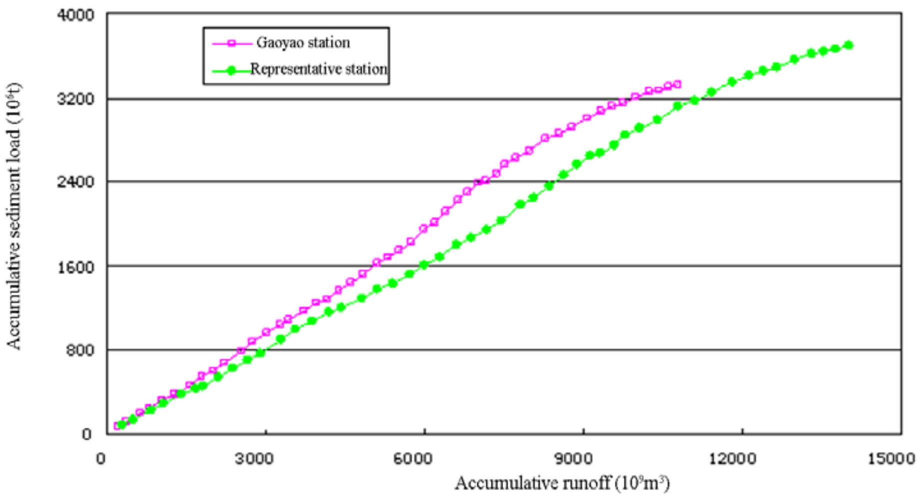
Fig.3.4 Relations of runoff and sediment load between Gaoyao Station and Qianjiang Station

3.3.2 Accumulative relations between runoff and sediment load in Pearl River Basin

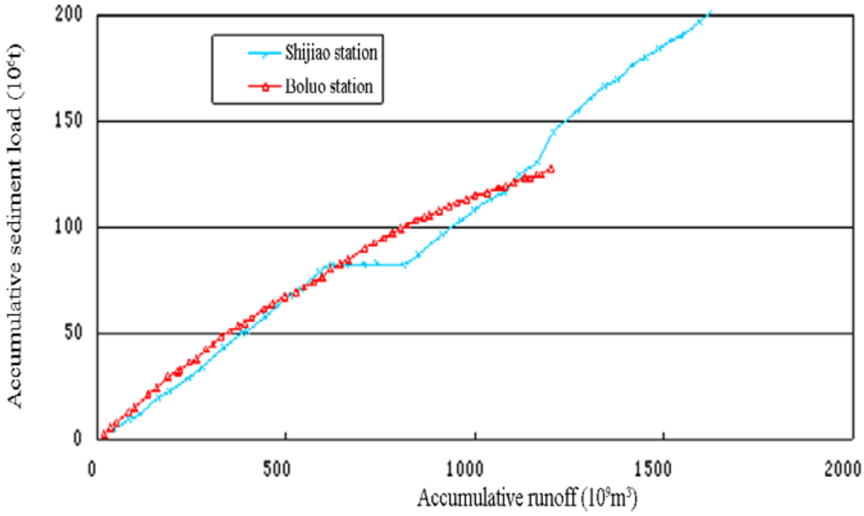
Changes in relation between accumulative water and sediment in the Pearl River Basin are shown in Fig 3.5. Deflection of relation curve of accumulative water and accumulative sediment to any axis reflects variations in relation between water and sediment. The double mass-curve of annual runoff~annual sediment load at representative stations on the mian stream and tributaries of the river basin are shown in Fig.3.5, the double mass-curves after 1990s of most stations deflect to the runoff axis, Xiaolongtan Station turned in 1994, Qianjiang Station in 1992, Gaoyao Station in 1992, Shijiao Station in 1998, Boluo Station in 1993, showing that sediment load decreased. The reason is the implementation of soil and water conservation and hydro projects. The double mass-curve of accumulative runoff and accumulative sediment load at Nanning Station has no obvious big deflection, showing that there is no systematic change in water and sediment relations. The double mass-curve of accumulative runoff and accumulative sediment load after 1992 at Nanning Station deflected to the sediment load axis, showing that there was an increase in sediment load. A turn occured on the double mass-curve of accumulative annual runoff~annual sediment load at the representative station in the Pearl River Basin, the curve began to deflect to the runoff axis after 1988, showing that there was a decrease in sediment load compared to runoff.



（a）Main stations on tributaries of West River



(b) Gaoyao Station and representative station in Pearl River Basin



（c）Shijiao Station on North River and Boluo Station on East River

Fig.3.5 Double mass-curve of annual runoff~annual sediment load at stations in Pearl River Basin

Changes in sediment concentration in Pearl River Basin are shown in Fig. 3.6.

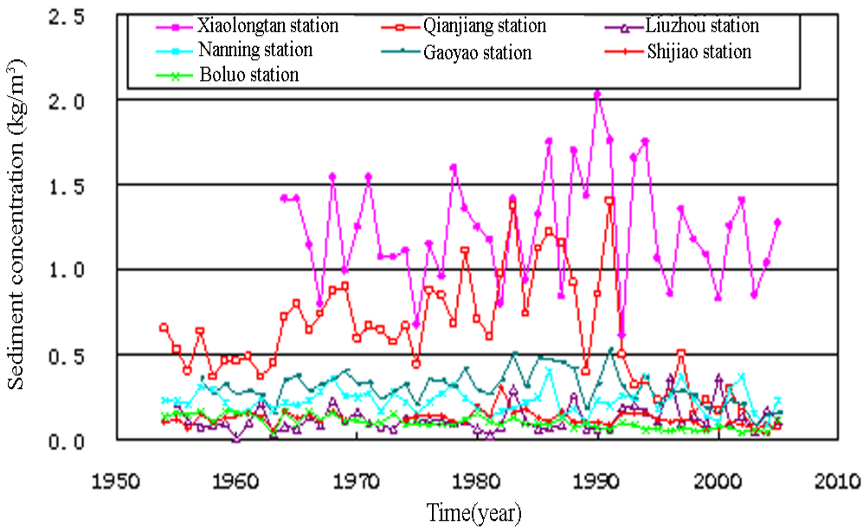


Fig.3.6 Changes in sediment concentration in Pearl River Basin

4. Causes of Variations in Runoff and Sediment Load in Pearl River Basin

4.1 Effect of climatic changes

Sediment loads in the Pearl River Basin fluctuate obviously, as shown in Fig 3.1, and its fluctuation almost being consistent with variations in runoff, and furthermore variations in runoff is basically consistant with the precipitation, as shown in Fig.4.1.

Table 4.1 Relations between precipitation and runoff as well as sediment load in Pearl River Basin

Hydrologic station	Relation	Correlation equation	Correlation coefficient	Number of samples	Markedness level
Gaoyao Station（West River）	precipitation(x)-runoff(y)	y=2.0941x- 82.46	$R^2 = 0.73$	N=51	P<0.01
	runoff(x)-sediment load(y)	y= 4.3256x-2810.3	$R^2 = 0.44$	N=51	P<0.01
Shijiao Station（North River）	precipitation(x)-runoff(y)	y=0.3371x-103.83	$R^2 = 0.79$	N=51	P<0.01
	runoff(x)-sediment load(y)	y=1.9516x-259.6	$R^2 = 0.65$	N=51	P<0.01
Boluo Station（East River）	precipitation(x)-runoff(y)	y=0.1123x+15.625	$R^2 = 0.68$	N=51	P<0.01
	runoff(x)-sediment load(y)	y=1.5075x-102.32	$R^2 = 0.52$	N=51	P<0.01

Regression analyses show that there are obvious correlative relations between precipitation and runoff, runoff and sediment load in the West River and the North River as well as the East River, as shown in Table 4.1. Therefore, the yearly fluctuation of sediment load is affected by climate change. The sediment load at the representative station in the Pearl River Basin during 1955～2000 showed a decreasing trend, which obviously was independentt of precipitation variation, because during the same period, the precipitation exhibited an increasing trend, as shown in Fig.4.1. Therefore, it is concluded that the decrease in sediment load in the Pearl River Basin is mainly related to human activities.

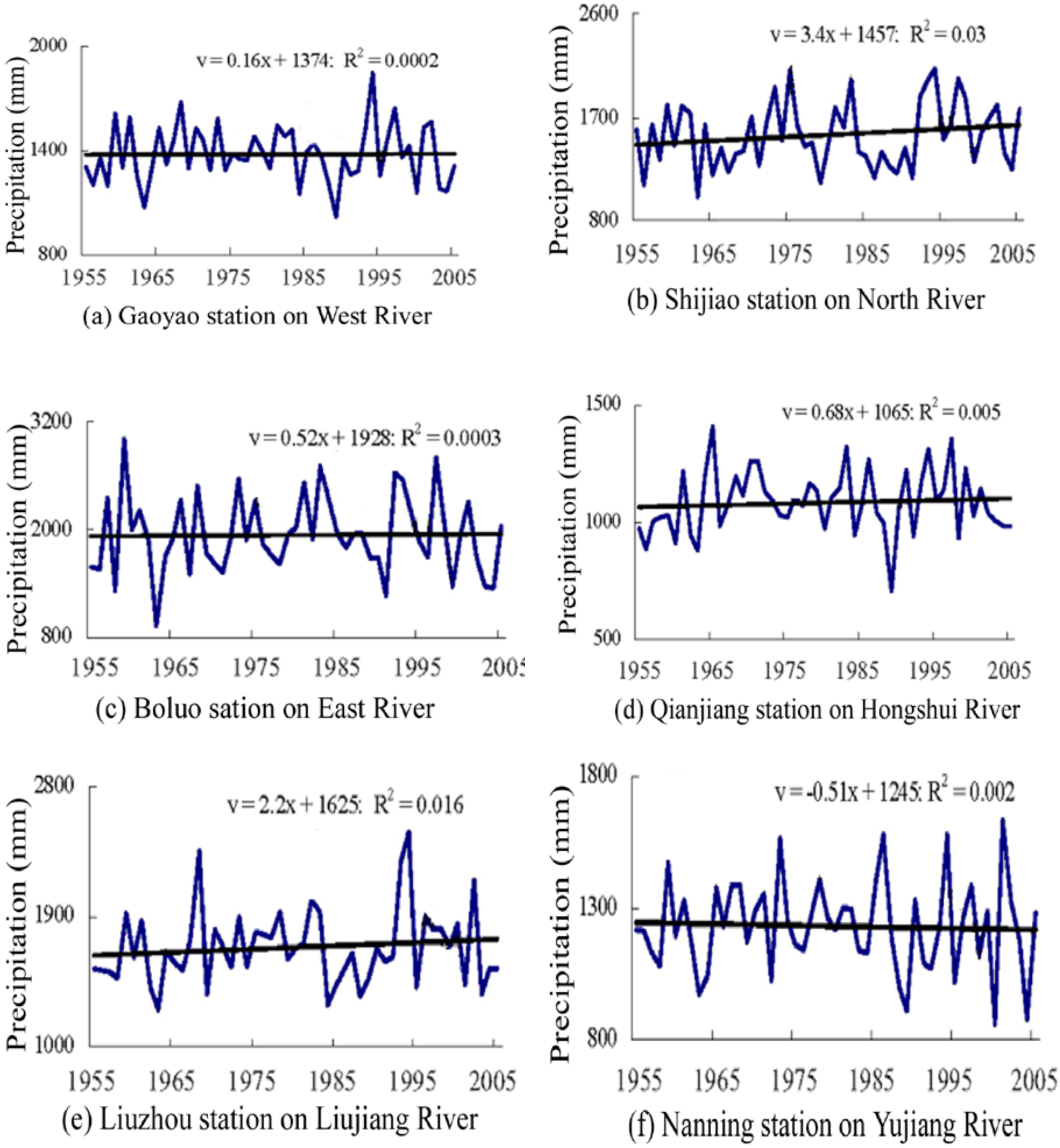


Fig. 4.1 Precipitation at main hydrologic stations in Pear River Basin

4.2 Effect of soil and water loss

4.2.1 Soil erosion

The Pearl River Basin is located in subtropical and tropical zones with plentiful precipitation and sunshine. The climate is favorable for vegetation growth. However, soil erosion has become seriously owing to rapid population growth and intense human activity. According to the data from the First National Remote Sensing Survey of Soil Erosion authorized by the State Council, there are 710 thousand km^2 eroded area in the Pearl River Basin, 75.7 thousand km^2 of international rivers in Yunnan, 9.5 thousand km^2 of independent rivers. The annual soil loss is over 0.5 billion tons.

Soil erosion mainly takes place in the limestone region of thin soil layer and hilly region of shale, sandstone and granite. The lime stone region is mainly in the Upper Pearl River and international rivers in Yunnan Province, predominantly in Guizhou Province. The area of soil erosion in this region is the largest and the situation is the most serious, resulted in barren land. In some areas soil erosion has threatened human existence. In sandstone and shale regions sheet erosion and gully erosion prevail, mainly in the West River Basin and middle and low mountainous region of the international rivers in Yunnan Province. In granite regions sheet ersion, gully erosion and slope disintegration prevail. Dangerous slope disintegration are mainly in low hilly areas of Guangdong, Guangxi.

Serious soil erosion leads to severe deposition in reservoirs, ponds and canals, raises the river channel beds, reduces the benefit of hydro projects and increases the burden of flood control in the lower reaches of rivers. For example, 54 reservoirs were heavily deposited by sediment, among which 6 reservoirs were completely filled up in Qianxinan Region in Guizhou Province.

4.2.2 Effect of soil erosion

Along with the increase in population and development of economy the eroded area in the Pearl River Basin increased rapidly. In Guanxi the eroded area increased to 30600 km^2 in 1980s from 12000 km^2 in 1950s, 1.55 times of the original. In Guangdong it increased to 17070 km^2 from 7444 km^2 in the same period, 1.3 times of the original. Since 1980s with the implementation of various measures of soil and water conservation the eroded area gradually decreased. In 1990s the eroded areas were 28100 km^2 and 8650 km^2 in Guangxi and Guangdong respectively, 91.2％ and 51％ of the figures in 1980s. Correspondingly, the sediment load of rivers also experienced the same up and down processes（Fig. 2.5(b)）. According to the second national remote sensing survey in 1995, the eroded area in the Pearl River Basin was 62700 km^2. According to the Bulletin of Soil and Water Conservation Survey in the Pearl River Basin 2004, the eroded area in the Pearl River Basin in 2004 was 62730 km^2. Thus, the eroded area in the Pearl River Basin remained unchanged in 10 years (1995-2004). In the same period the sediment load entering the sea reduced by 30% compared to the previous decade (1985～1994）. Obviously, the reduction in sediment load in late decade was not correlated with soil and water conservation in the watershed.

4.2.3 Soil and water conservation

Since 1980 26 small watershed management projects have been established in various types of soil erosion in the Pearl River Basin as pilot projects focused on protection. Since 1990 integrated management projects have been carried out focused on development of society, ecology and economy with economic benefit as the first priority. In 1992 the Upper Nanpan and Beipan Rivers were listed as the national key protection regions approved by the Ministry of Water Resources. The first batch of projects was in 26 small watersheds in 7 counties of Yunnan and Guizhou Provinces. The projects were started in 1992 and commissioned in 1996. In 1998 21 projects in small watersheds were checked and accepted. The erosion controlled area was 677.96 km^2 with a total investment of 60.6659 million yuan in 21 small watersheds, and economic, social and ecological benefits were significant. Until 1998 the accumulative erosion controlled area in the Pearl River Basin was 30011 km^2， soil erosion was preliminarily controlled in the basin, resulted in the reduction in river sediment load. Since June 1999 8 cities and 54 counties in Yunnan, Guizhou, Guangxi and Guangdong have been listed as national key soil and water conservation regions. In 2 years the projects were completely commissioned. In 2003 a comprehensive watershed management project was implemented in the region of lime rock in the Upper Nanpan and Beipan Rivers approved by the State Council. The project included 136 small watersheds in 17 counties of Yunnan, Guizhou and Guangxi. The total area was 3378.7 km^2 among which 1813.6 km^2 was eroded land, accounting for 53.7% of the total. In 2006 1483.5 km^2 eroded land was controlled with significant ecological, economic and social benefit.

4.3 Effect of vegetation

In the Upper Pearl River Basin the vegetation coverage has been increased by afforestation, irrigation and intensive farming, while in the Lower Basin, particularly in the delta area the vegetation coverage has been decreased due to rapid urbanization and industrialization, and deforestation. Using vegetation cover exponential relation NDVI (Normalized Difference Vegetation Index) to reflect photosynthesis of vegetation cover, the annual change in the spatial distribution of vegetation coverage and time series from 1982 to 2003 in the Pearl River Basin was analyzed. The results showed NDVI declined from 1982 to 2003 in the Pearl River Basin, indicating that the activity of vegetation cover decreased. Fig. 4.2 shows the average annual NDVI per unit area, which indicates that NDVI changes spatially. In the middle and lower reaches NDVI was in the most significant level, particularly in the delta area; in the Liujiang and Guijiang Rivers it was in the significant level; while in the upper reaches, such as the Nanpan, Beipan, Youjiang, Zuojiang, and Yujiang Rivers, it was not in the significant level. The spatial difference of NDVI was resulted by the comprehensive influence of urbanization process, agricultural activity and local climate.

In the Upper West River only the sediment load at Liuzhou Station on the Liujiang River had an incresed trend, while it decreased or remained unchanged at most stations. This fact shows that the sediment load is closely related to vegetation cover.

When the vegetation cover increases, the sediment load decreases, or vise versa.

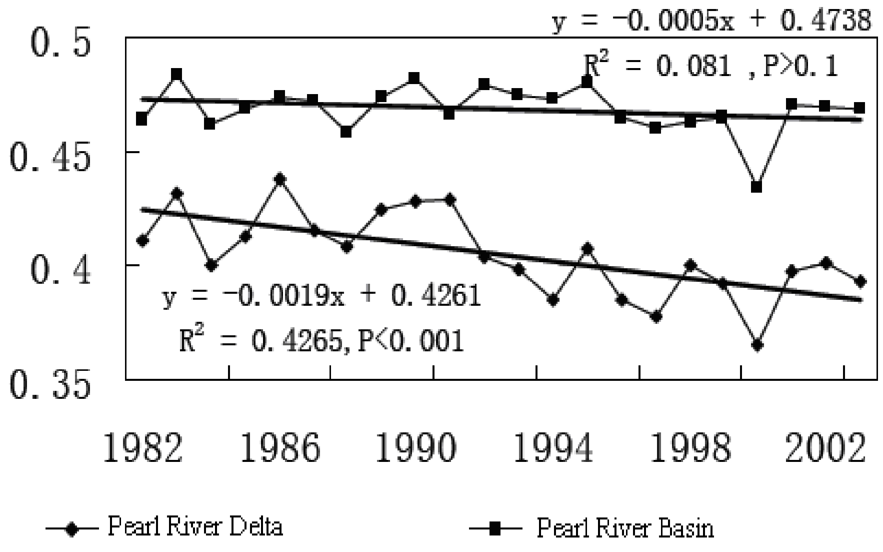


Fig.4.2 An average annual NDVI per unit area of Pearl River Basin

4.4 Effect of hydro projects

At present there are 388 medium-sized and large dams in the Pearl River Basin with a total reservoir storage capacity of 47.108 billion m^3. Tables 4.2 and 4.3 list those dams and the characteristics of several large dams, respectively. Along with water impoundment sediment has been trapped in those reservoirs. The role of Yantan Hydro Project on the West River and the Feilaixia Hydro Project on the North River is most significant in trapping sediment load and decreasing the river sediment load below the projects.

Due to scarcity of data from reservoirs the Yantan Hydro Project is taken as an example to study the effect of reservoir sedimentation on the sediment load.

The Yantan Hydro Project is located on the Hongshui River, a tributary of the West River. The project controls an area of 107 thousand km^2 and the reservoir storage capacity is 2.6 billion m^3. The controlling hydrologic stations above and below the reservoir are Tian'er Station and Qianjiang Station, their controlled areas are 98.5 thousand km^2 and 128.9 thousand km^2, respectively. Although the controlled area of the Qianjiang Station accounts for 36.7% of Gaoyao Station on the Lower West River (352 thousand km^2), its average annual sediment load (1955-2005)（42.27 million tons / yr）accounted for 62.8% of Gaoyao Station（67.25 million tons / yr）. According to analysis, sediment loads of the two stations have significant correlation (R=0.78, N=50, $P<0.01$). It can be concluded that the change in sediment load at the Qianjiang Station has significant effect on the sediment load of the West River. In 1991 the Yantan Hydro Project was commissioned. Since then, reservoir sedimentation has developed rapidly. From 1992 to 2002 the average annual amount of reservoir deposition was 42.38 million tons, accounting for 70% of the incoming sediment load (60.90 million tons / yr) and 67% of that of Gaoyao Station (63.10 million tons / yr). Reservoir sedimentation reduced the released sediment load. Thus, the sediment load at Qianjiang Station decreased rapidly. At Qianjiang Station from 1992 to 2002 the average annual sediment load (21.16 million tons / yr) was only 34% of the average annual sediment load from 1981 to 1991 (64.41 million tons / yr). At Gaoyao Station the corresponding figures were 76.58 million tons / yr and 63.10 million tons /yr, a reduction of 18％.

Generally speaking, the effect of reservoir sedimentation on the change in sediment load below the reservoir is complex, as both reservoir sedimentation and channel degradation below the dam take place simultaneously. If the Yantan Hydro Project were not built, what would be the sediment load at Qianjiang Station after 1992. To get the answer, the sediment load data from 1992 to 2002 at Tian’er Hydrologic Station were used to recover the natural sediment load data at Qianjiang Station. The results show that the average annual sediment load at Tian’er Hydrologic Station is 94% of that of the Qianjiang Station. Therefore, the natural average annual sediment loads at Qianjiang Station from 1992 to 2002 could be obtained by using the factor of 0.94, which reflected the actual situation without Yantan Project. Combined those data with those before 1992 the tendency of long-term (1955-2002) change of sediment load at Qianjiang Station was increasing (Fig. 4.3).

Pictures 18 and 19 show Baisejingxi Reservoir and Xinfengjiang Reservoir in the Pearl River Basin, respectively.

Picture 18 Baisejingxi Reservoir (taken by Yang Jingbo)

Table 4.2 Large and medium-scale dams in the basin

Item	Large Dam			Medium Dam			Total		
	Numbers	Total storage (bil.m^3)	Flood storage (bil.m^3)	Numbers	Total storage (bil.m^3)	Flood storage (bil.m^3)	Numbers	Total storage (bil.m^3)	Flood storage (bil.m^3)
West River	24	14.649	5.708	212	5.953	1.847	236	20.602	7.555
North River	7	4.218	1.666	41	1.193	0.353	48	5.412	2.019
East River	4	17.240	4.207	35	0.804	0.166	39	18.044	4.373
Pearl River Delta	5	1.450	0.351	60	1.601	0.517	65	3.051	0.868
Total	40	37.557	11.932	348	9.551	2.883	388	47.108	14.815

Table 4.3 Main characteristics of some large dams in the Pearl River Basin

River system	Name of dam	Rivers	Catchment area (km^2)	Total storage (bil.m^3)	Beneficial storage (bil.m^3)	Flood storage (bil.m^3)	Construction time or power generating
West River	Dumu	Nanpan River	196	0.10	0.058	0.004	
	Xijin	Middle reach of Yujiang River	81328	3.0	0.600		Completed in May 1964
	Lalang	Middle reach of Longjiang River (tributary of Liujiang River)	9337	0.112	0.022	0.010	Completed in Apr. 1971
	Luodong	Lower reach of Longjiang River (tributary of Liujiang River)	15300	0. 32	0.022	0.070	Completed in Dec. 1971
	Mashi	Rongjiang River (tributary of Liujiang River)	19940	0.269	0.063	0.108	Completed in Dec. 1972
	Dahua	Hongshui River	112200	0.911	0.043		1982
North River	Feilaixia	The North River	3.4097	1.870	0.315	1.307	1999
	Tanling	Lianjiang River	142	0.177	0.137	0.028	
	Nanshui	Nanshui River	608	1.243	0.710	0.23l	May 1971
	Changhu	Yujiang River	4800	0.149	0.055	0.042	
	Xiaokeng	Fengwan River	139	0.113	0.053	0.060	
East River	Xinfeng River	Xinfeng River	5734	13.896	6.489	1.147	1969
	Fengshu dam	The East River	5150	1.940	1.254	0.571	Dec.1975
	Baipenzhu	Xizhi River	856	1.220	0.385	0.610	1985
	Xiangang	Shahe River	295	0.138	0.066	0.097	Jul.1963

The sediment loads of the Liujiang and Yujiang Rivers in 1955~2005 were increasing（Fig. 2.1(b)), meantime the recovered sediment loads of the Qianjiang River in 1955~2002 were also increasing. Obviously the summation of the sediment loads of the three stations should be increasing. In the past several decades under natural conditions the river channel of the Lower Pearl River would not have big change. Therefore, if without the Yantan Hydro Project, the sediment load entering the sea form the West River (Gaoyao Station) should be increasing, contrary to the existing situation. As many hydro projects have been also commissioned on the North and East Rivers and reservoir sedimentation has been serious, it could be concluded that reservoir sedimentation is the main factor of reduction in sediment load in the Pearl River Basin.

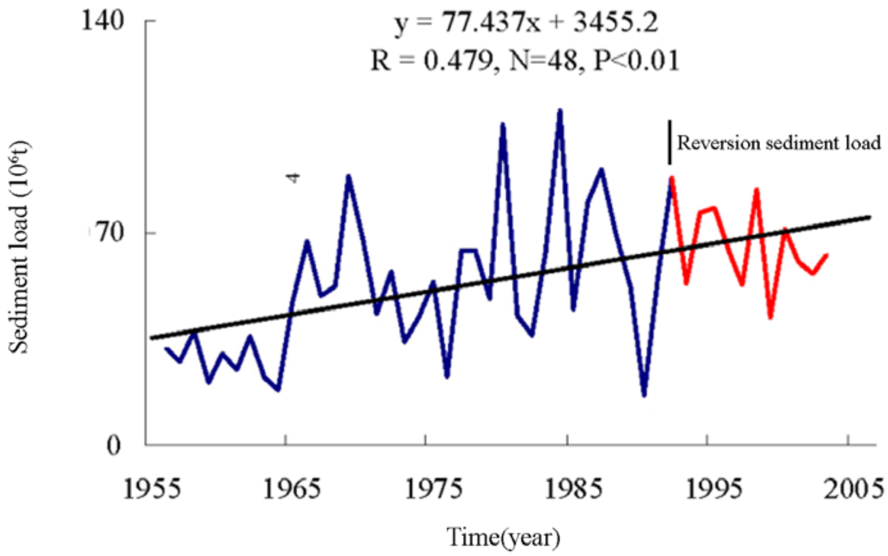


Fig.4.3 Recovered sediment load at Qianjiang Station after the construction of Yantan Dam

Picture 19 Reservoir of Xinfeng River (website: www.gdwater.gov.cn)

4.5 Effect of sand mining in river channels

Sand mining in the Pearl River channel induced the lowering of the river channel. Deposition in the mined channel decreased the sediment load of the downstream river channel. According to measured data, on the leveed channel reach of the North River in 1975~1999 the amount of channel erosion was 108.939 million m^3 and the average lowering was 2.10 m. The main reason was sand mining. After 1980s sand mining had a certain effect on the decrease of sediment load at Shijiao Station.

4.6 Effect of sediment deposition in river channels

Compared the runoff and sediment load at Dahuangjiangkou Station on the main tributary Xunjiang River and those at Wuzhou Station on the main stream (Fig. 4.3), it was found that the annual runoff at Wuzhou Station was larger than that at Dahuangjiangkou Station, while the annual sediment load at Wuzhou Station before 1986 was larger than that at Dahuangjiangkou Station, but it was smaller than that after 1986 at Dahuangjiangkou Station. There exists a confluence zone between Dahuangjiangkou Station and Wuzhou Station. After 1986 the river channel between Dahuangjiangkou Station and Wuzhou Station was in deposition. The amount of deposition during big floods was large, such as in 1994. Obviously, deposition in stream channels has an effect on the reduction in river sediment load.

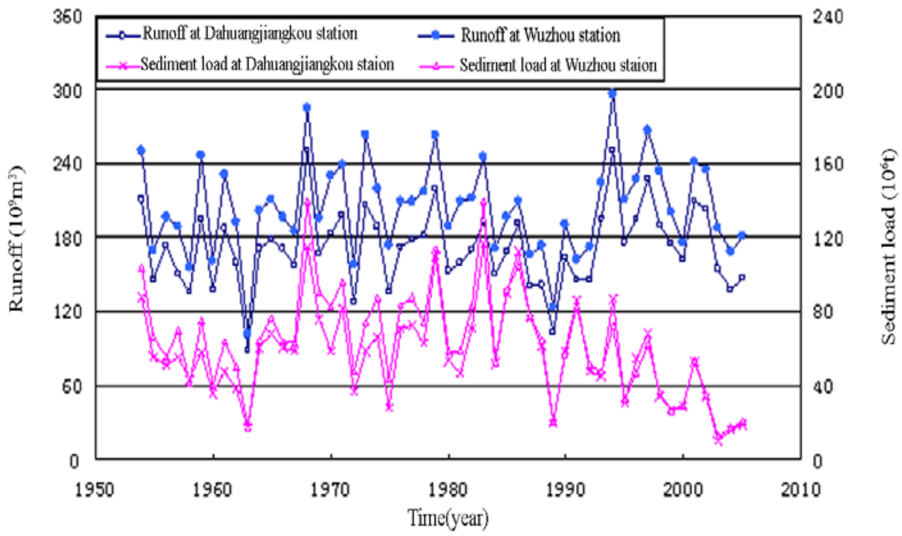


Fig.4.3 Comparison of runoff and sediment load between Dahuangjiangkou and Wuzhou Stations

4.7 Analyses of factors influencing variations in runoff and sediment load

In 1954-1998 the average annual runoff and average annual sediment load at Shijiao Station on the North River was 42.7 billion m^3 and 5.81 million tons, respectively. The Feilaixia Hydro Project was commissioned in 1999. In 1999-2005 the average annual runoff and average sediment load was 39.0 billion m^3 and 3.11

million tons, respectively. Compared with those in 1954-1998 the reduction in runoff was 8.5%, while the reduction in sediment load was 46.5%. In 1999~2005 the average annual sediment load was 2.70 million tons less than that in 1954-1998. Based on the correlation between annual runoff and sediment load in 1954-1998 the calculated average annual sediment load was only 1.78% less than the measured. According to this correlation the average annual sediment load would be 5.09 million tons. Thus, the reduction in sediment load induced by the change in runoff would be 720 thousand tons, accounting for 26.8% of the total reduction, the reduction in sediment load by human activities was 1.98 million tons, 73.4% of the total. After 1999 the reduction in sediment load was mainly caused by reservoir sedimentation.

In 1954-1987 the average annual runoff and average annual sediment load at Boluo Station on the East River were 23.6 billion m^3 and 2.92 million tons, respectively; in 1988-2005 they were 22.2 billion m^3 and 1.58 million tons, respectively. The average annual runoff in the late period was 94.0% of the former period, while the sediment load of the late period was only 54.0% of the former period. In 1988~2005 the average annual sediment load reduced 1.35 million tons compared to the long-term average. According to the correlation between the annual runoff and sediment load the calculated average annual sediment load was 97.9% of the measured. According to this relationship the calculated average annual sediment load in 1988~2005 would be 2.60 million tons. Thus, the decrease in sediment load induced by the change in runoff was 0.32 million tons, accounting for 23.6 % of the total reduction; while the decrease in sediment load induced by human activities was 1.03 million tons, accounting for 76.4% of the total reduction.

Consequently, the reduction in sediment load in the Pearl River Basin was mainly induced by human activities and the effect of runoff was the second.

Picture 20 shows the beautiful Detian waterfall in Heishui River.

Picture 20 Detian waterfall in Heishui River

5. Conclusions

Through analyzing variation trend of water and sediment and its reasons in the Pearl River Basin, some conclusions can be obtained as follows.

(1) The runoff and sediment load of the Pearl River Basin including the West River and the North River as well as the East River, mainly come from the West River Basin, accounting for 77.2% and 89.6% of the total, respectively. The sediment load of the West River Basin mainly comes from the Liujiang River, the Yujiang River and the Hongshui River in its upper reaches, among which the sediment load of the Hongshui River is the largest, accounting for 61.6% of the total of the West River (Gaoyao Station).

(2) From changes in the annual runoff at the representative station of the Pearl River Basin, the annual runoff of the Pearl River Basin has big yearly changes, but no obvious variation trend in recent years. There is certain yearly change in annual runoff at stations on the West River, but no big change in decades, no obvious change trend except Xiaolongtan Station on the Nanpan River showing decreasing trend. There are yearly variarions to a certain extent in runoff at Shijiao Station on the North River and Boluo Station on the East River, but no obvious trend.

(3) From changes in the annual sediment load at the representative station in the Pearl River Basin, the annual sediment load in the Pearl River Basin before 1988 generally had an increasing trend, and an obviously decreasing trend after 1988. There exist big variations in annual sediment load in the West River. Except the sediment load at Liuzhou Station on the Liujiang River had obviously increasing trend and one at Nanning Station on the Yujiang River no obvious trend, the sediment load at stations on the main stream and tributaries of the West River generally had a decreasing trend. The anuual sediment load at Shijiao Station on the North River and Boluo Station on the East River changed remarkably, showing a decreasing trend, and one at Boluo Station on the East River showed more obviously decreasing trend.

(4) The sediment load increases with the runoff increases, the relation between the sediment load and the runoff follows an exponential relation, i.e., $W_s = KW^m$, in which W and W_s are runoff and sediment load, respectively, K is a coefficient. Correlativity of sediment load and runoff at stations on tributaries of the West River including the Nanpan River and Liujiang River as well as Yujiang River, and at Shijiao Station on the North River is better, correlation coefficient ranging from 0.6518 to 0.7750, then at Boluo Station on the East River with correlation coefficient 0.6301. Correlation of sediment load and runoff at stations on the Hongshui River and the main stream of the West River are worse, the corresponding correlation coefficients are 0.2735 and 0.4989 respectively.

(5) Corelation coefficients of water and sediment between Gaoyao Station and Qianjiang Station on the Upper West River are 0.67 and 0.69, respectively, which indicate that water and sediment from the Hongshui River have a big influence on the water and sediment of the main stream of the West River.

(6) Changes in the sediment load in the Pearl River Basin are mainly induced by sediment deposition of hydro projects, soil and water conservation, channel sand mining, and sediment deposition in river channels. After a certain periods of construction of hydro projects, decrease in sediment load is most dramatic.

(7) Sediment yield in the Pearl River Basin is closely related with the vegetation cover of the watershed. Vegetation cover of the Liujiang River is the worst among the Pearl River Basin, and its sediment load shows an increase trend. While the vegetation cover of the Nanpan River is relatively good, and the sediment load at Xiaolongtan Station on the Nanpan River obviously shows a decrease.

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