Integrated Sediment Management –with the Yellow River as an example

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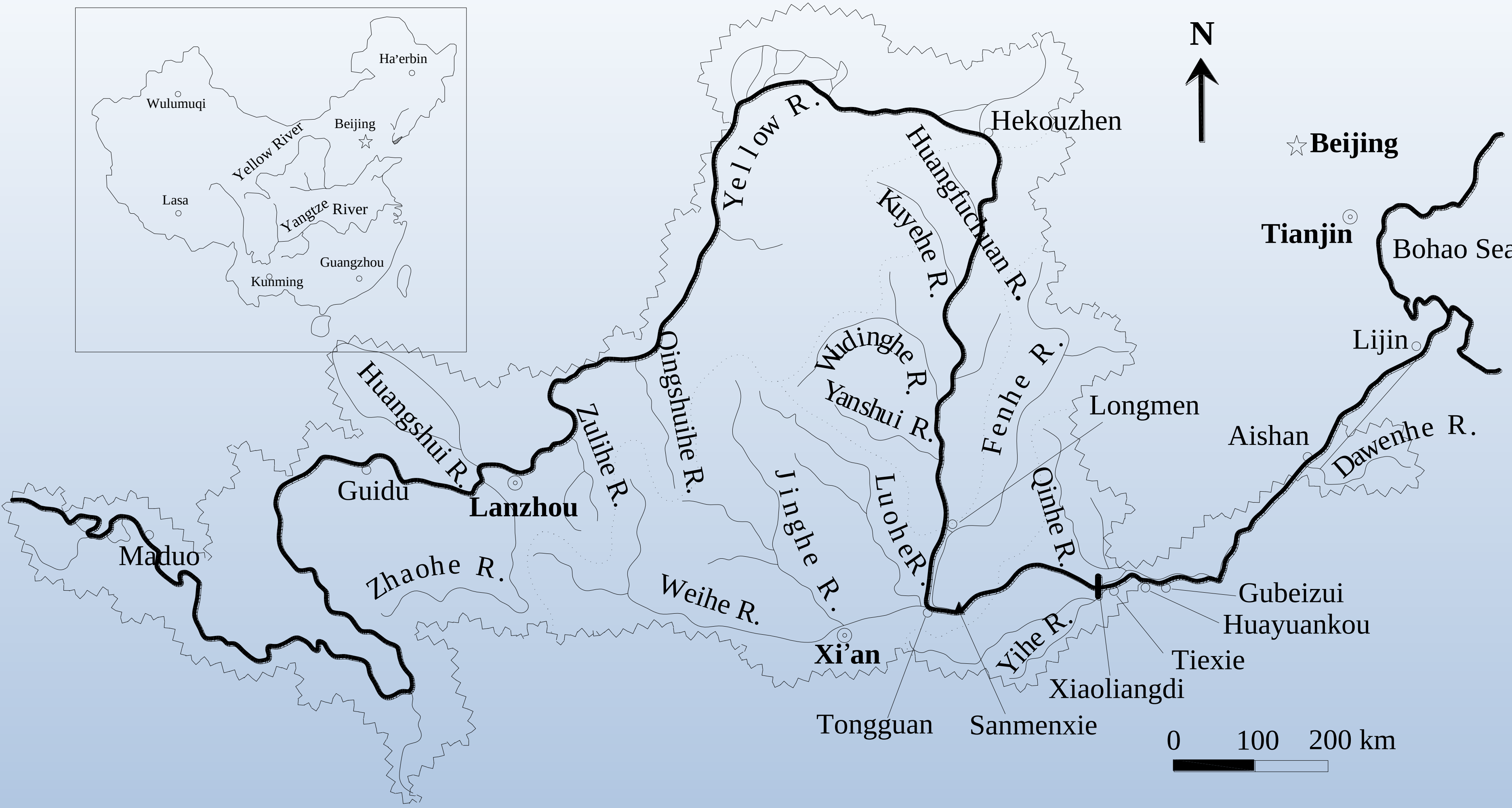
Main contents of the lecture can be found in the book:

Wang Z, Lee J. and Melching S., 2015. River Dynamics and Integrated River Management, Springer Verlag and Tsinghua Press, Berlin and Beijing

Chapter 6 and Chapter 2

Contents

1. The Yellow River

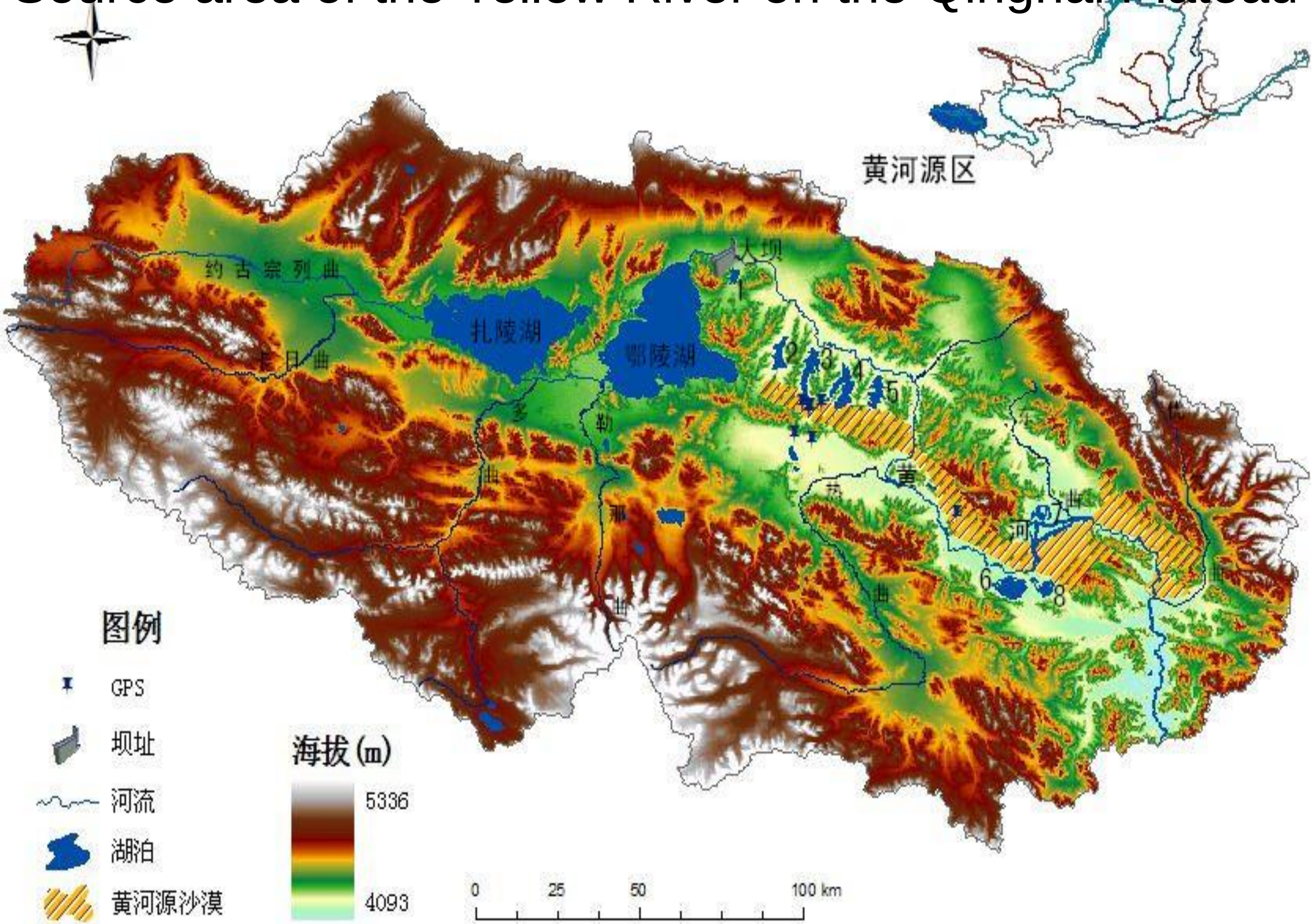


The Yellow River basin, tributaries and important hydrological stations.

YR- 5464 km long with a watershed of 0.75 million km^2

Total runoff 58 billion m^3

Source area of the Yellow River on the Qinghai Plateau



The origin of the Yellow River - 4656 m

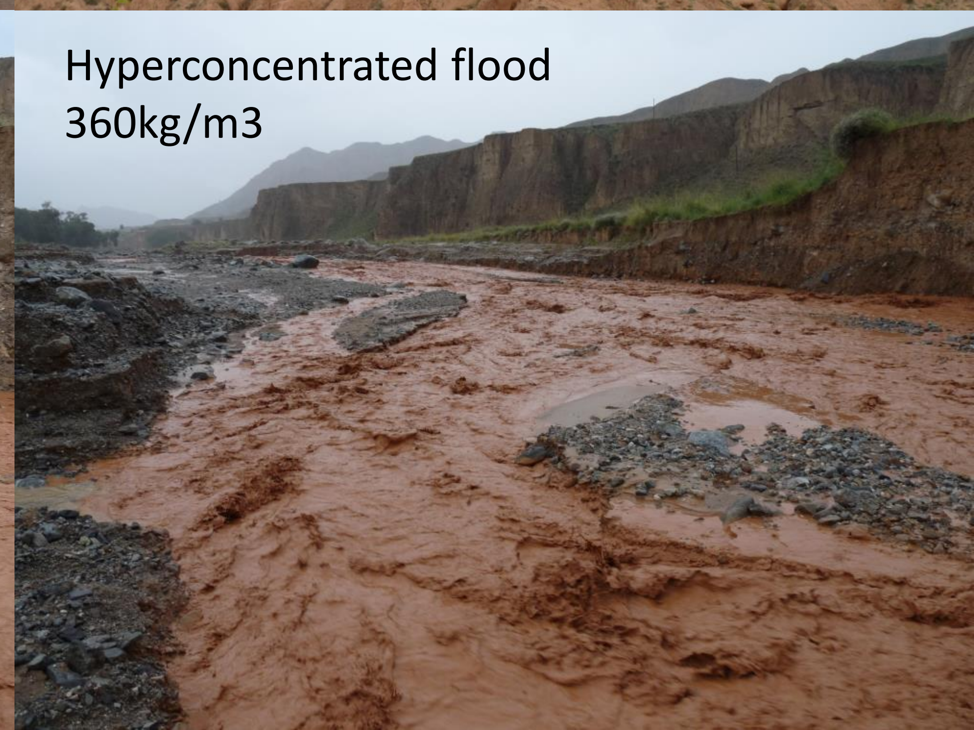
Star sea –near the origin of the Yellow River

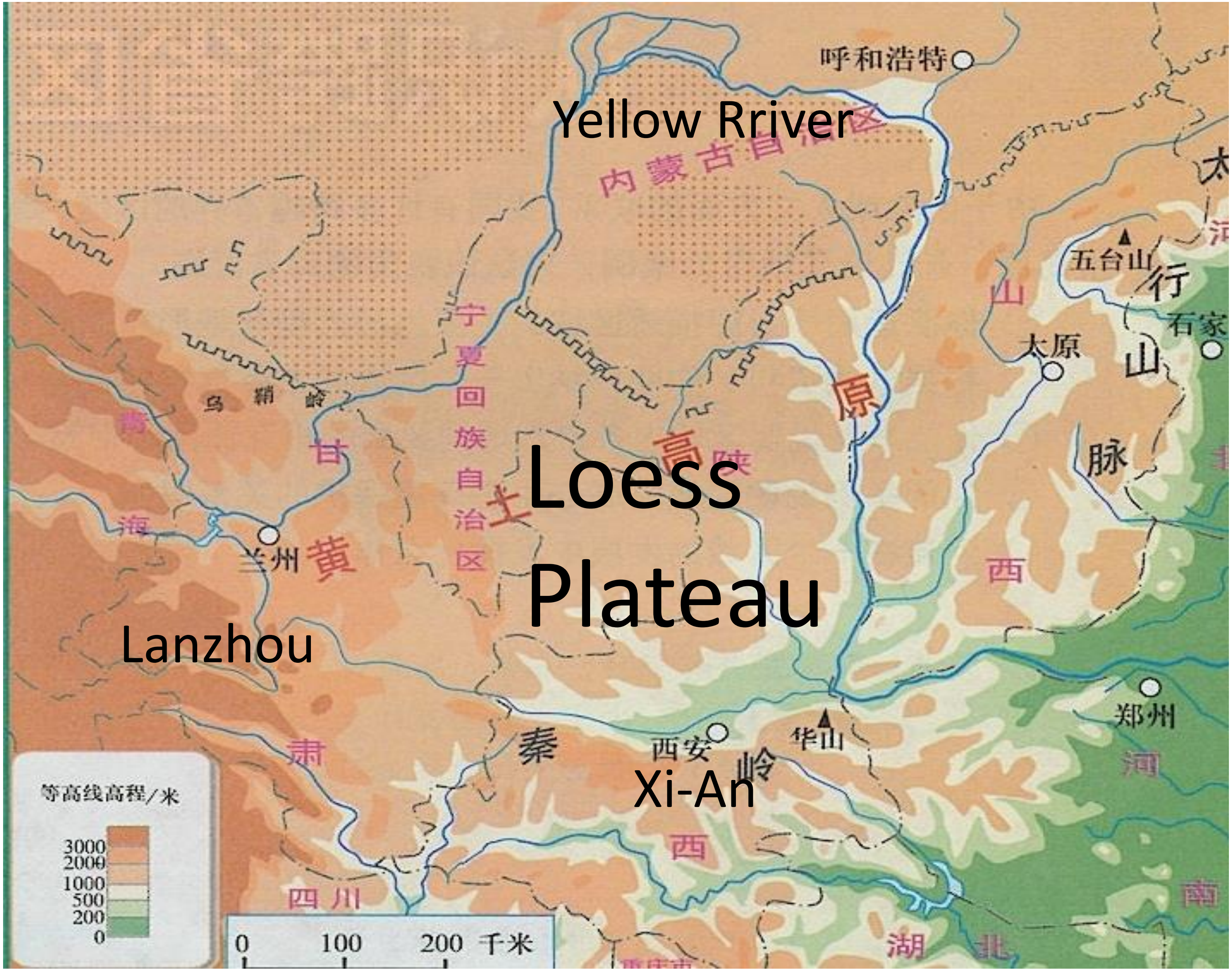
Camp fire with bullshit at the origin of YR

The main driving force for water erosion is continuous incision of the river bed. The Yellow River incised several hundreds meters in Quaternary

Uplift of the Tibetan plateau caused incision of the Yellow River and its tributaries (Daheba river and Qushian River – two tributaries of the Yellow River)

Soil erosion on the banks





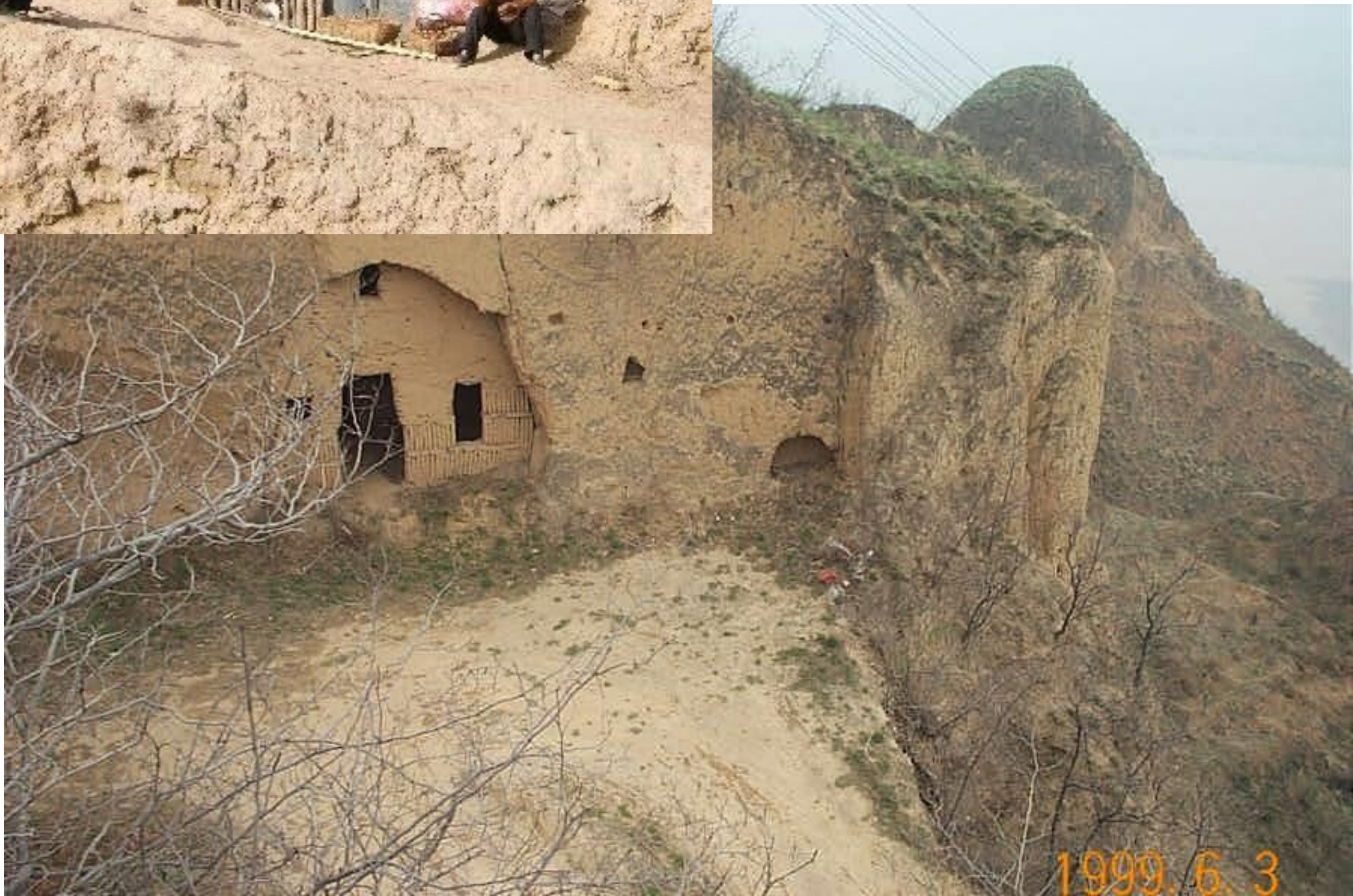
Loess plateau- 640,000 km^2. The average sediment yield from the area is 10,000 t/yr km^2

The rate of soil erosion was as high as 30,000 t/km^{2}yr in the north part of the loess plateau

The long term average of the total soil erosion was 2.3 billion tons/yr and 80% are from the loess plateau.

More than 2/3 of sediment erosion are gully erosion in the loess plateau

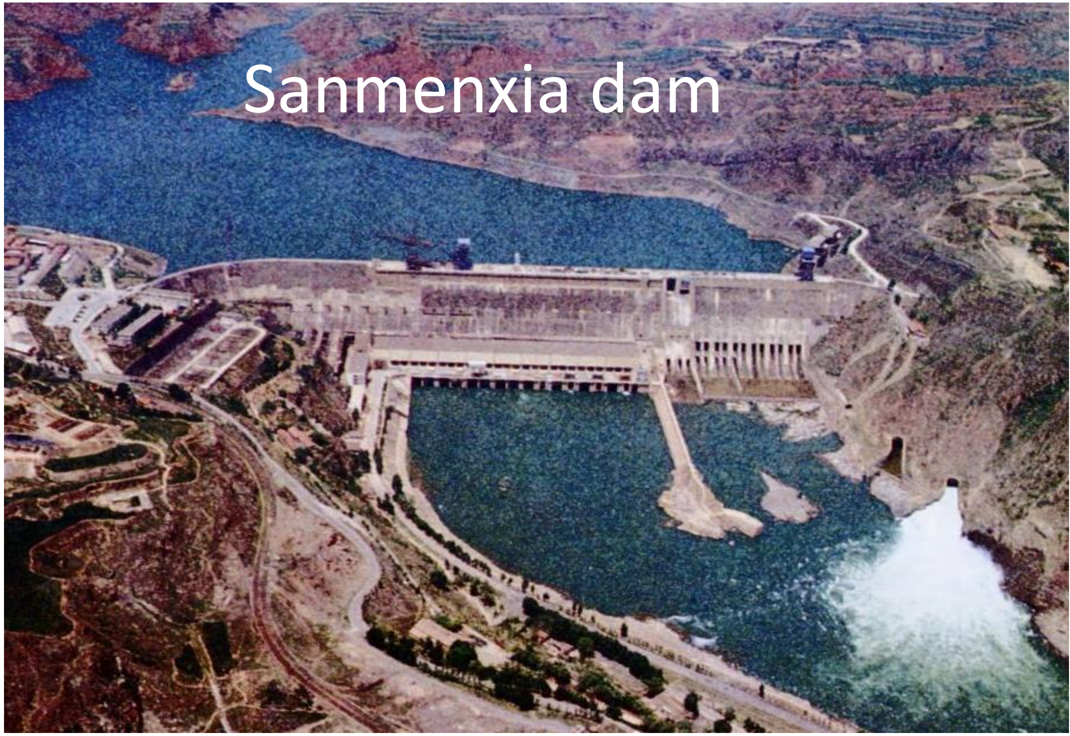
People lived in caves. Agriculture and fodder harvest exacerbate erosion

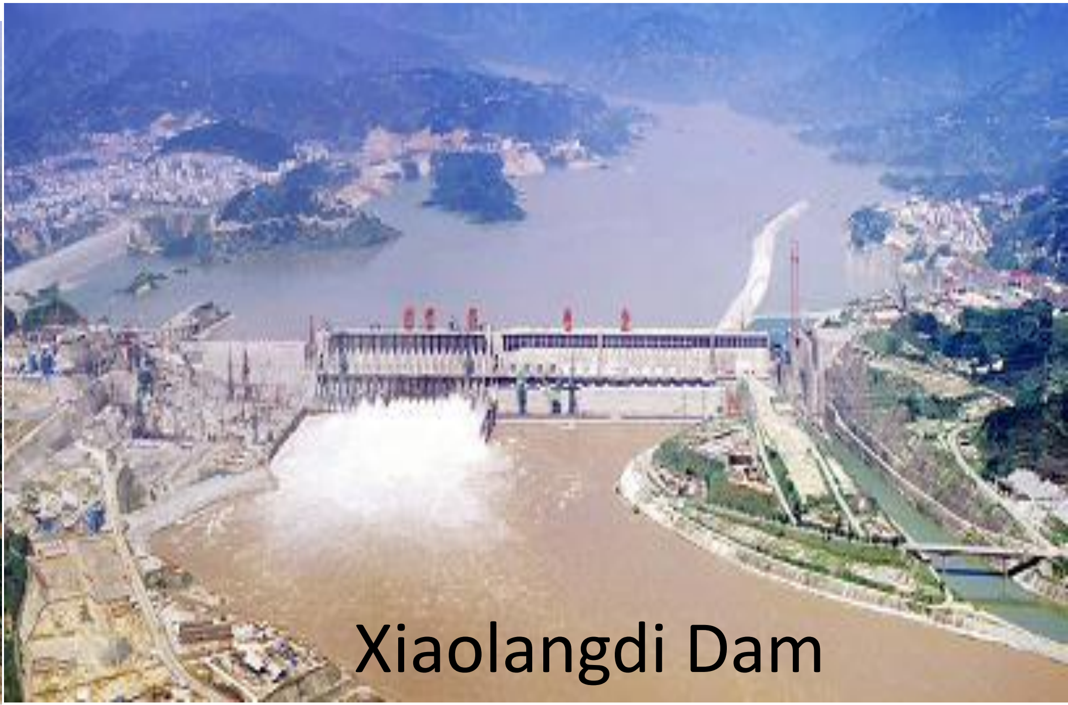


The long term average sediment load was 1.6 billion tons/yr. The sediment concentration in the middle reaches of the Yellow River was as high as 911 kg/m^3

The Weihe River flows into the Yellow River at Tongguan (in the Sanmenxia Reservoir). The Tongguan elevation is the flood stage at Tongguan Station for the flood discharge of 1000 m^3/s

Sanmenxia dam is the first large dam on the Yellow River, which was impounded in 1960. Xiaolangdi Dam is 131 km downstream of the Sanmenxia Dam, which is the most important dam on the river and was impounded in 1999.





Xiaolangdi Dam impounded in 1999, which is used for flood control, power generation, trapping sediment, and artificial flood

The lower Yellow River is a perched river. The river bed is 10-15 m higher than the surrounding ground.

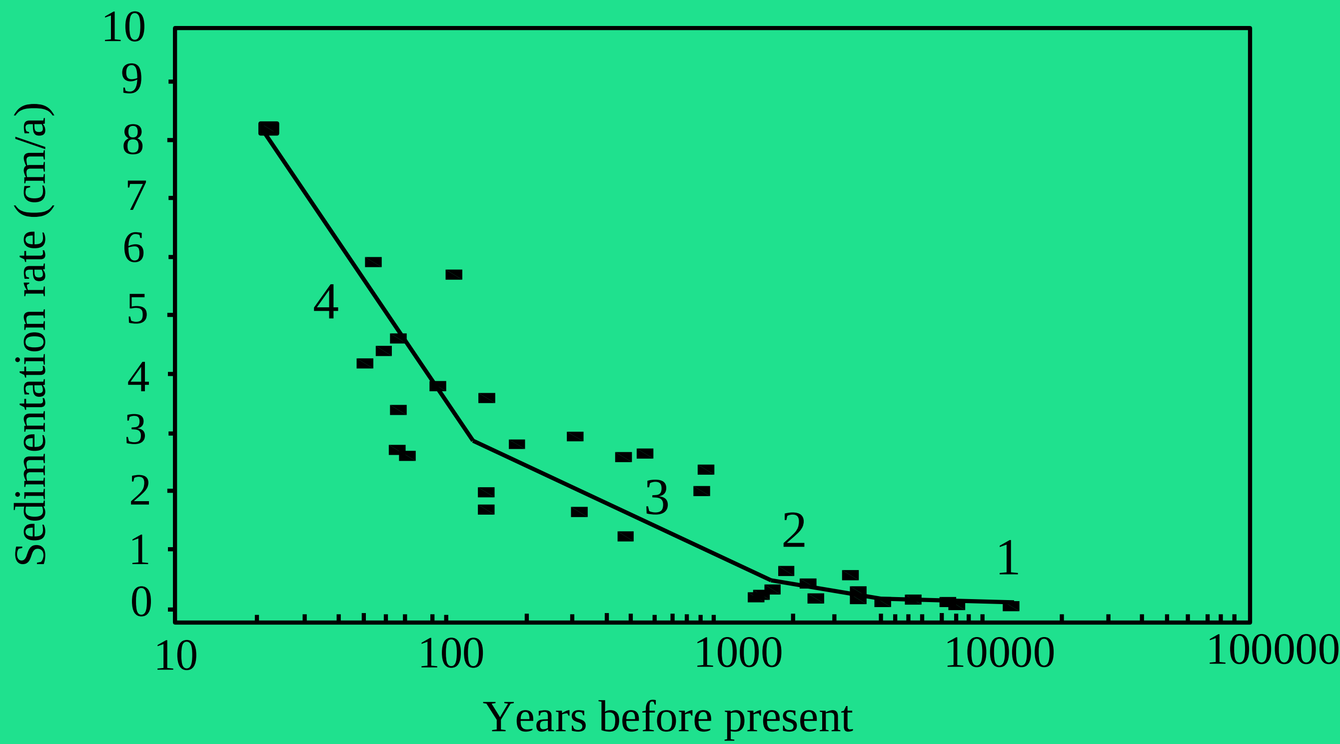
A huge amount of sediment was transported to the flat lower reaches and deposited there, causing continuous aggradation

The river flows into the Bohai sea and created land at the delta with its heavy sediment load at a rate of 25 km^2/yr

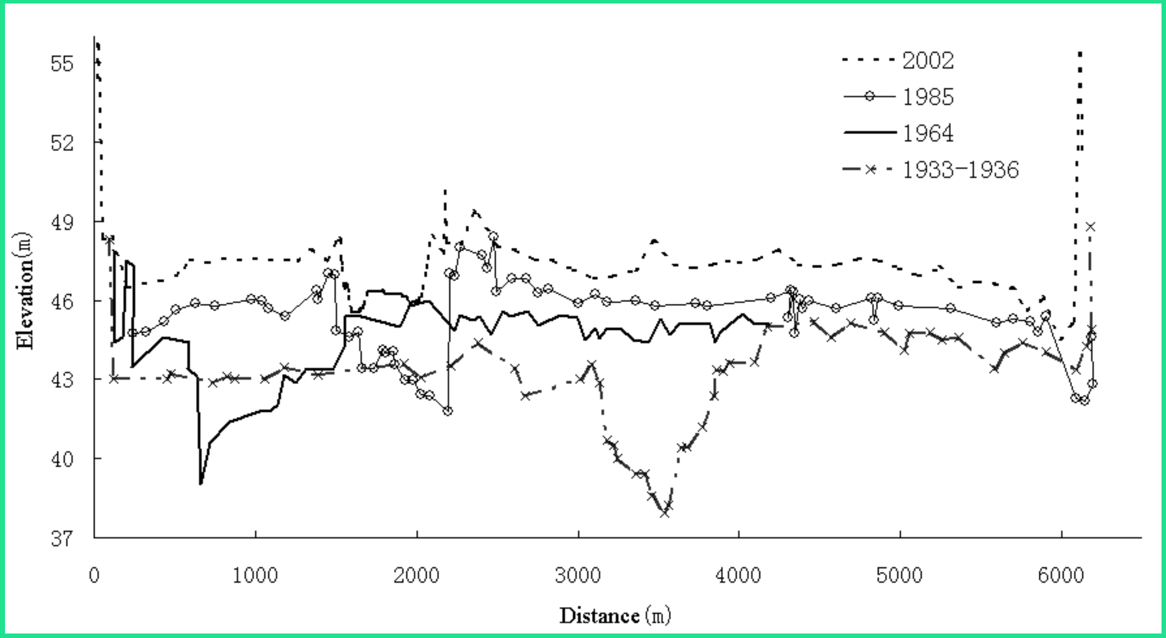
The second largest oil field of China-Shengli oil field was developed on the Yellow River delta

2. Flood disasters in the history and 2000 years debates on the river training strategies

Sedimentation rate in the lower Yellow River during the past 10,000 years



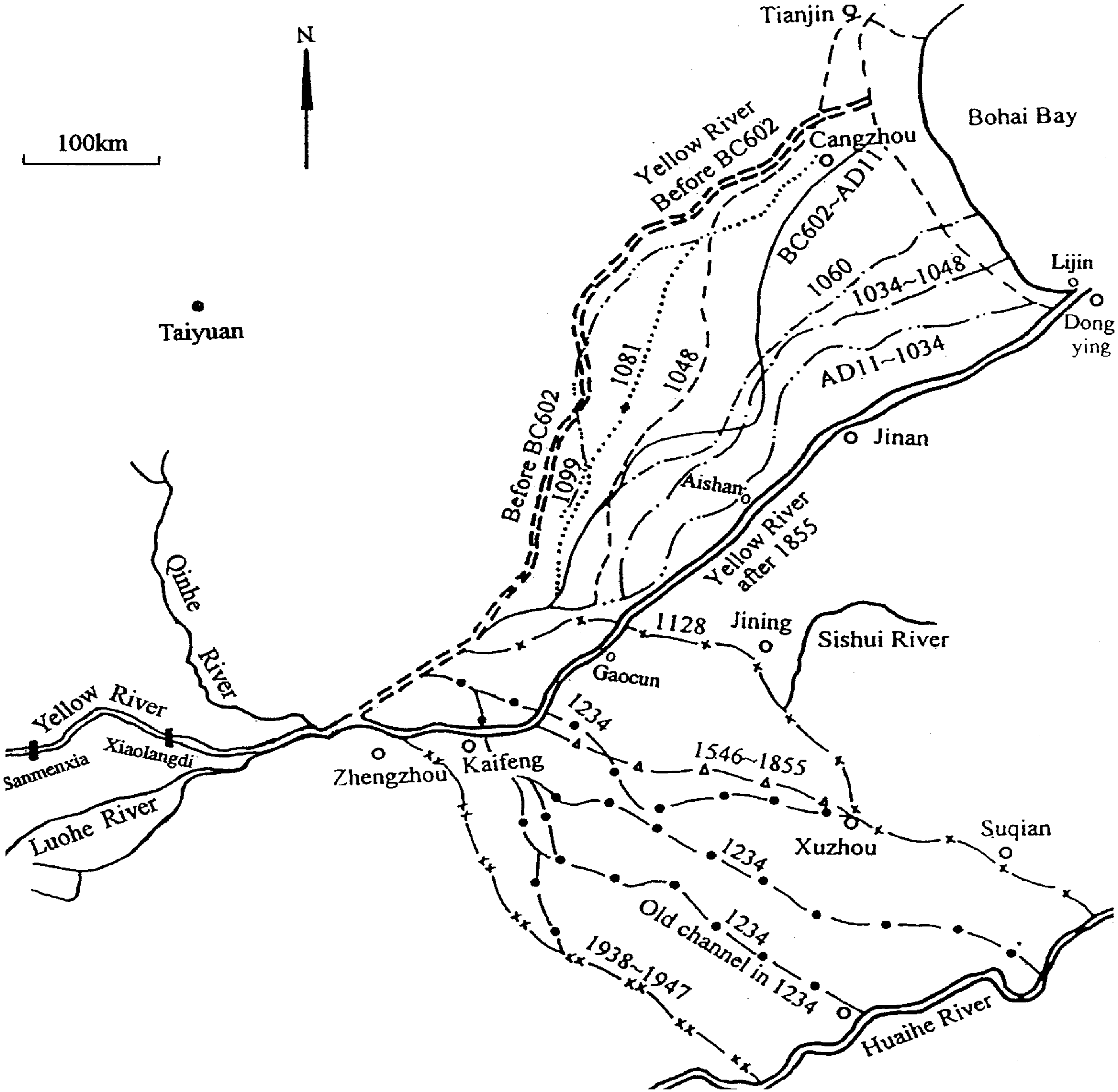
Sedimentation enhanced the riverbed of the lower Yellow River in the period 1933-2002 (Sunkou station is 440 km from the river mouth)



Levee breaches and flood disasters in the Past 900 Years

year	Discharge m3/s	Flooded counties	Lives claimed
1117			1,000,000
1642		Kaifeng	300,000
1761.8	32000	24	50,000
1843.8	36000	27	30,000
1855.8	27000	53	200,000
1933.8	22000	67	18,293
1938.6.9		44	890,000
1958.8	22300	1700 villages	No data

Levee breach in 1933



Large avulsions and abandoned channels of the Yellow river

(26 large avulsions in 2,600 years)

Important Events

- Tongwaxiang Levee Breach – The levee was breached by flood and an avulsion occurred at Tongwaxiang in Aug. 1855, which killed more than 200,000 people and resulted in 7 million refugees.
- The Yellow River changed its course and flows into the Bohai Sea since then.
- The river captured the Daqing River course, which was too small to allocate the Yellow River water. Therefore, the river flooded the nearby areas every year until 1890.

The river captured the Daqing River course, which was too small to allocate the Yellow River water. Therefore, the river flooded the nearby areas every year until 1890.

Huanyuankou levee breach

- In 1938 Japanese army invaded China from northeast to sourthwest. Chinese army exploded the grand levee of the Yellow River at Huayuankou (near Zhengzhou) in order to stop Japanese army.
- The levee breach caused a great avulsion and the river changed the course from north to south and captured the Huaihe River channel.
- Then the river flowed on the plain without fix channel between Huayuankou and the Huaihe River for 8 years and changed 54,000km^2 of farmland into a desert.

Chinese army exploded the levee at Huayuankou and caused an avulsion in 1938. The flood killed 890,000 people and created 54,000 km^2 desert.

The grand levee at Huayuankou was exploded in 1938 in an effort to stop the Japanese army. About 890,000 people were killed and 3.9 million people lost their homes and farmland

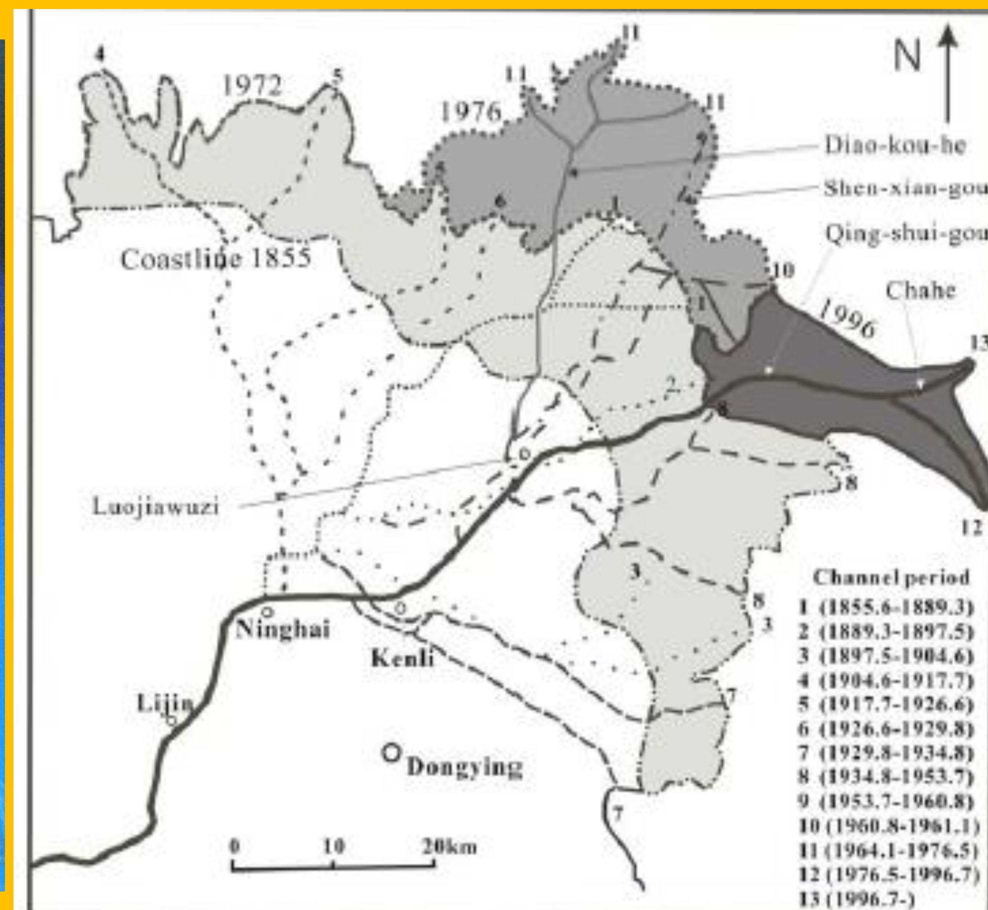
The flood killed 2000 （7400）Japanese soldiers and slowed the Invasion of Japanese army to central China until 1940. The flood helped the Chinese army in the Wuhan campaign and Changsha campaign

- In 1946 the government and hydraulic engineers made effort to close the breach but failed. (from the bed)
- In 1947 people finally closed the breach and make the river back to the north channel. (from two sides)

Monument for Huangyuankou Breach.

New levee at Huangyuankou

After the large avulsion at Tongwaxiang in 1855, the Yellow River shifted to the present cause and pour into the Bohai Sea. In the past 150 years (except for 1938-1947) 12 small avulsions occurred and created 4500 km^2 of land, on which the second largest oil field of China was found.



wo training strategies and two thousands years debates

Two strategies and four great river trainers

Zhang Rong (AD 0004) described the Yellow River "Bucket of water, sediment six", which means 60% of the Yellow River flood was sediment. The key point for Yellow River training is the sediment management, for which there were two strategies.

1 Depositing sediment in wide river and diverting flood (Wang Jing)

2 Scouring sediment with converging flow in narrow channel (Pan Jixun) - Confine the flow within a narrow channel, close all branch channels, enhance the flow velocity to carry sediment into the sea.

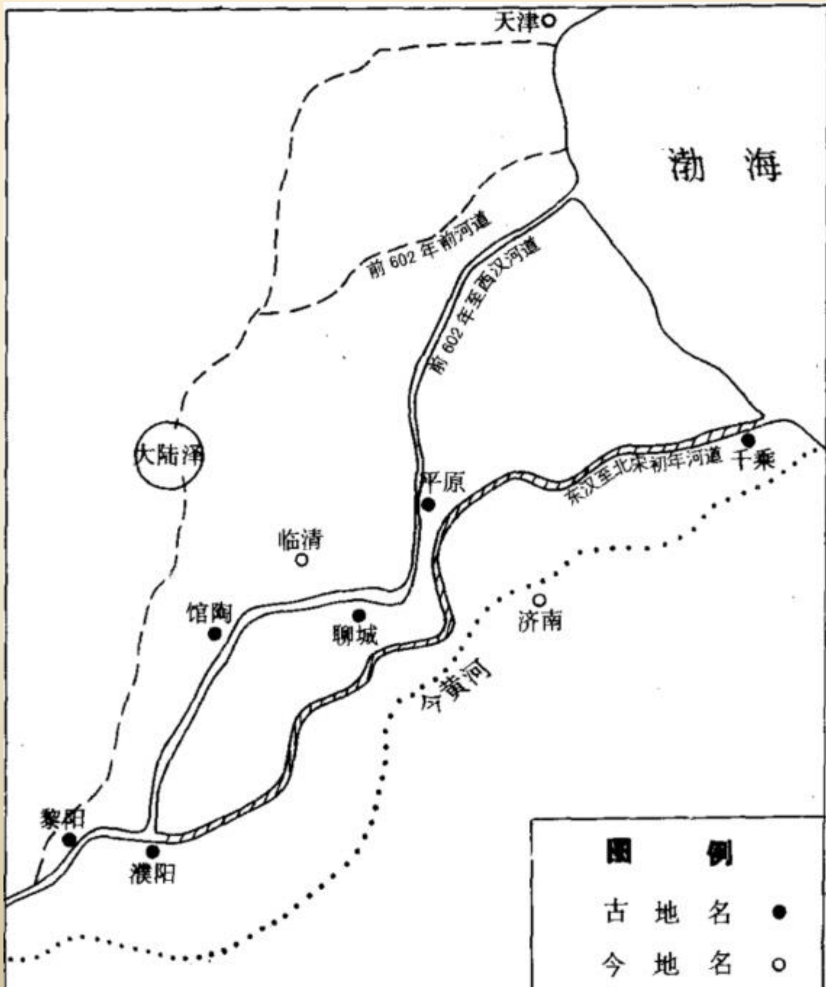
Four great masters have practiced the two strategies in the past 2000 years: Wang Jing, Pan Jixun, Jin Fu and Wang Huayun

Wide river and depositing sediment

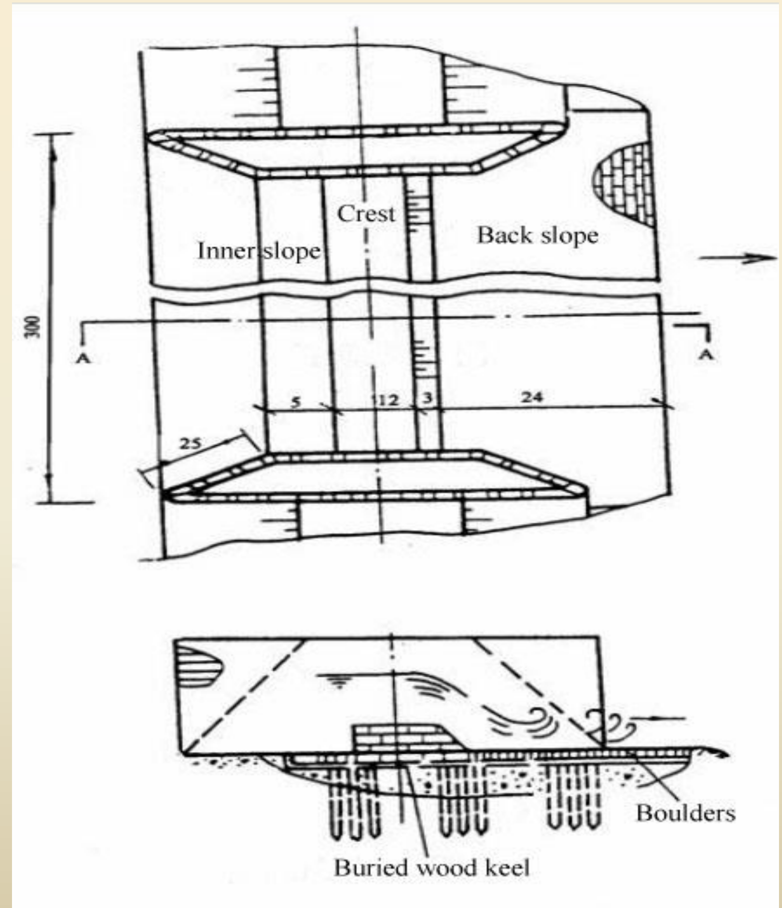
- Wang Jing （AD30-85）proposed and practiced the wide river and depositing sediment strategy from AD69.
- In the following 800 years after Wang Jing the Yellow river was calmed and very few flood disasters occurred. (王景治河八百年安流）

The technology of Wang Jing from historical records was only Water gates per 5 km and wide river channel.

Water gate=Spillway weir for flood water diversion



Yellow River Flood flow

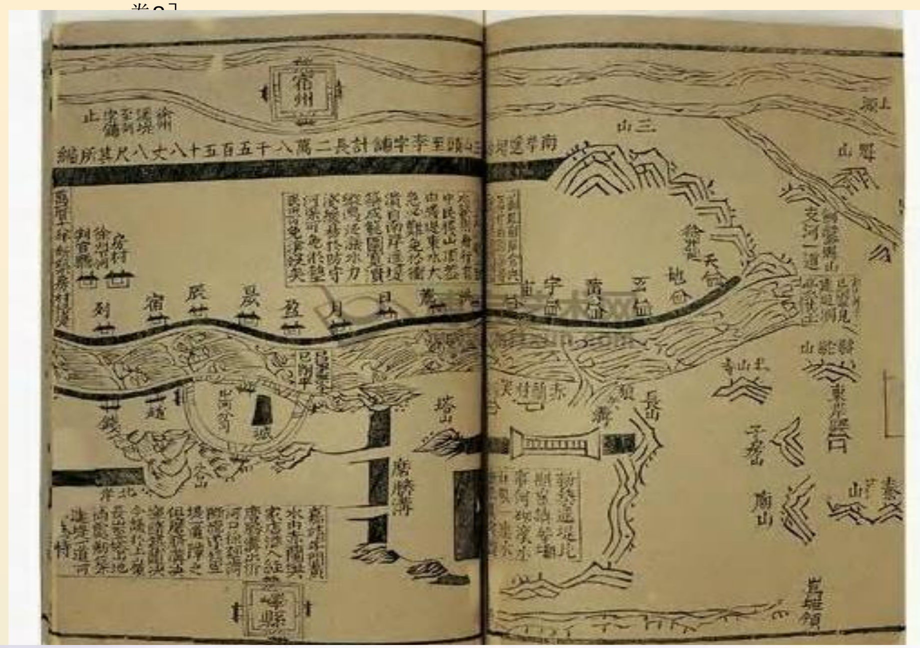


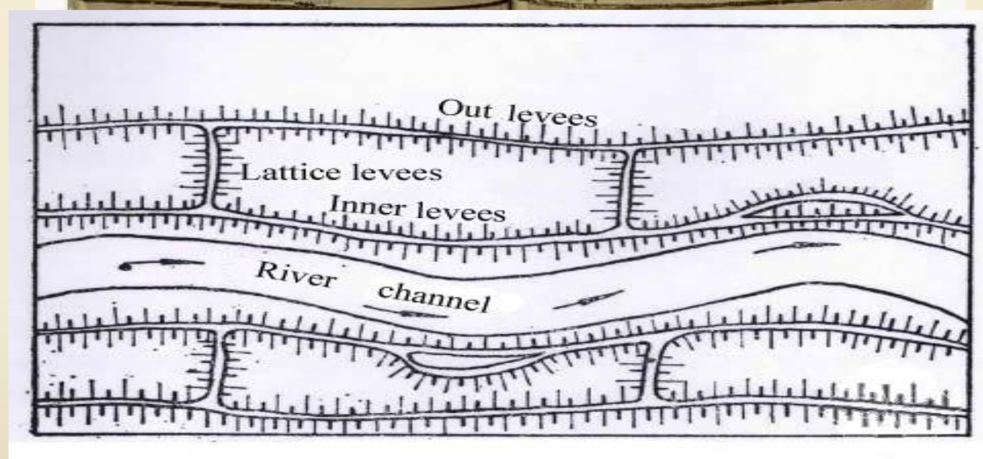
Water gate side view

Narrow channel and scouring sediment

Pan Jixun （1521-1595）proposed the strategy of scouring sediment with converging flows by narrowing the channel. He regulated the levee system, blocked many branches of the river and made the river flowing in a single channel in the period 1565-1592.

Pan Jixun1521-1595 Viceroy of the Yellow River and Minister of construction and industry





Pan published a book “Overview of Yellow River flood defence” and explained the mechanism of Scouring sediment with converging flows in narrow channel for sedimentation and levee breach control

Yellow River training in Qing Dynasty

- Jin Fu （1633～1692） and Chen Huang in Qing Dynasty adopted the narrow channel and scouring sediment theory and was among the most famous river training practitioners in Chinese history.
- The Yellow River breached the levee frequently and caused great catastrophes as Jin took over the job of river training although it was not long after Pan.
- Jin applied Pan's theory and practiced "converging flow with narrow channel and scouring sediment with high velocity of flow".
- Jin proposed the measurement of flow discharge and used the method in the design of channel.
- He introduced clear water from several parallel rivers into the Yellow River to increase the sediment carrying capacity

Narrow river strategy practitioner

Jin Fu （1633～1692 Minister of military）and Chen Huang in Qing Dynasty were the third great Yellow River trainer.

The Yellow River breached the levees and caused great catastrophes after death of Pan. Jin and Chen applied Pan’s theory and practiced “converging flow with narrow channel and scouring sediment with high flow velocity.

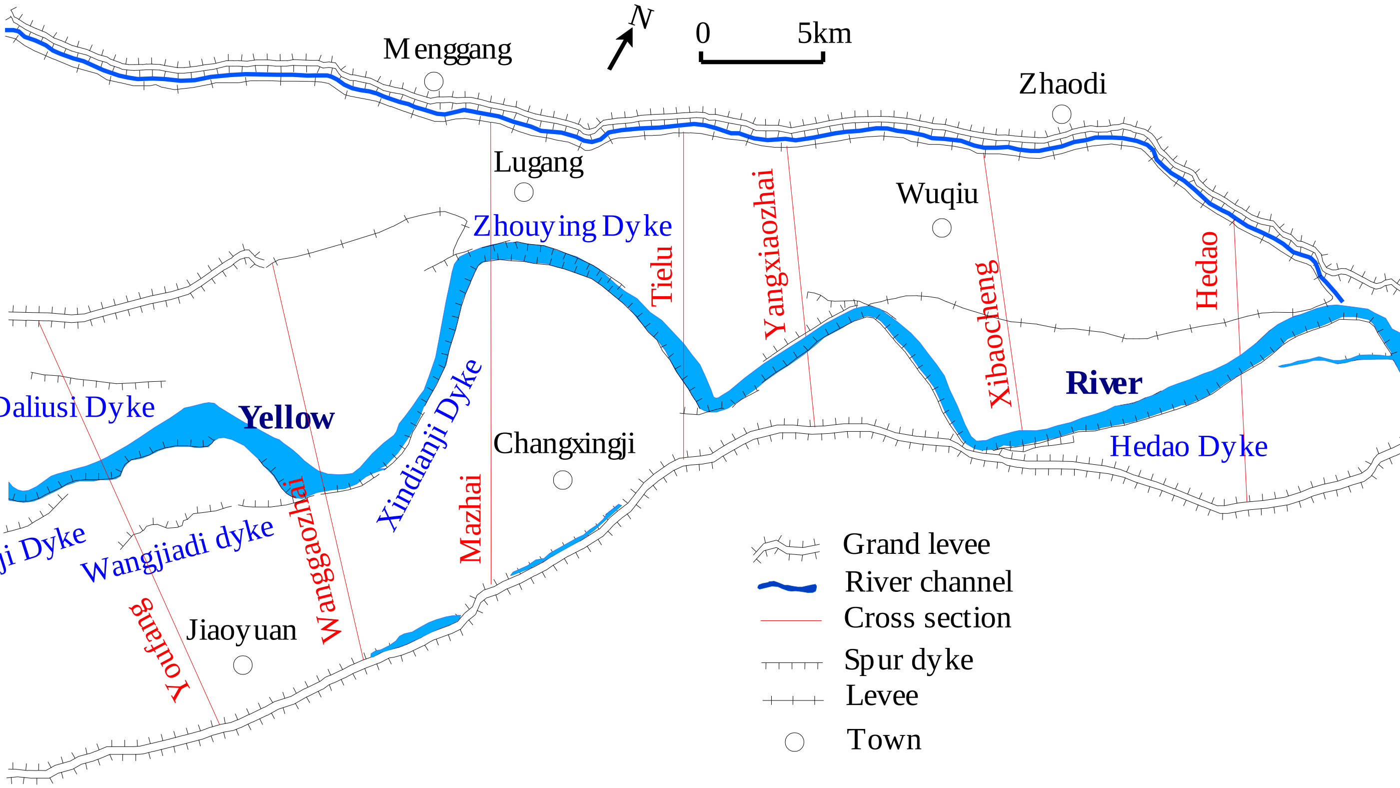
Jin and Chen were measuring the water level and discharge shown in a movie of their story. Jin invented the method for measurement of flow discharge.

Wide river strategy practitioner

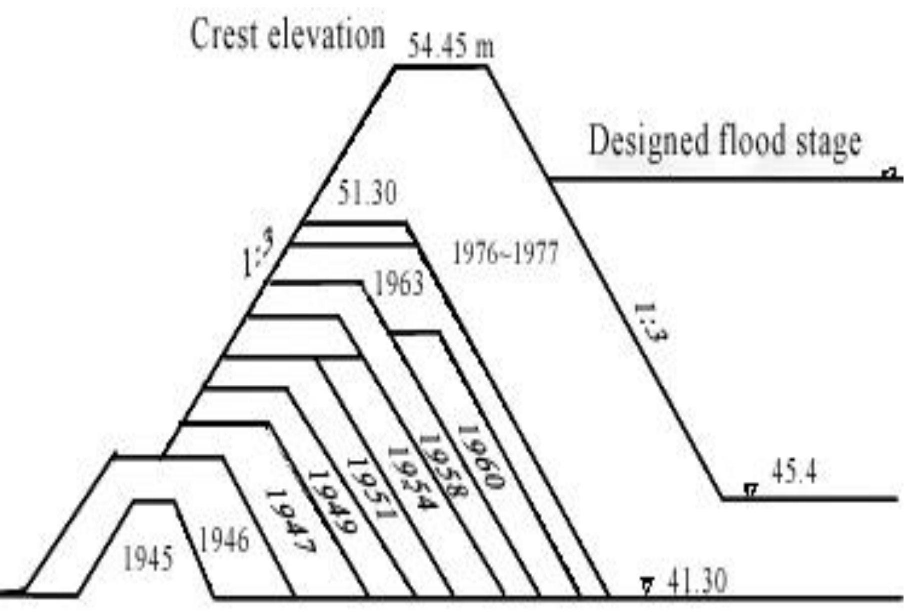
Wang Huayun（1908-1992）was vice minister of water resources of China and director of the Yellow River commission.

Wang Huayun was in charge of the Yellow River training from 1950 to 1990. He applied the wide river and depositing sediment strategy. Wang proposed 16 words for river training
“宽河固堤，蓄水拦沙，上拦下排、两岸分滞”
Widen river and enhance levees, store water and trap sediment, deposit sediment upstream and discharge sediment downstream, divert sediment and water to detention basins

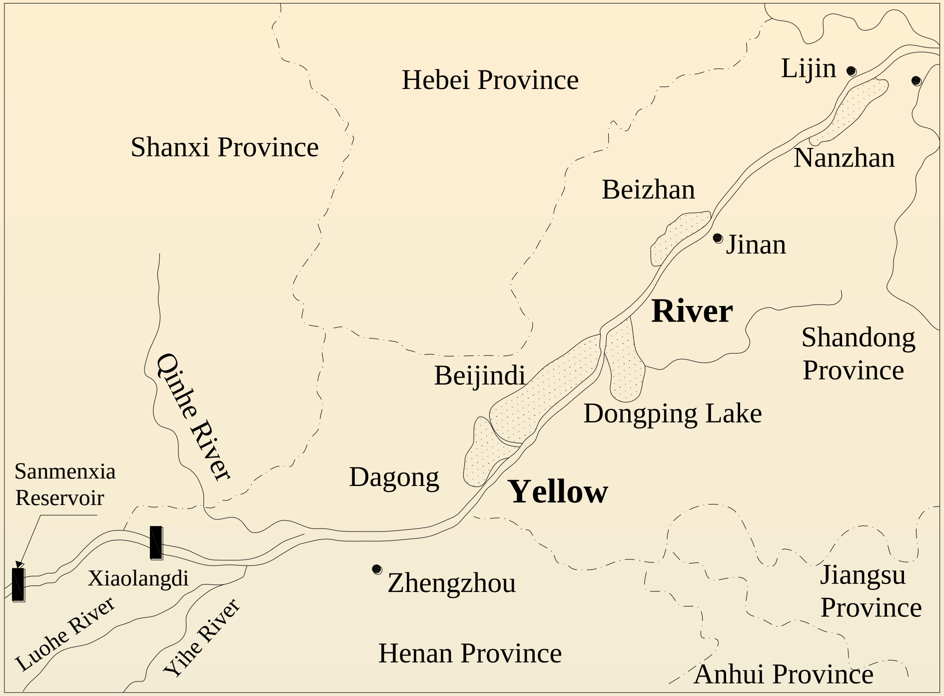
Wide river valley defined by the Grand Levees (10-20 km) in the reach in Henan Province



The grand levees were enhanced and reinforced 9 times and the crest elevation of the levees is 3 m higher than 100 years flood stage (which can control 1000 years flood together with the operation of the reservoirs and flood detension basins).



Anti-seepage wall-40 m deep



Divert water and sediment to the basins on the lee side of the levees, allowing sediment deposition making the levee wider and higher.

Construct 5 flood detention basins: Dagong, Beijindi, Dongping, Beizhan, and Nanzhan for flood detention and sediment deposition

Doufuwo flood diversion gate: 1200m^3/s

Lijia-an flood diversion gate：150m^3/s

25 large dams on the river trapped more than 10 billion tons of sediment.

Longyangxia Dam

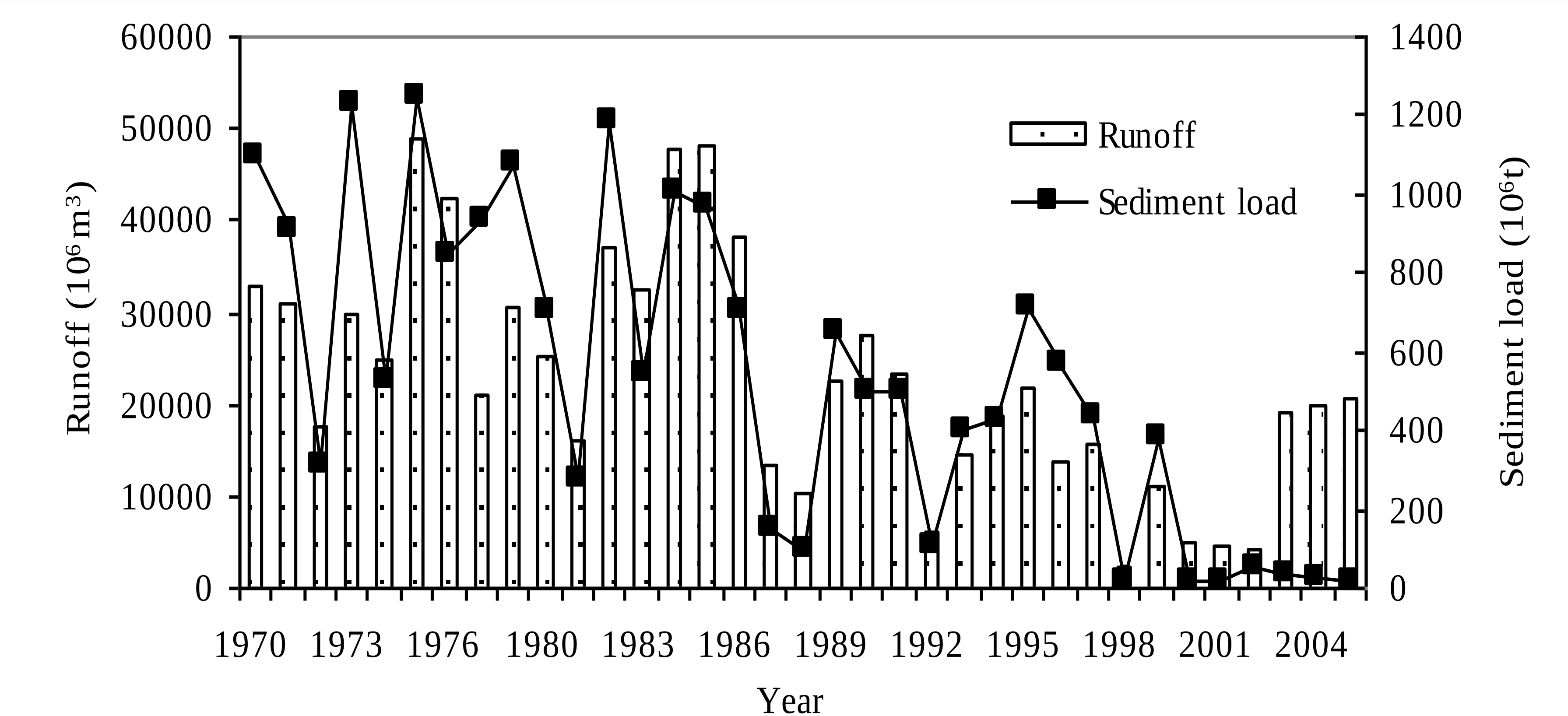
Liujiaxia Dam

According to the vegetation-erosion dynamics, erosion from the Loess Plateau can be controlled by revegetating the hills and gullies, constructing check dams (or farmland creation dam) replacing slope farm land with terrace farmland and performing small watershed management. In the meantime the loess plateau can be re-greened

Slope farmland has been replaced with terrace land.

People constructed 110,000 (59000) earth dams on the rivers and gullies in the plateau with sediment trapping capacity of 21 bm^3 for farmland creation and sediment yield reduction

Two new problems: 1) much less sediment erosion results in very slow farmland creation. More than 100 years are needed for the earth dam to be filled. 2) many earth dams failed during high flood events. The security of the land creation dams has become a challenge.



- Sediment load transported to the ocean by the Yellow River has been reduced by 90% in the past 30 years due to erosion control, sediment trapping by reservoirs on the river and check dams on the loess plateau, sediment deposition on the flood plain and flood diversion.

Debate on the two strategies

- The narrow channel and scouring sediment strategy was spoken highly (less land and looks more sophisticated). Pan Jixun and Jin Fu enjoyed high reputation. Qing dynasty agreed and local people built temple for Jin.
- Nevertheless, the result of the strategy was not good. Levee breaches continuously happened.
- The debate on wide or narrow river strategies became international as Freeman proposed to further narrow the river as he visited China in 1917
- Engles conducted physical model experiments in 1931-1934. The result indicated that wide river is better.
- Franzius conducted another experiment and support narrow river theory. Ben Yen indicated Franzius' results was not so reliable as Engles's.

Wide river or narrow river?

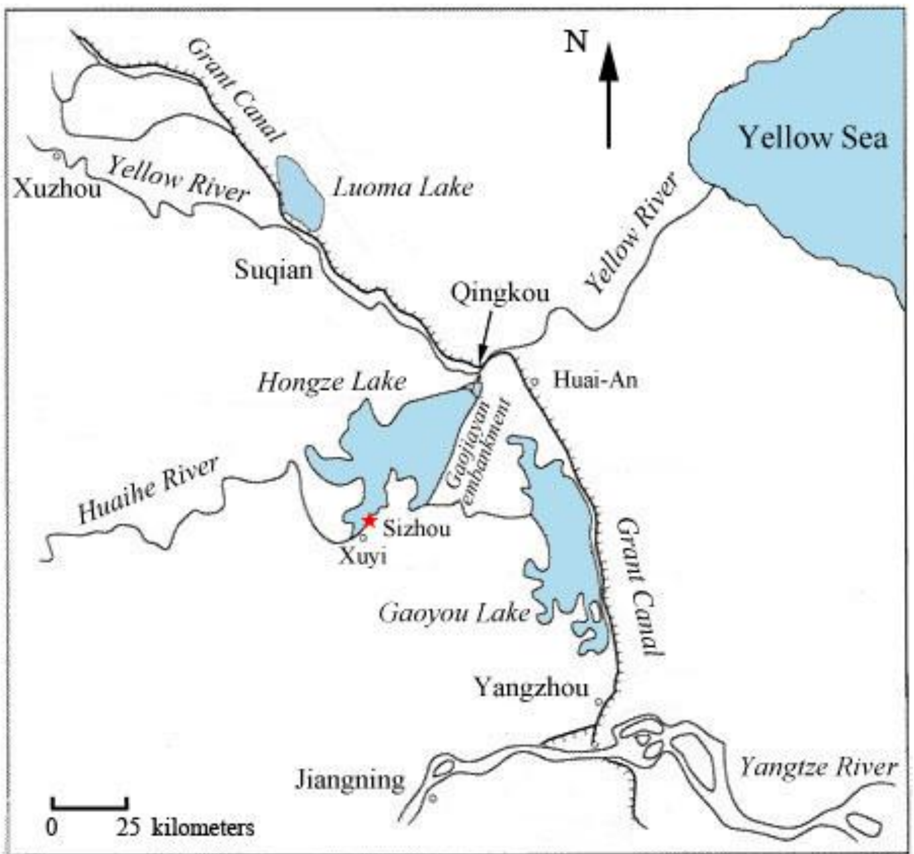
In a historic view， the narrow river strategy transferred the sediment problem to the downstream reaches and late time. There is an evidence proving that the narrow river and scouring sediment strategy can cause long term consequence:

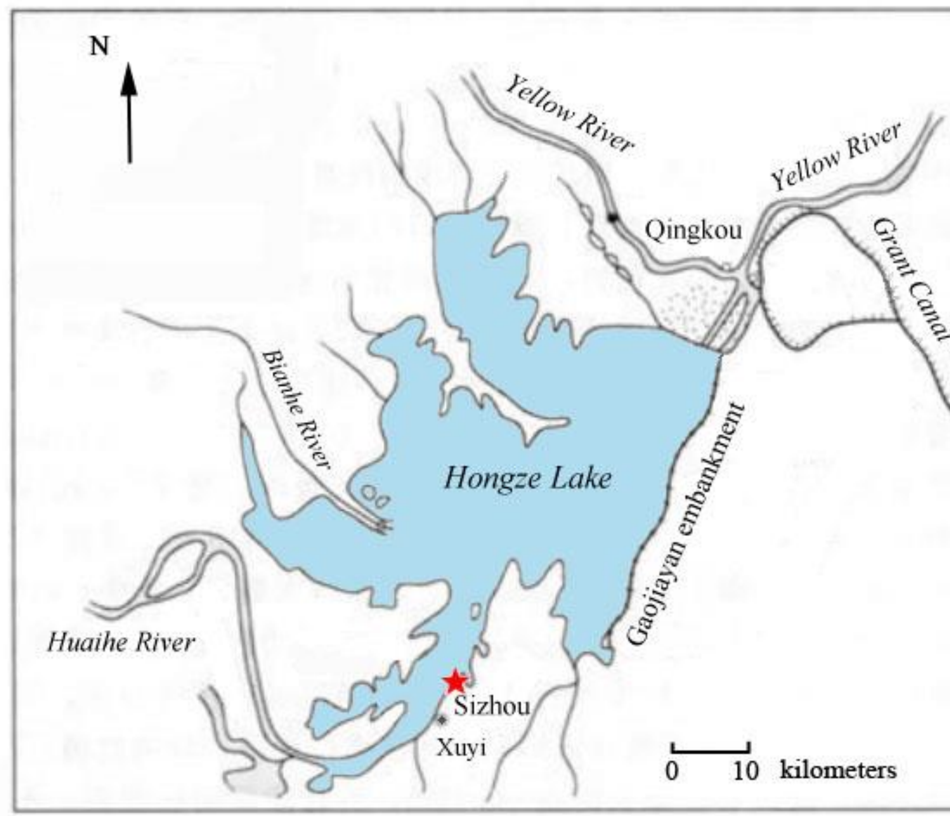
In 1680 a flood carried a lot of sediment and buried the Sizhou Town and killed many people, which was a consequence of the narrow river strategy practiced by Pan Jixun and Jin Fu.

Sizhou town is unearthed after 330 years sleep under sediment-East Pompaii

Sizhou town was a center of transportation and commerce with a population of 300000. Boats navigated across the Huaihe (Yellow River) through ship locks at Qingkou. Pan and Jin commanded million labors for training of the Yellow River and the Grand canal with Headquaters at the town.

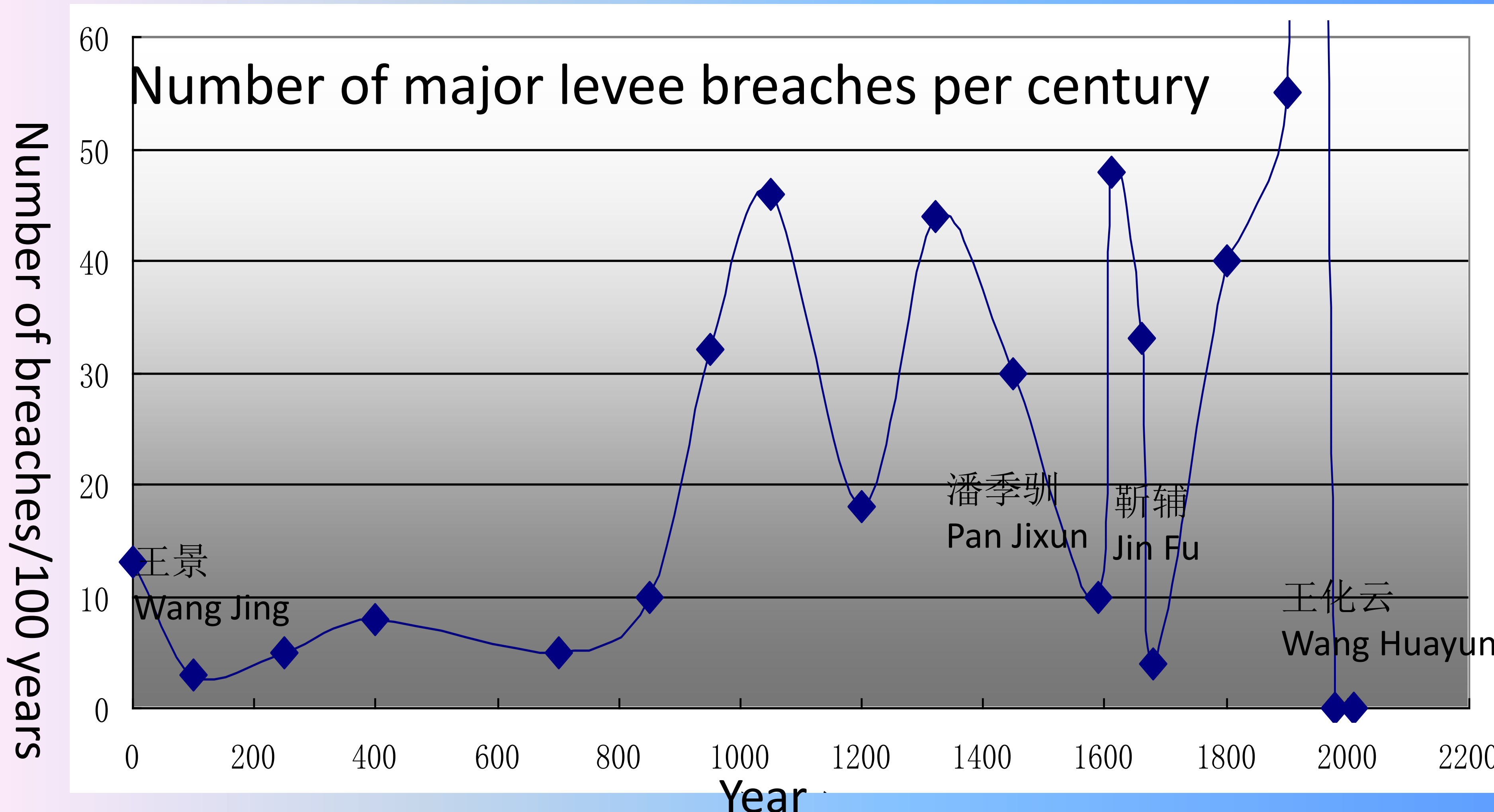
In 1128 the Yellow River changed its course from north to south and captured the Huaihe River at Qingkou. Before Pan the Yellow River sediment deposited upstream of Qingkou. Pan and Jin trainned the river and most of sediment was transported to the Huaihe river, which was not able to transport so much sediment. Sediment deposited at Qingkou and formed a sediment dam. Water from the Huaihe was stored and formed the Hongze Lake. Sizhou town was located by the Huaihe River.





in 1680, a flood from the upper Huaihe River breached the levee. Flood water flowed with 9 m water head into the Sizhou town and sediment scourred from the lake bed was transported into the town. The Sizhou town was finally buried under 9 m thick sediment.

- The narrow channel and scouring sediment strategy is difficult to manage. Pan and Jin were very skillful and very carefully managed the high velocity flow. Thus, they maintained short periods of low breaches.
- Soon after Pan and Jin, the levee breaches became more than before .
- Suffer from levee breaches and floods people remembered the relatively safer time during Pan and Jin and therefore regarded them as gods.



Results of the two strategies for levee breach and flood control in the past 2000 years

- The wide channel and depositing sediment strategy resulted in long term flood safety. Wang Jing applied this strategy and resulted in 800 years low frequency of breaches. Wang Huayun used the strategy and no levee breach occurred in the past 60 years, which is a only period of zero levee breaches in the Yellow River history.
- Wang Jing and Wang Huayun were not so well known as Pan and Jin although their training projects resulted much better effects for flood control.
- This can be understood as "Good general has no brilliant achievements in wars" (Sun Tzu's The Art of War) because he has defeated the enemy before the war.

3. New problems and management strategies

Water resources of the Yellow River basin

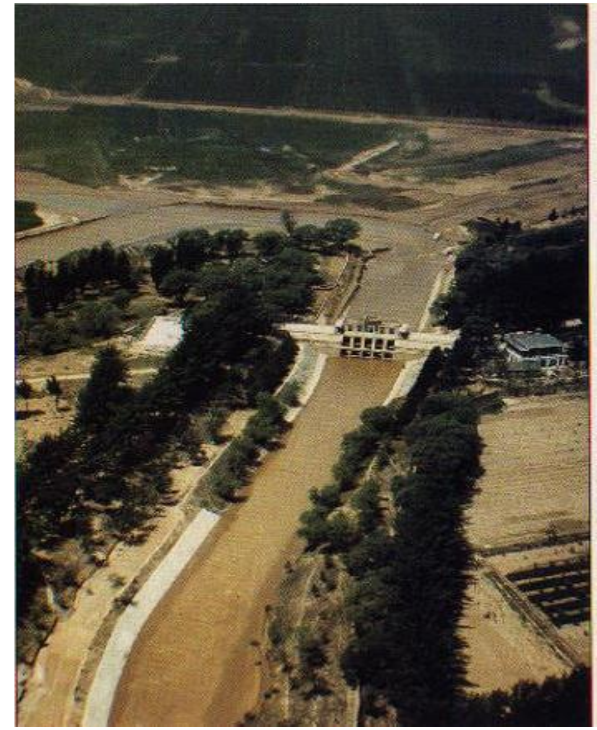
- Precipitation 476 mm
- Total runoff 58 billion m^3
- Population 107 million
- Water per capita 542 m3 (1/4 of the national average)
- Water per farmland 4850 m^3 /ha
- At least 10 billion m^3 of water is needed to transport sediment to the river mouth
- 2-3 billion of water are diverted to Qingdao,Hebei and Tianjin
- Water shortage about 10 billion m3

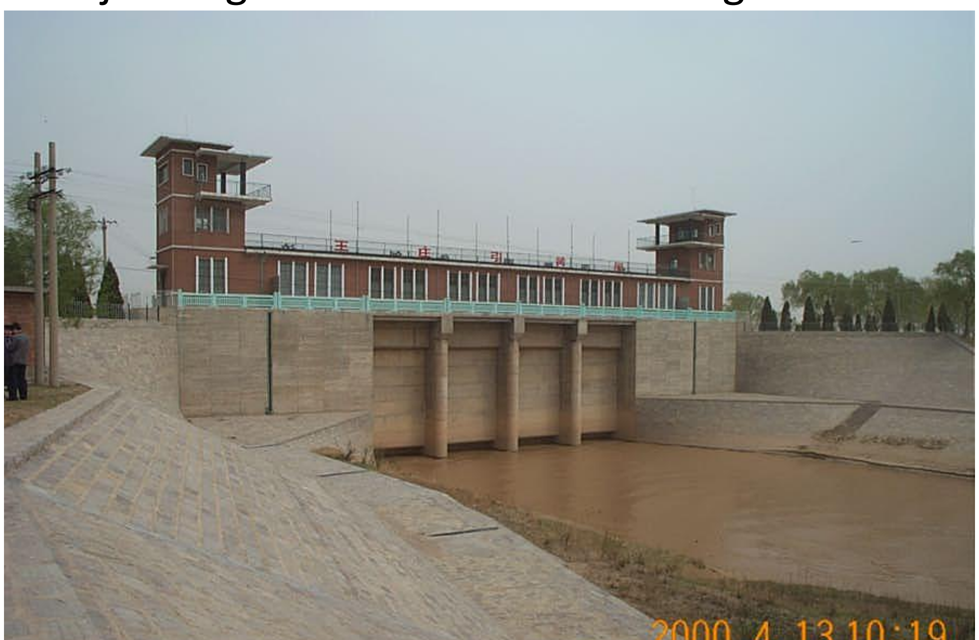
There are 97 water diversion gates, 26 pump stations and 21 siphon stations along the lower Yellow River. The total capacity is more than 2000 m3/s. The volume of water and sediment diverted from the YR are listed as follows:

2012	11.2 billion m3 water	24.3 million tons of sediment
2011	10.4 billion m3 water	23.3 million tons of sediment
2010	9.7 billion m3 water	26.1 million tons of sediment
2009	9.3 billion m3 water	20.6 million tons of sediment
2008	7.1 billion m3 water	19.1 million tons of sediment

Bo-ji-li irrigation district in Shandong Province （1966）

Peoples victory canal in Henan (1951)



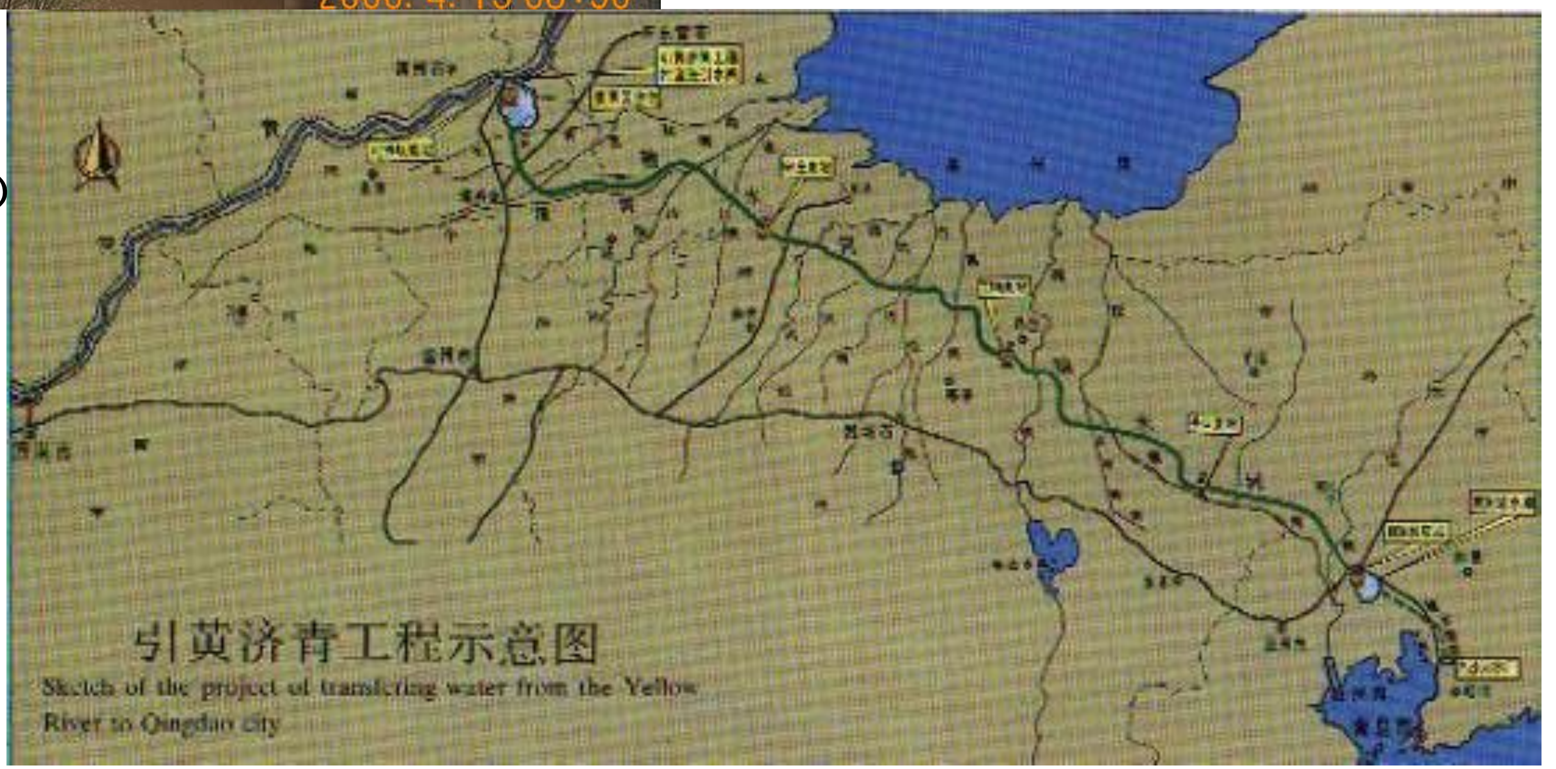


Wangzhuang water diversion gate (1969，$50m^3/m$）

Dingzikou Pump station

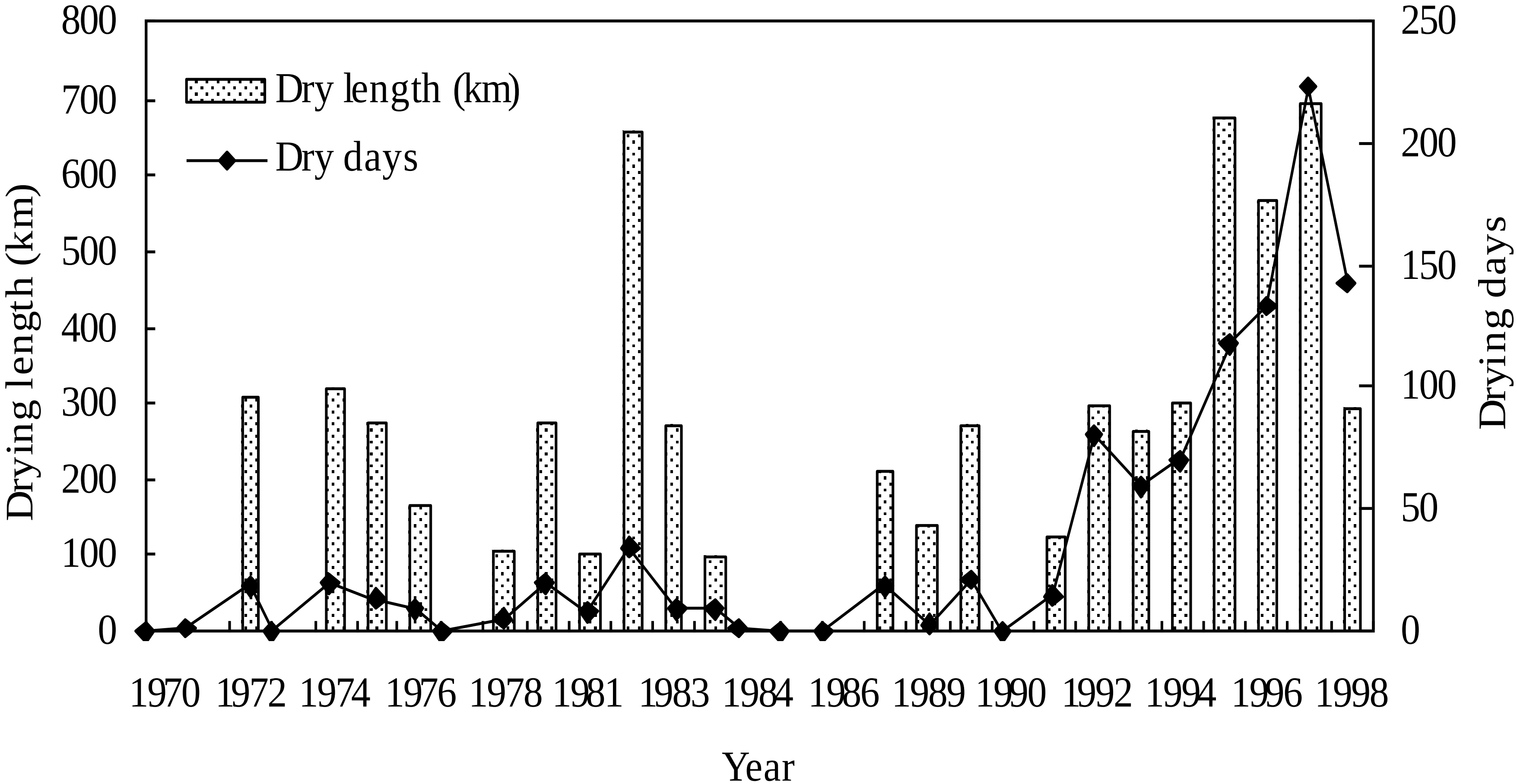
Inter-basin water transfer from the Yellow River to Qingdao city with a capacity of 120 m3/s

Dayuzhang water diversion project (120m^3/s） - Yellow – Tsingdao



Problem 1: Too much water was diverted the flow in the Yellow River was cutoff in dry years

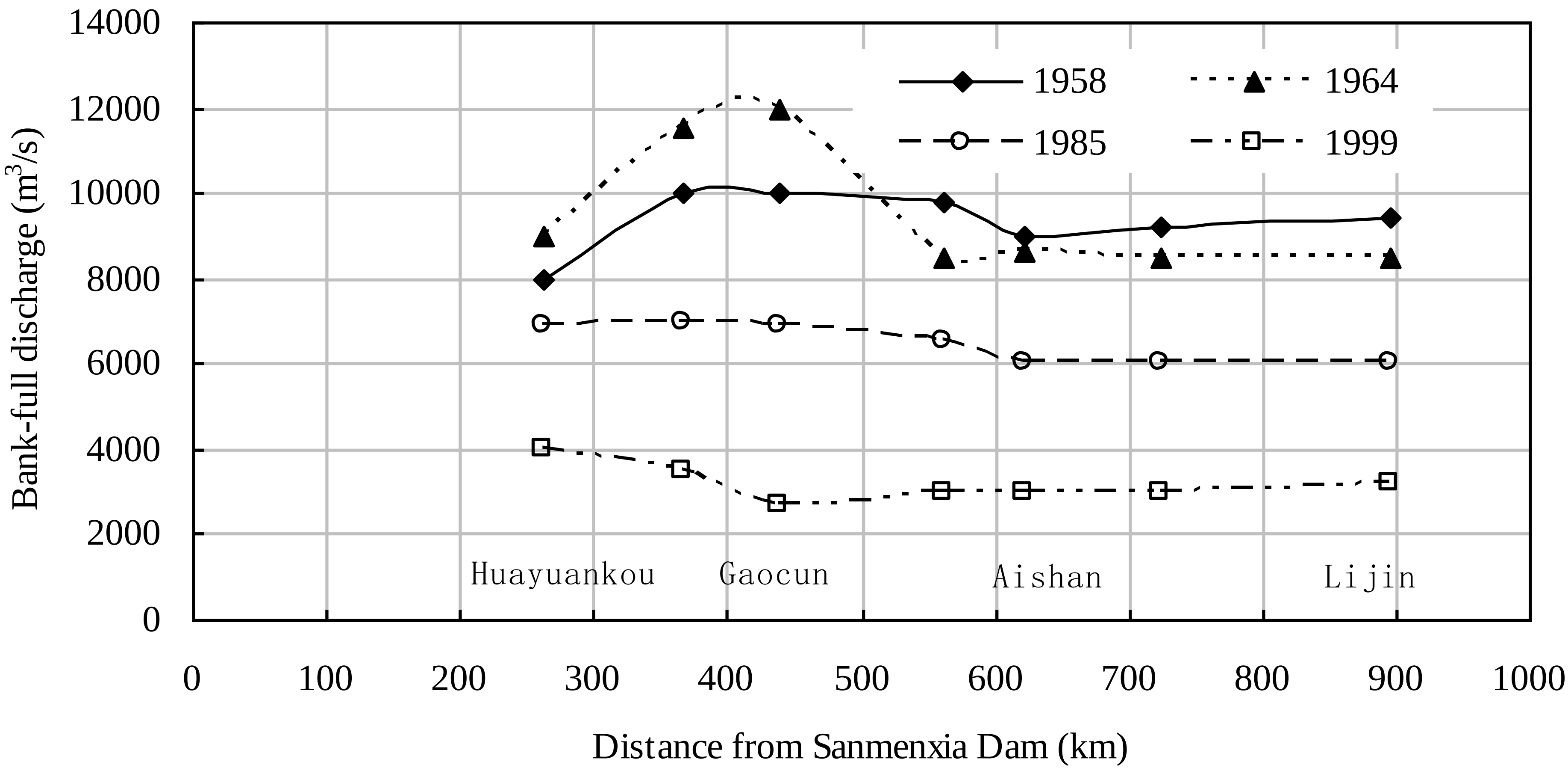
The river flow was cut off and the river bed is drying up in the flood season in 1977



Dry days and dry length of the lower Yellow River from 1972-1998

Problem 2: River morphology changed due to water and sediment diversion

Water diversion caused the river channel shallower

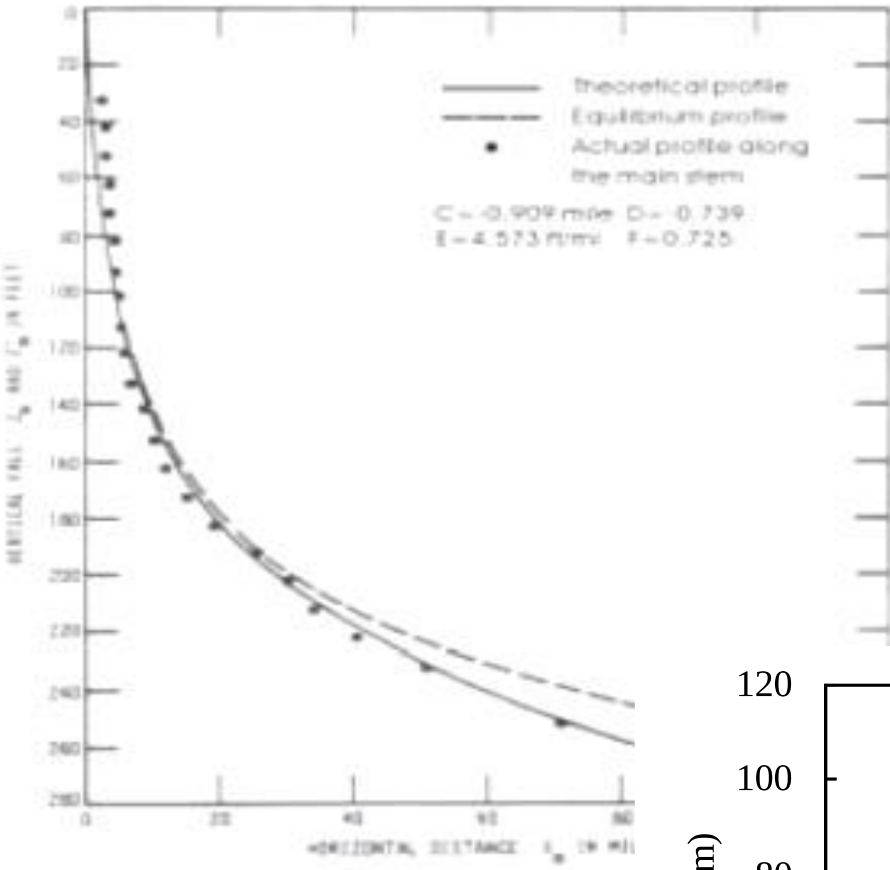


Bank-full discharge of the lower Yellow River channel reduced from 9000 m3/s in 1950-1970 to 3000 m3/s in the 1990s and further reduced to 2000 m3/s in 2002.

According to the minimum stream power theory, the morphology of fluvial rivers develops to reach the minimum stream power (Yang, 1983). This can be described by the following equation:

$$\frac{dP}{dx} = \frac{d}{dx}(\gamma sQ) = \gamma(Q\frac{ds}{dx} + s\frac{dQ}{dx}) = 0$$

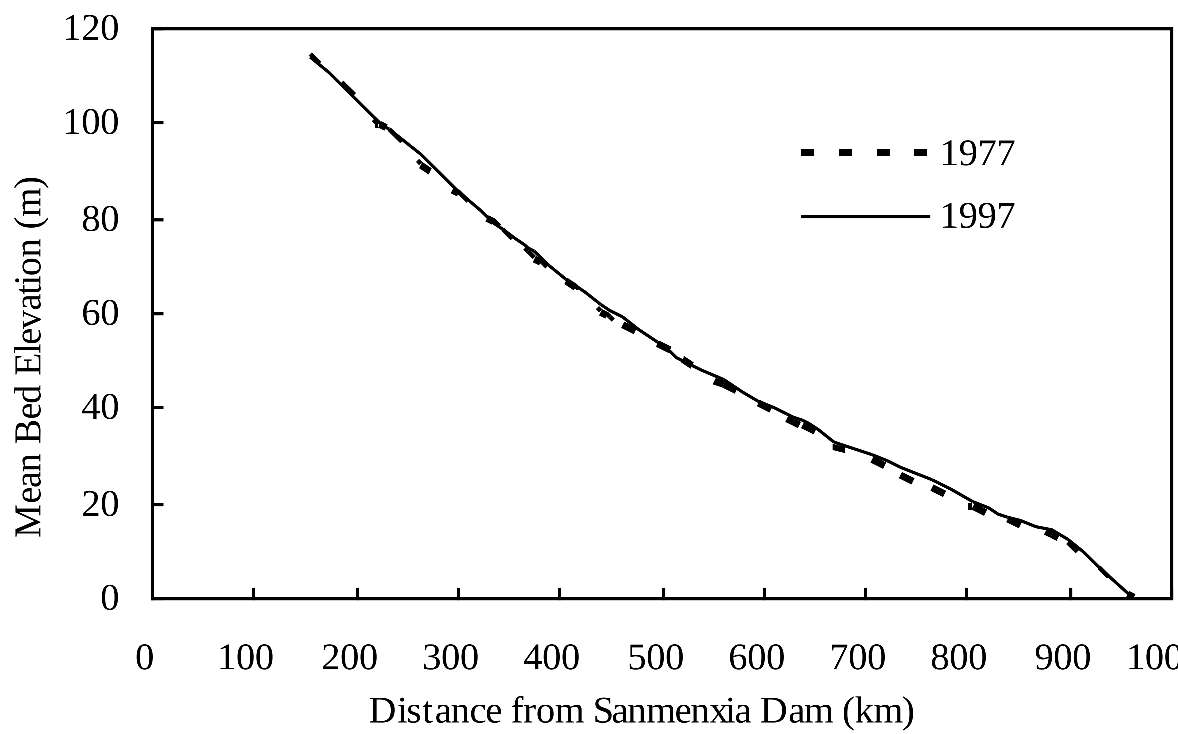
For most rivers, the discharge increases along the course due to the inflow from tributaries; thus the term *sdQ/dx* is positive. According to equation (1), the term *Qds/dx* must be negative, or the slope of the riverbed decreases along the course; so that these rivers exhibit concave riverbed profiles.



Longitudinal bed profile for Big Muddy R

Normal river profile

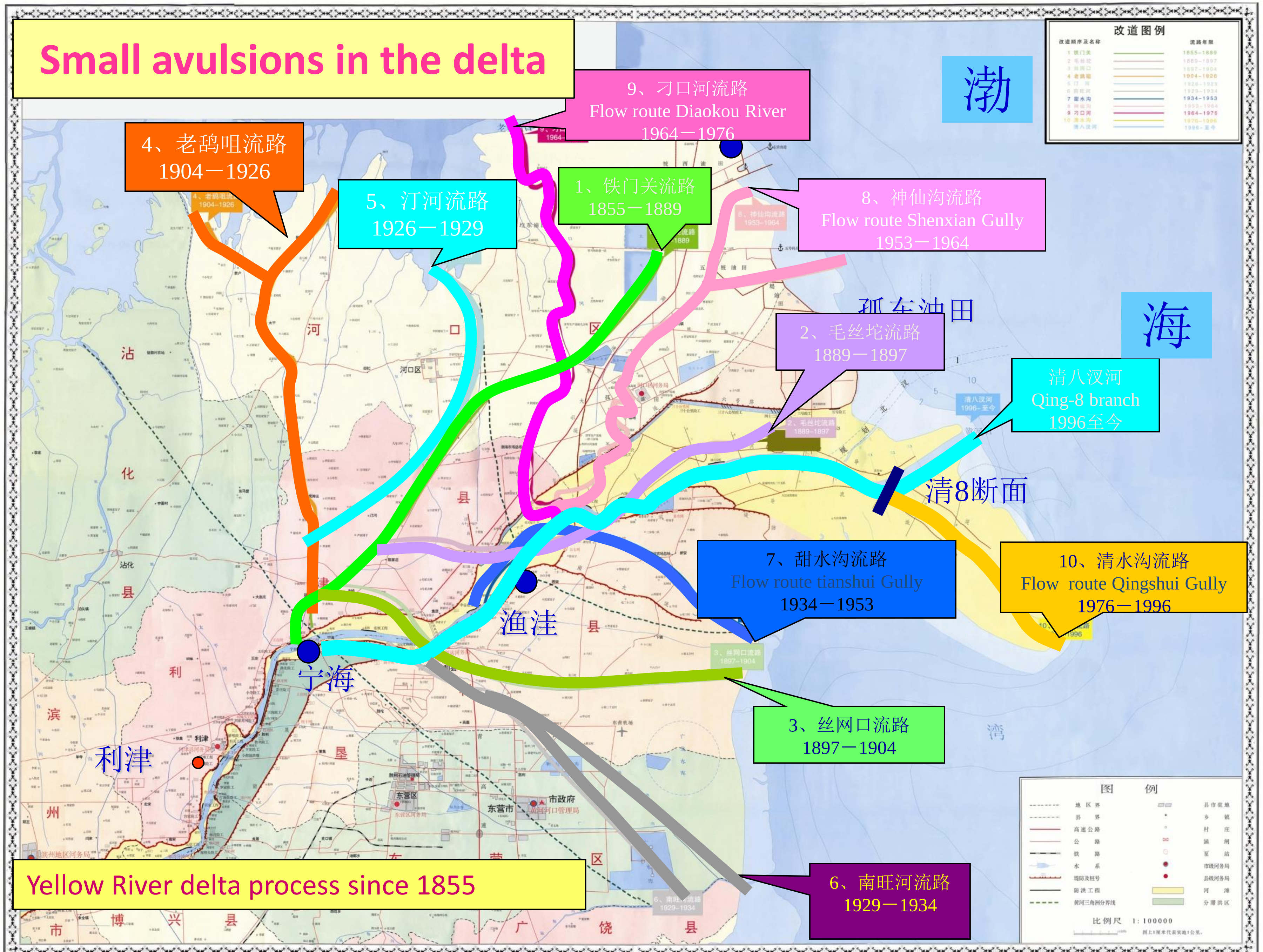
S-shape Longitudinal bed profiles of the lower Yellow River because of water diversion and discharge reduction along the course (ds/dx is positive)



Problem 3 Land loss in the Yellow River delta

1. The Yellow River created land at a rate of 25 km2/year in the past.
2. Sediment reduction has resulted in a great change of the delta from land creation to land loss (5-10 km2/yr).
3. The Shengli oil field is in the Yellow River delta. A part of an oil field under sea water was silted up in the 1990s. Now no enough sediment can be used for the project.

Small avulsions in the delta



Yellow River delta process since 1855

Table 3-2 Shift of the river course and the 11 river channels

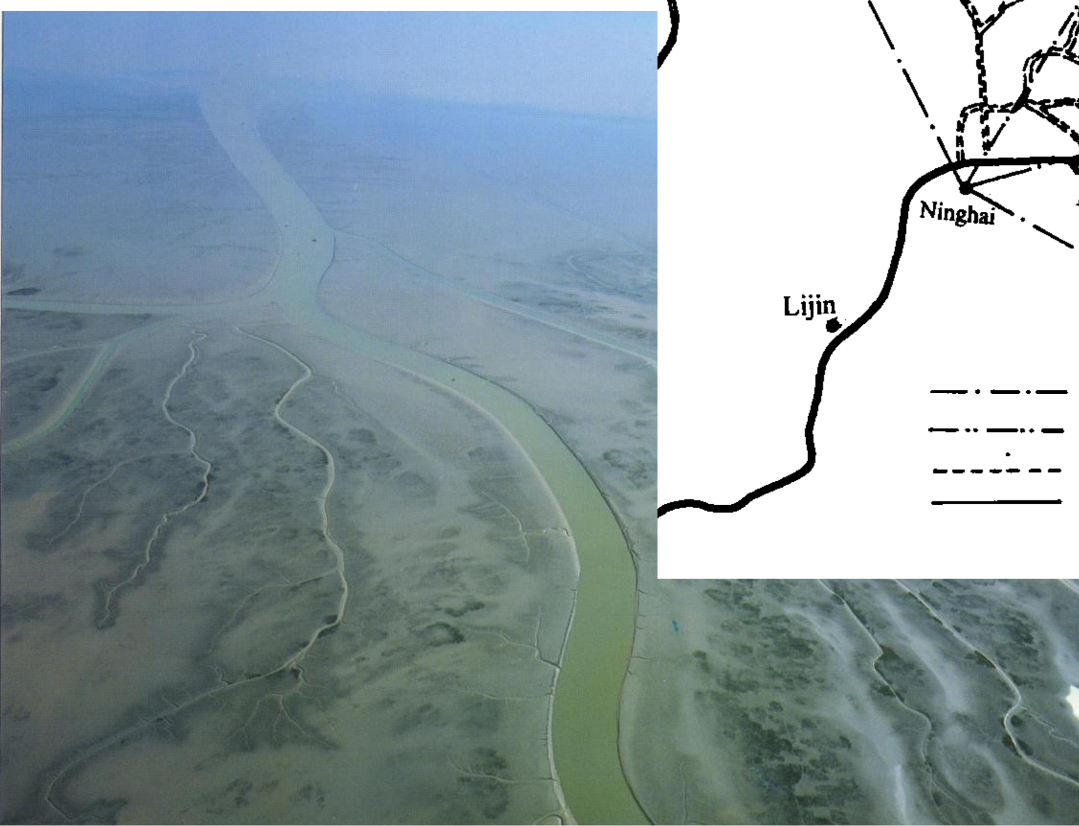
No.	Year (AD)	Used time* (years)	Length** (km)	Diversion point	Name of the channel
0	1855		49	Tong-wa-xiang	
0	1881		71		
0	1889.4	32.5***	75		
1	1889.4		61	Xie-jia-yuan	
1	1897.6	5.10	71		
2	1897.6		59	Ling-zi-zhuang	
2	1904.7	5.9	65		
3	1904.7		57	Yan-wo	
3	1917.8	11	63		
4	1917.8		57	Tai-ping-ling	
4	1926.7	6.11	67		
5	1926.7			Ba-li-zhuang	
5	1929.9	2.11	65		
6	1929.9		73	Ji-jia-zhuang	
6	1934.1	3.4	65	Channel changed many times	
7	1934.1			Yi-Hao-Ba	
7	1950		75		Tian-shui-gou
7	1953.7	9.6	85		Tian-shui-gou
8	1953.7		75		Shen-xian-gou
8	1964.1	10.6	102		Shen-xian-gou
9	1964.1		70	Luo-jia-wu-zi	Diao-kou-he
9	1976.5	12.4	103		Diao-kou-he
10	1976.5		66	Xi-he-kou	Qing-shui-gou
10	1987		106		Qing-shui-gou
10	1996.7	20.2	112		Qing-shui-gou
11	1996.7		94	Cha-he	Qingshuigou-Chahe
11	1997.12	1.5	102		Qingshuigou-Chahe
11	1999.11	3.5	105		Qingshuigou-Chahe

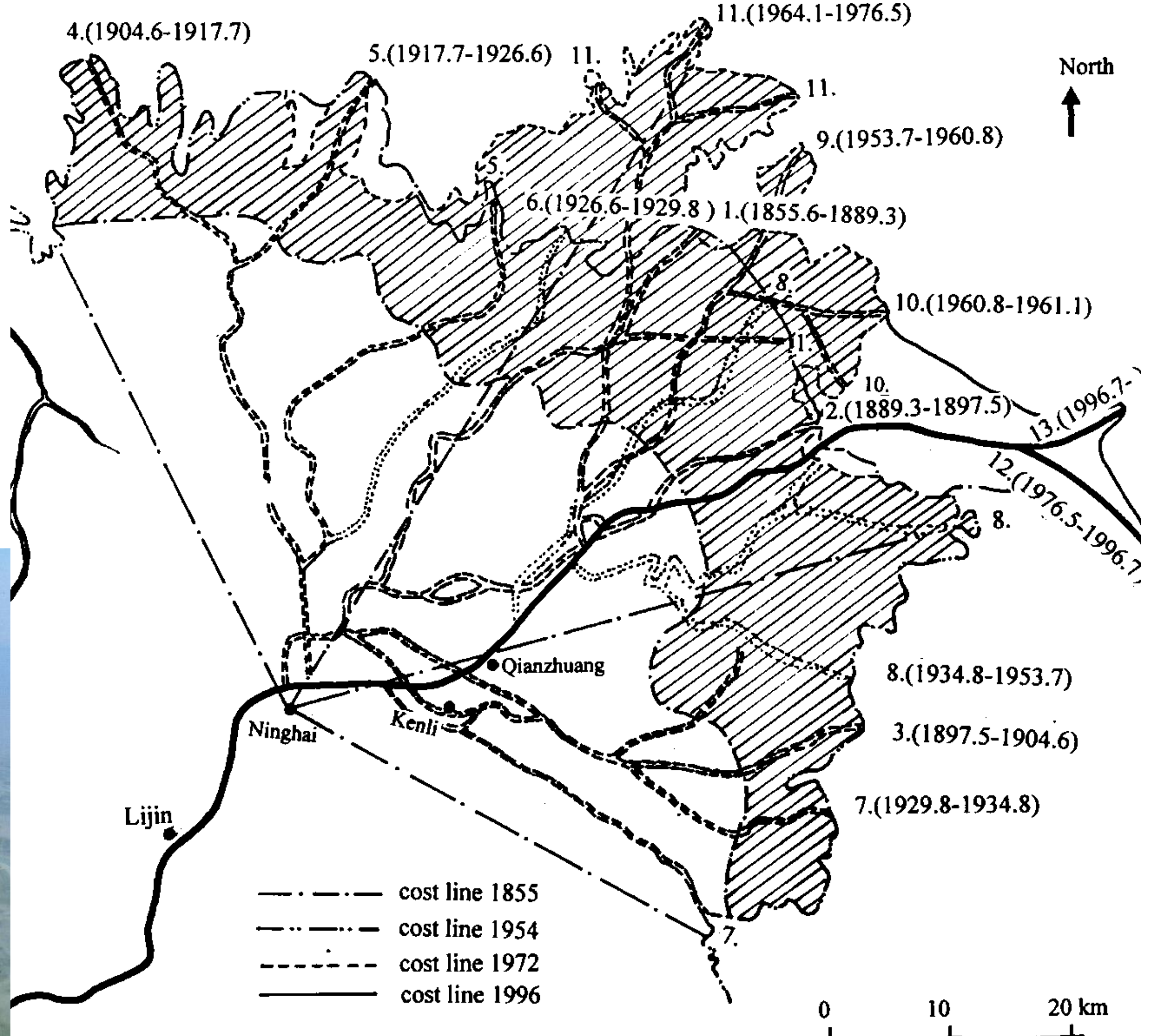
***** Used time = the time period for the river flowed in a channel. Because the river often breaches the levee and water flowed outside of a channel sometimes, the used time of a channel is less than the time period from the river began to flow in the channel to it shifted to another channel.

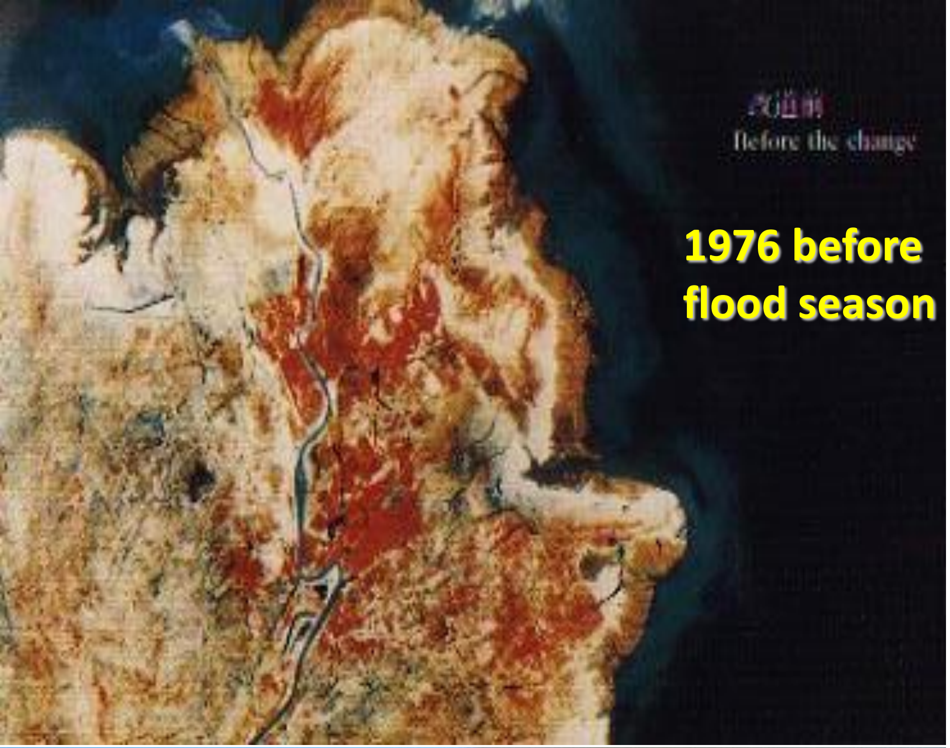
****** Length = distance from the hydrological station Lijin to the mouth of the river

******* 32.5 = 32 years and 5 months.

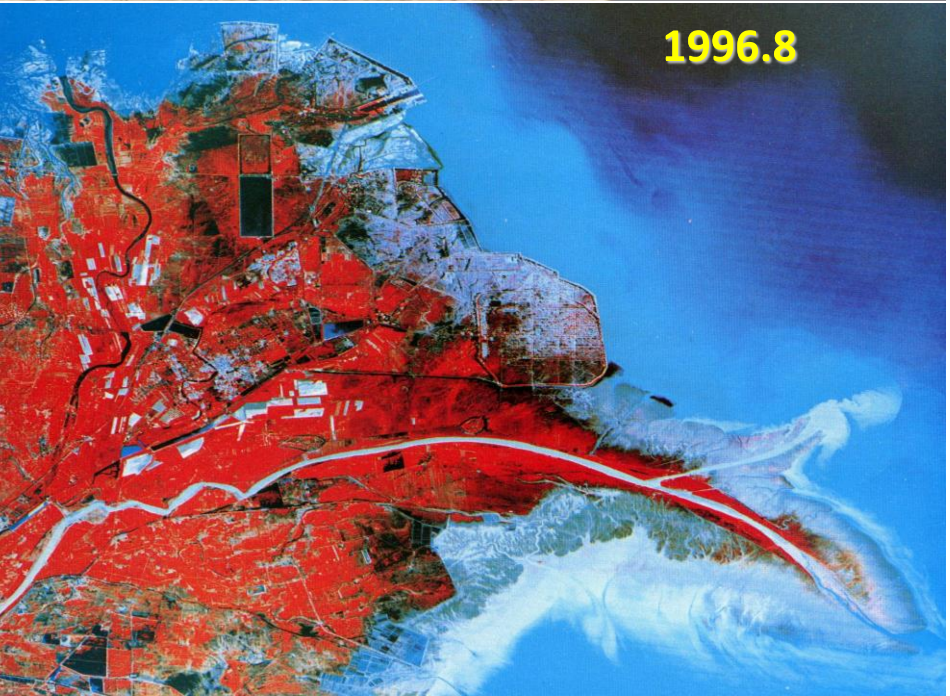
The new and old Yellow River channels in the new delta

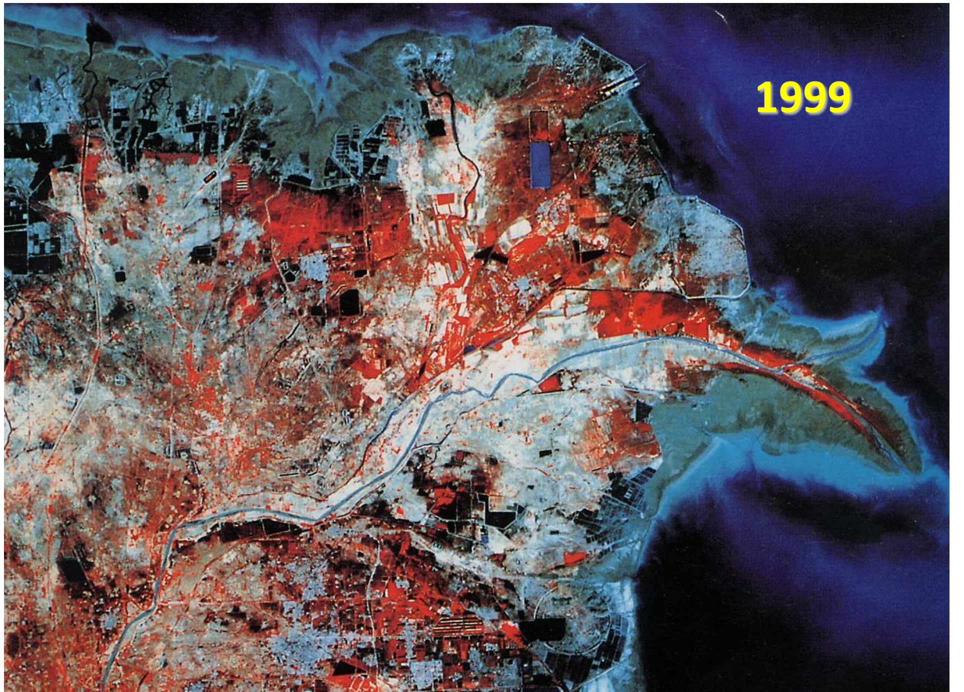


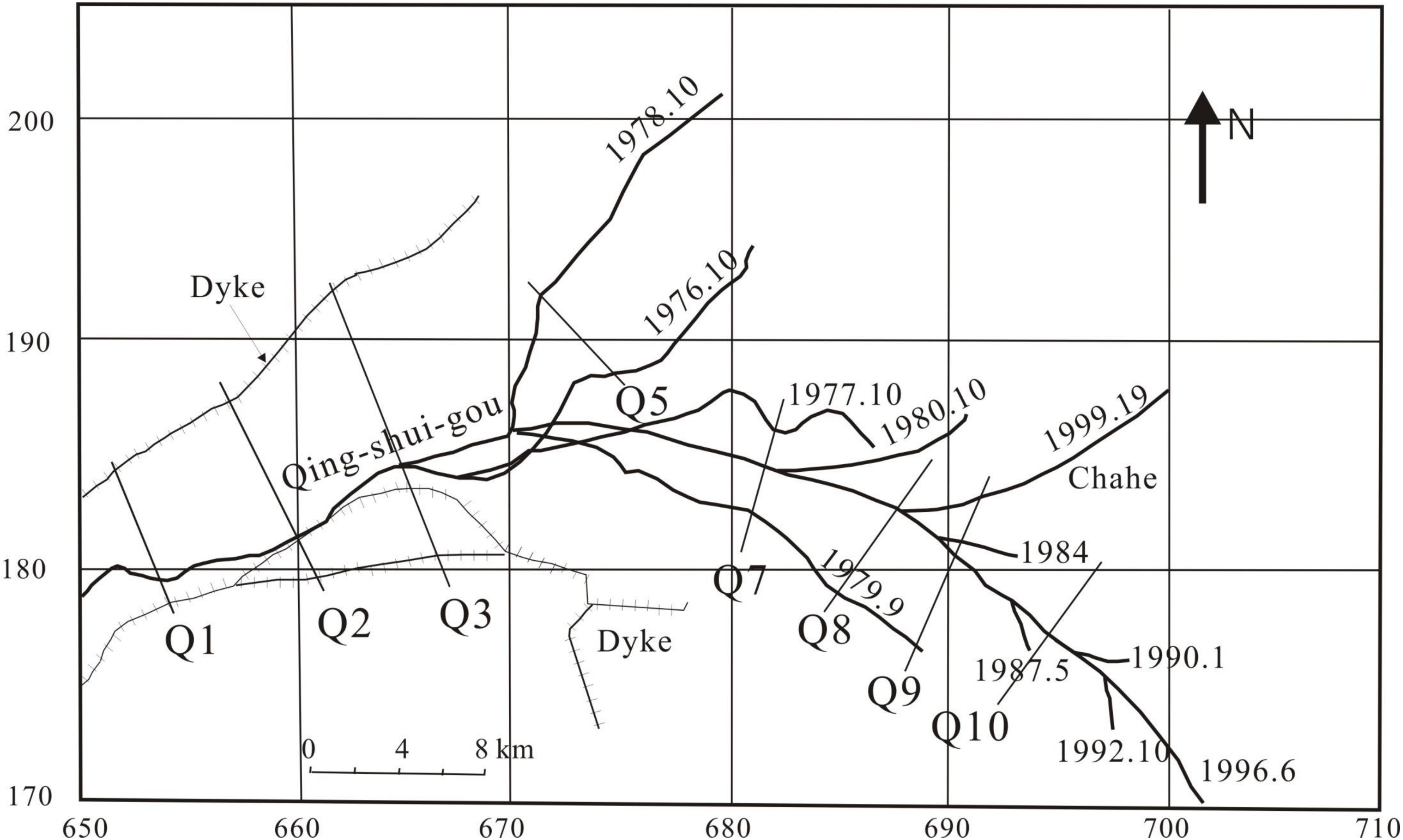



Before the change
1976 before flood season

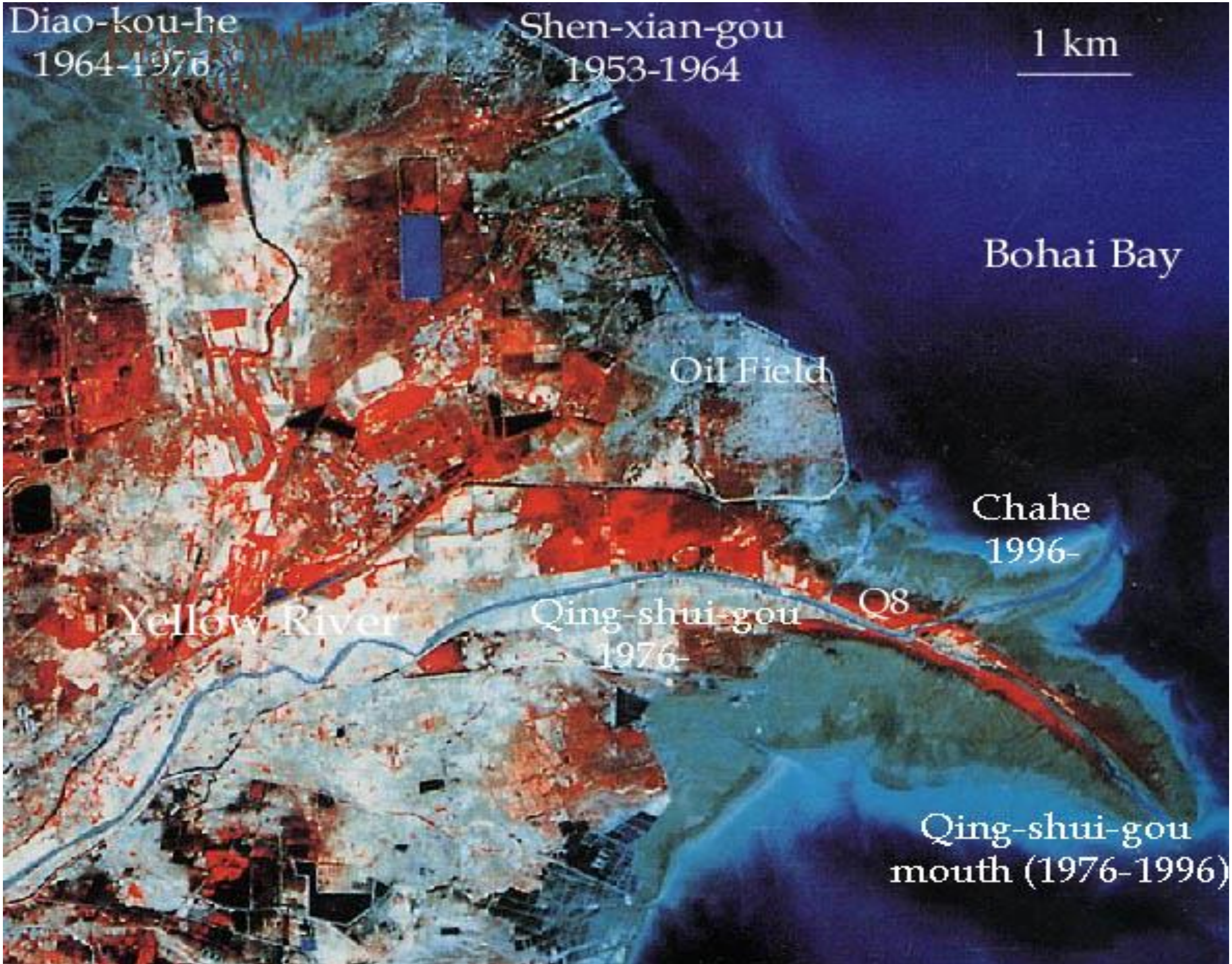

After the change
1976 flood season


1996.8

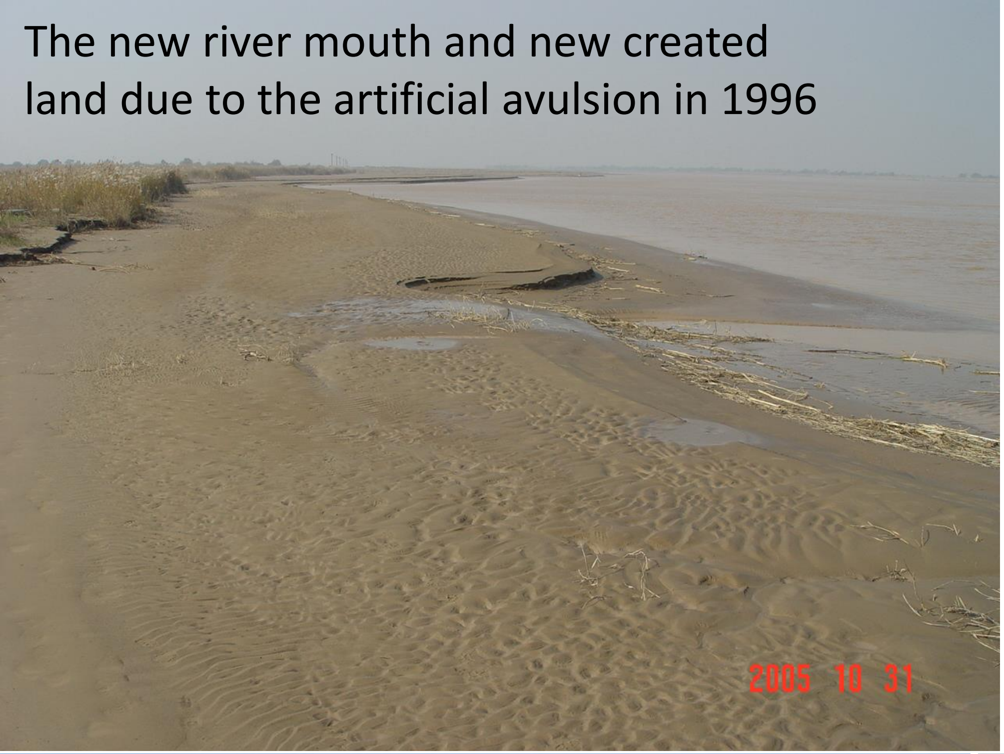

1999



Motion of the Qingshuigou channel after the avulsion in 1976 and the shift at Q8 in 1999



Satellite image (2000) of the modern Yellow River Delta and the Qingshuigou-Chahe Channel

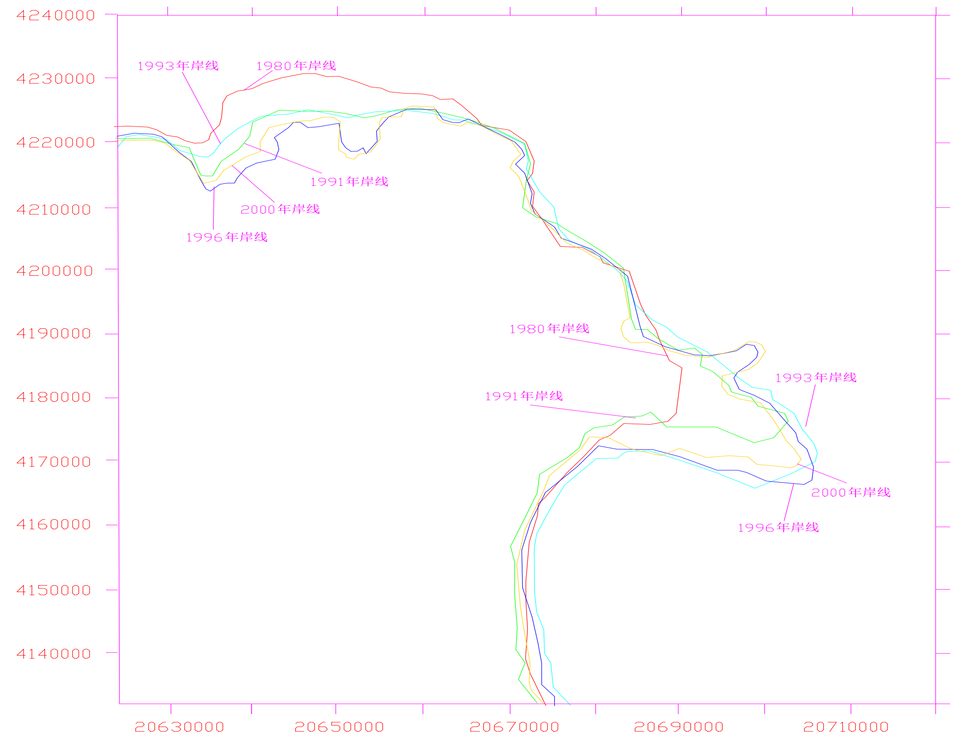

The new river mouth and new created
land due to the artificial avulsion in 1996
2005 10 31

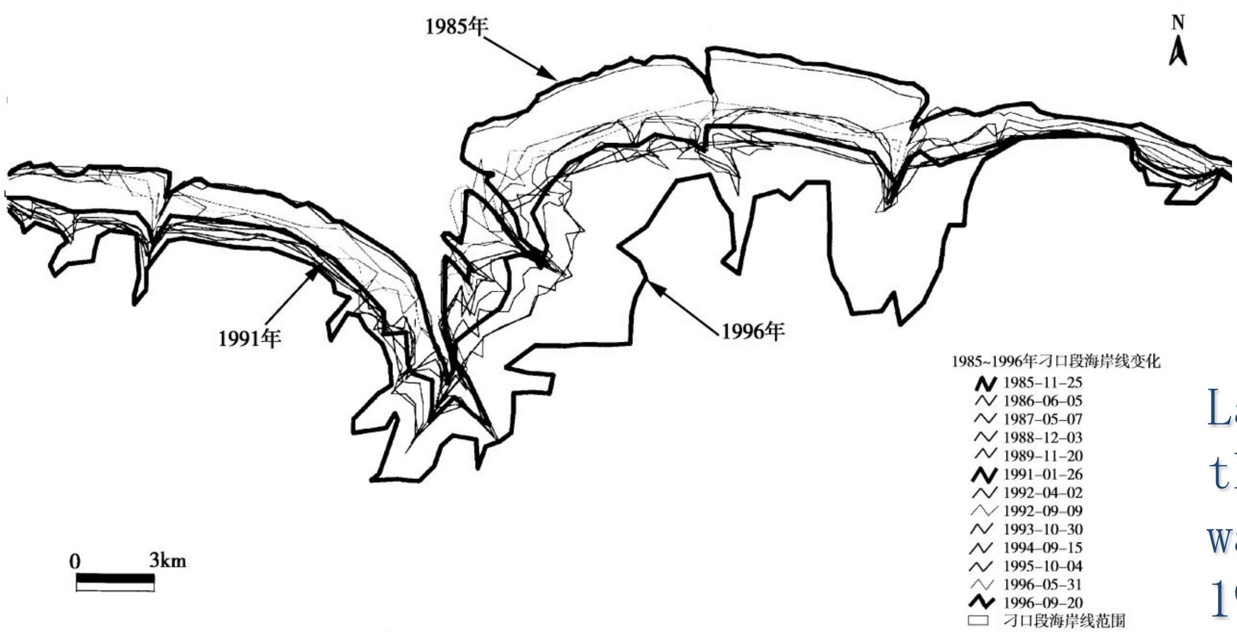

The new Qingshuigou-Chahe mouth in 2001


Wet land national nature reserve
2007/05/10


Oil extraction from the new created land
6. 9. 2001

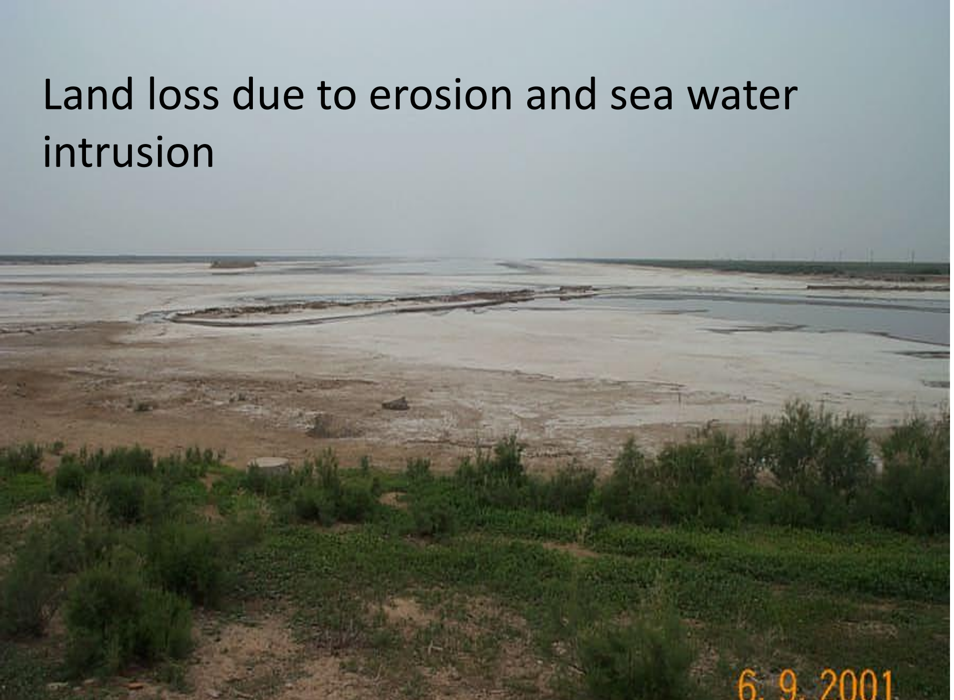
Because less and less sediment is transported to the delta, the Yellow River has stopped land creation since 2000. Wave erosion is resulting more and more severe land loss.

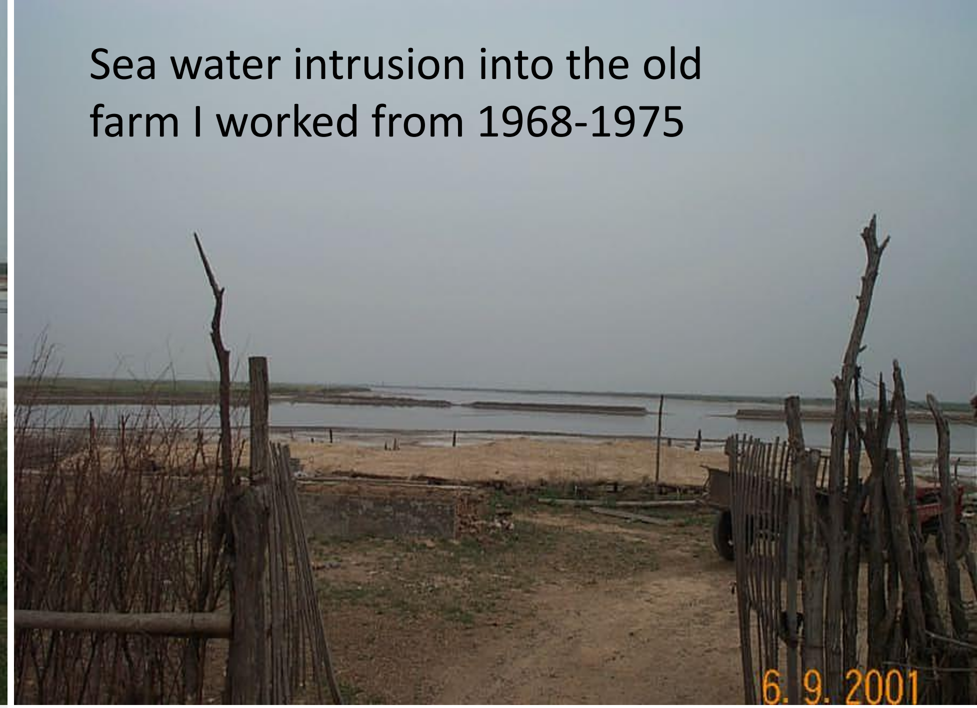




Land creation at the Qingshuigou mouth and land loss at the Diaokouhe mouth

Land loss and retreat of the coast line due to wave erosion from 1985-1996


Land loss due to erosion and sea water intrusion
6. 9. 2001


Sea water intrusion into the old farm I worked from 1968-1975
6. 9. 2001


Breakwater and levees to protect the new created land at the new river delta
2005 10 31


Breakwater to protect the new oil filed
2007/05/10

Strategies

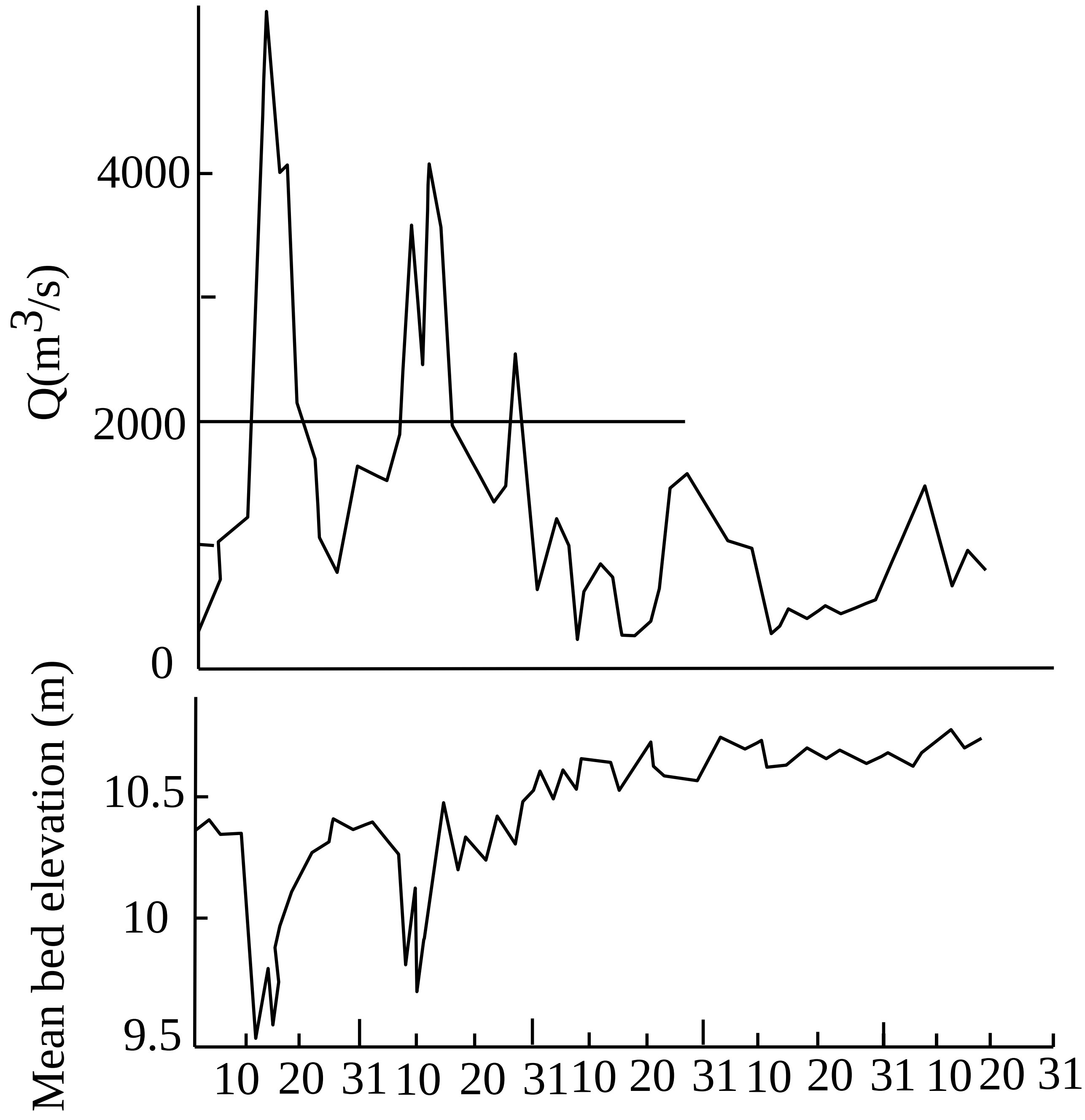
1. Creation of artificial flood to scour the lower Yellow River bed and transport the sediment to the delta for land creation
2. Inter-basin water transfer project - from the Yangtze River basin to the upper Yellow River basin

Strategy 1 Scour the river bed with artificial flood

- The Yellow River sediment consists mainly of silt with median diameter between 0.01-0.03 mm.
- The bed sediment can be scoured at high flood and sediment deposits at low flood discharges. The critical flood discharge is found between 1500-1800 m3/s
- The Xiaolangdi reservoir has been used since 1999 to create artificial floods with discharge higher than 2000 m3/s. Thus the floods scours sediment from the lower Yellow River channel and transports to the delta for land creation.
- It was measured that 9 artificial floods scoured 356 million tons of sediment from the river bed and transported to the delta in 9 years. In average the artificial floods can transport 40 million tons of sediment from the lower Yellow river to the delta per year.

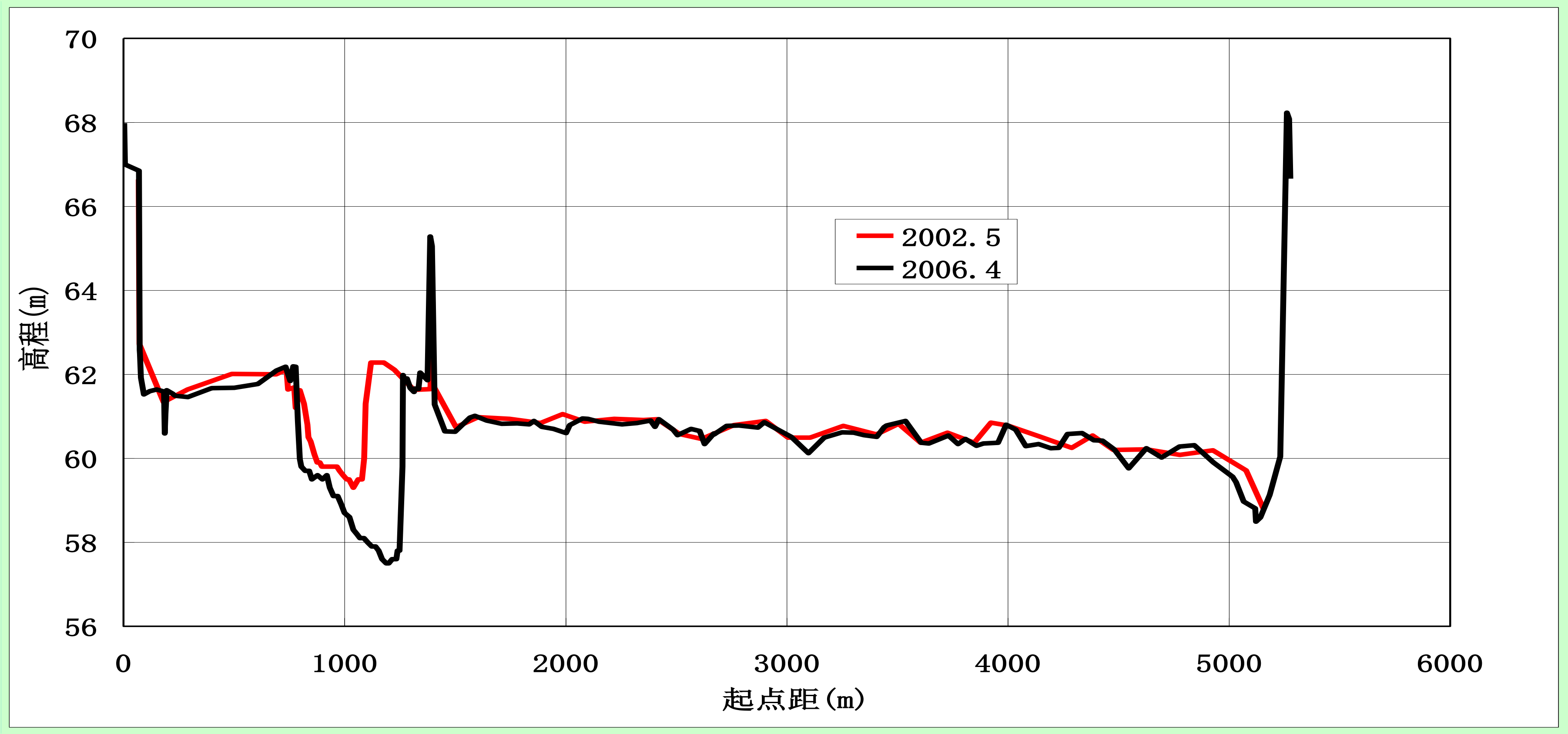
Mirror relation Between the discharge and bed elevation-

The river bed was scoured during flood and resilted in the falling limb of the flood



Artificial flood was created by releasing water from the Xiaolangdi Reservoir. A part of reservoir sediment was released with water. The flood scoured sediment from the lower Yellow River bed

The artificial flood had high velocity (about 2 m/s) and scoured the bed sediment and banks. The concentration increased from about 10 kg/m3 to 30 kg/m3. The sediment was transported to the delta.



Scouring with artificial floods occurred mainly in the channel and thus resulted in deep channel. The flood stage has reduced more than 1.5 m after 10 years scouring. The bankfull discharge in the lower Yellow River increased from 2000m³/s in 2002 to 4000m³/s in 2010

Strategy 2 South-North Inter-basin Water Transfer Project

- **China is planning to transfer 17 billion m^3 water from the upper Yangtze River basin to the Yellow River to ease the water shortage in the lower Yellow River basin.**
- **The Dadu and Yalong Rivers are the main source for the project because they are the closest rivers from the upper Yellow River.** The diverted water is 60-70% of the total annual runoff at the dam sites.

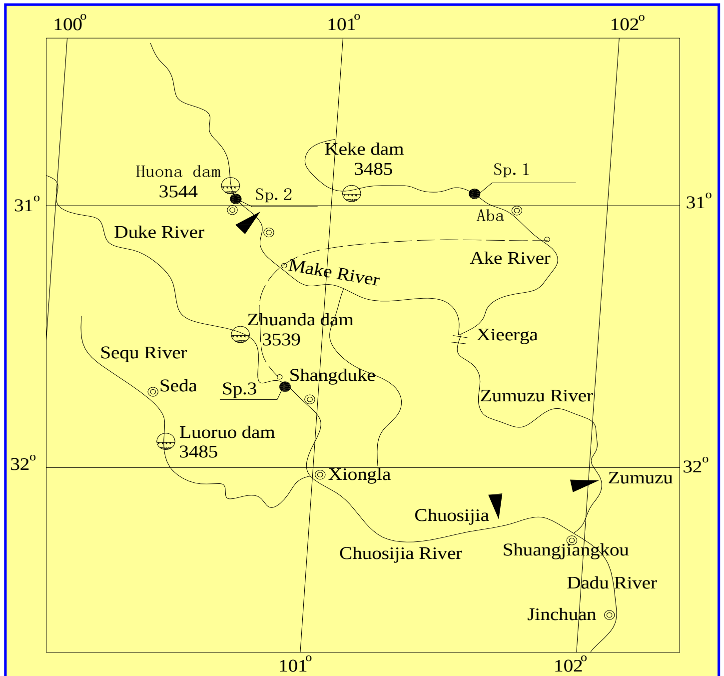
Inter-basin water transfer projects

- The Dadu River, Yalong River and Jinsha River are very close to the upper Yellow River, which will transfer 1.7 billion tons of water to the upper Yellow River

Inter-basin water transfer projects

- Water transfer from the Jinsha River, Yalong River and Dadu River to the Yellow River

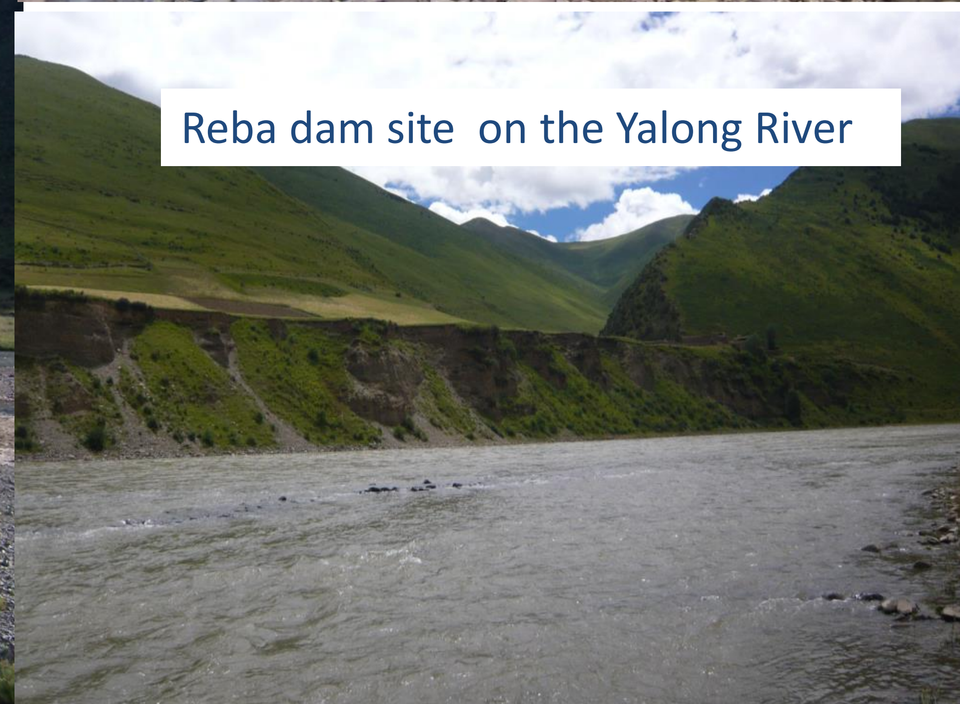
Dam sites on the tributaries of the Yangtze R. for inter-basin water transfer to the Yellow River.



Zhuanda Dam site on the Duke R.

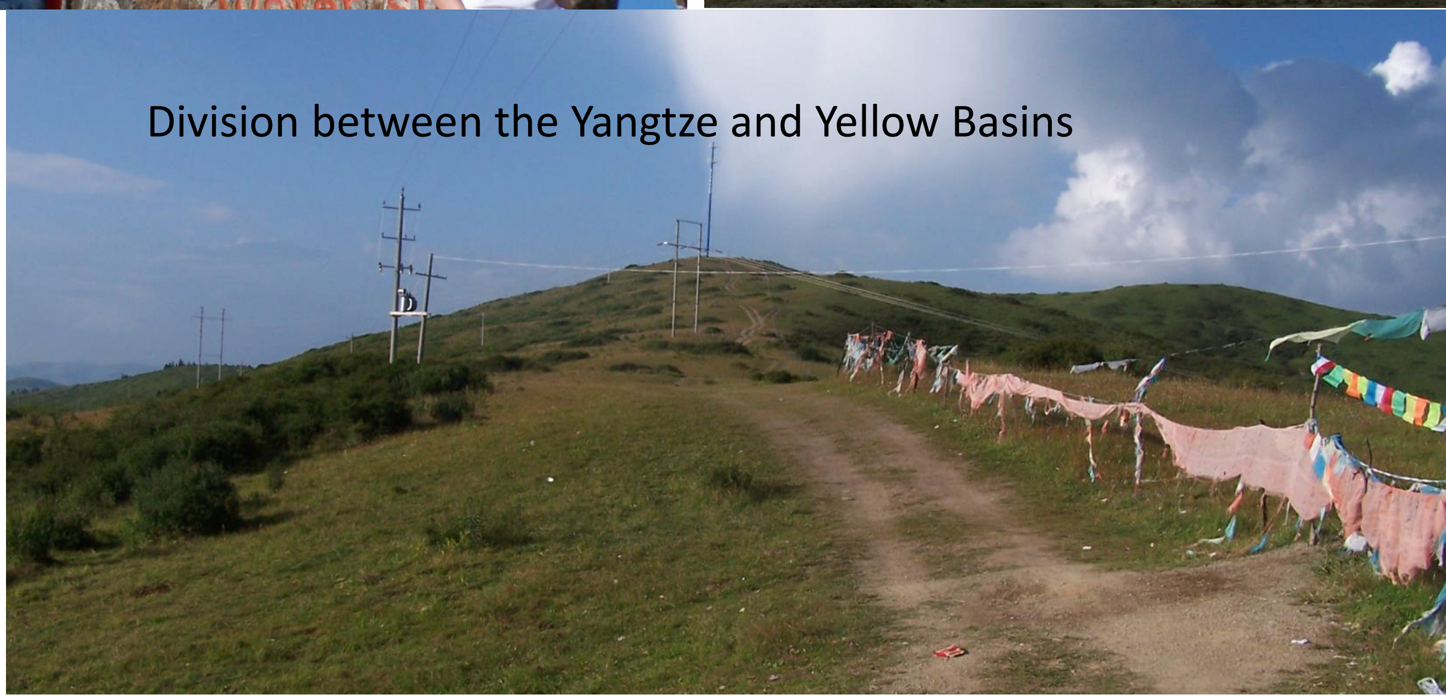
Keke dam site on the Ake R.

Reba dam site on the Yalong River




Yellow River
Changjiang River
2007/08/


Baihe river


Division between the Yangtze and Yellow Basins

4. Lessons from the Sanmenxia Reservoir

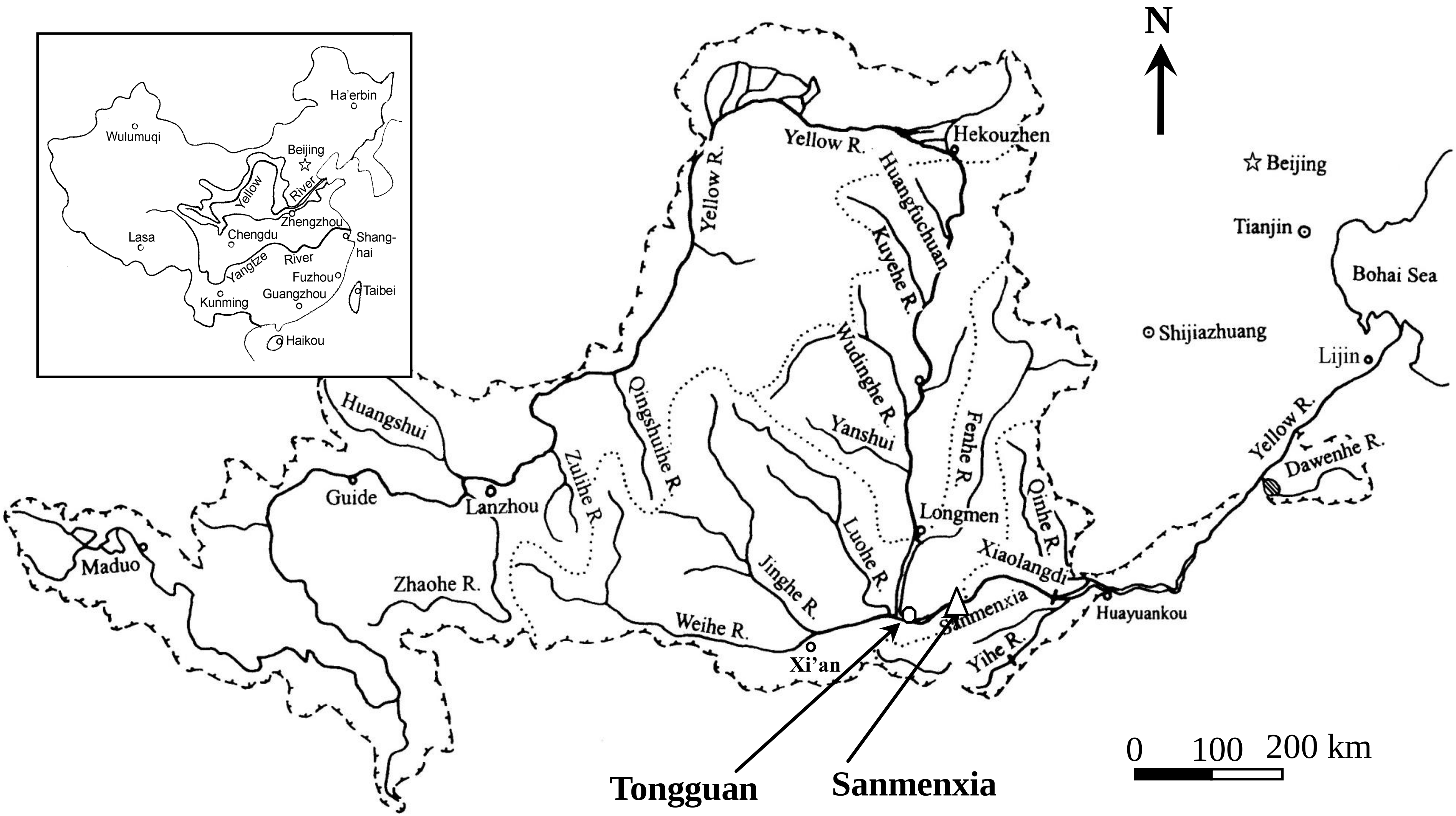
Sanmenxia reservoir

Sanmenxia reservoir is the first large reservoir on the Yellow river. The designed reservoir capacity was 35.4 billion m^3 with a normal pool level of 350 m and installation capacity of 1160Mw.

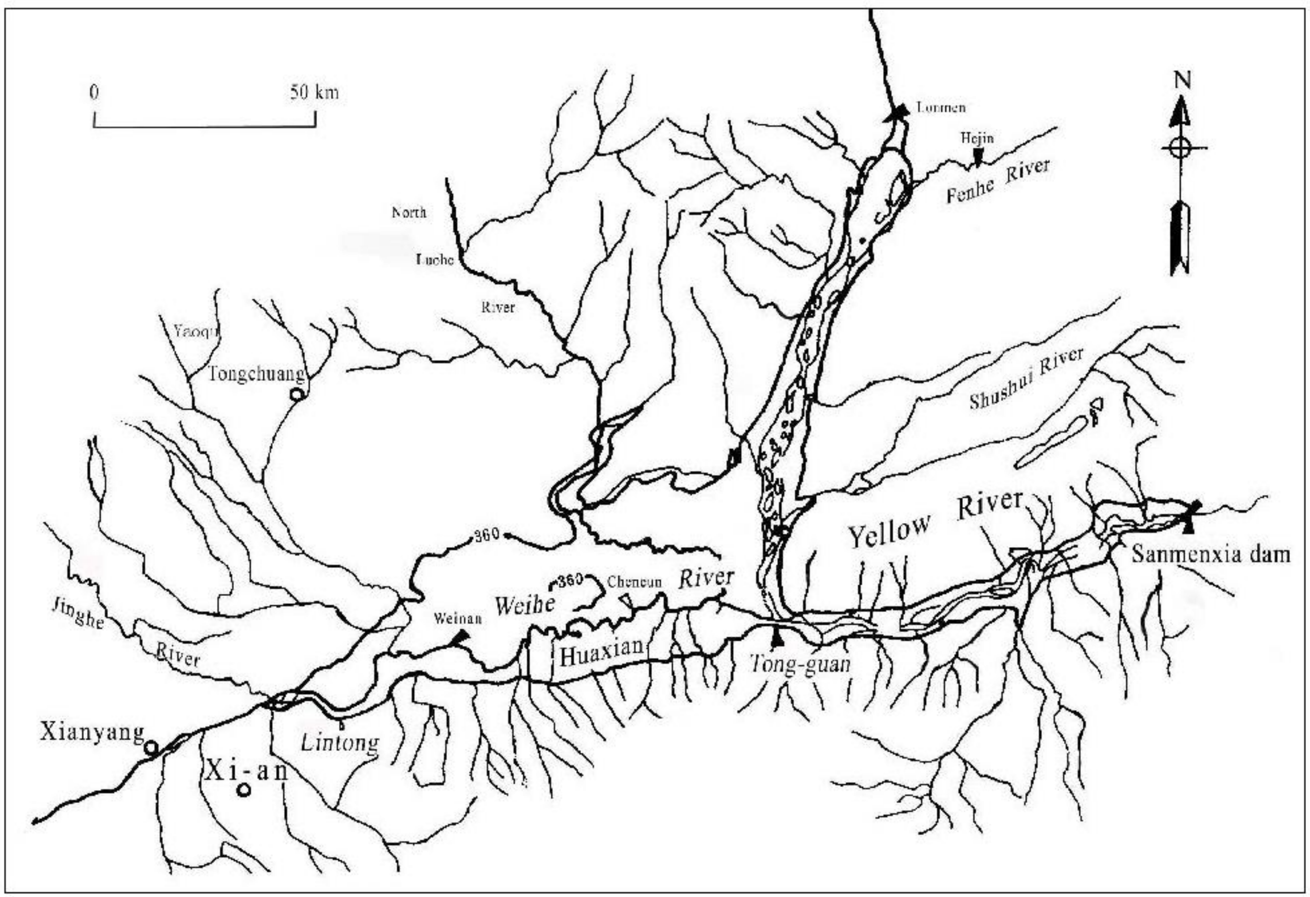
The reservoir consists of three parts: YR from the dam to Tongguan; Lower Weihe from Tongguan to Xianyang; YR from Tongguan to Longmen.

The reservoir stored water and sediment from 1960.9-1962.3. During the first 18 months, 93 percent of the incoming sediment (2 bi m3) was trapped in the reservoir. The reservoir lost 17% of its capacity due to sedimentation. Backwater sediment deposition extended over 180 km upstream of the dam.

The operation mode had to be changed. The pool level reduced to around 320 m and the installation capacity was reduced to 25 Mw (late increased to 40 Mw).



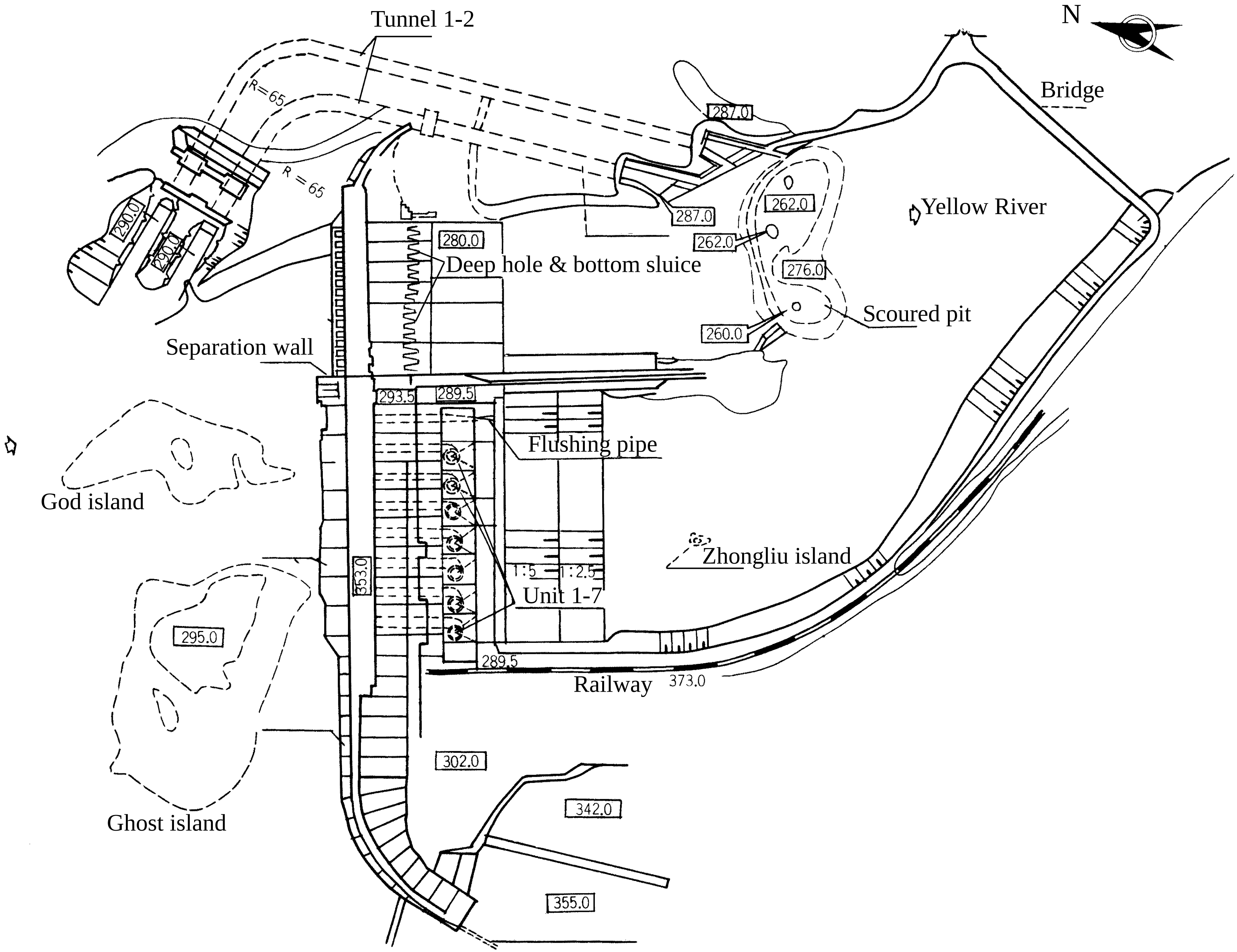
The Yellow River and its tributaries (the Weihe River is the largest one), and the locations of Sanmenxia Dam, Tongguan, and the city of Xi'an



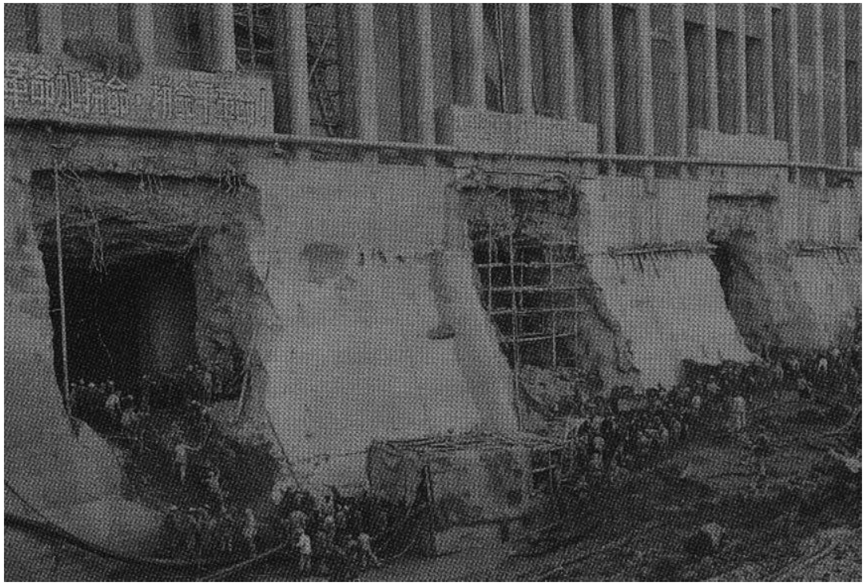
Three parts of Sanmenxia Reservoir

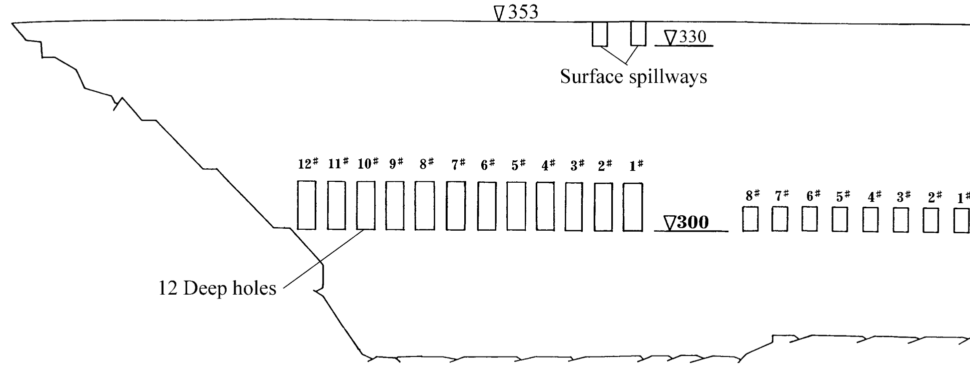
Sanmenxia reservoir

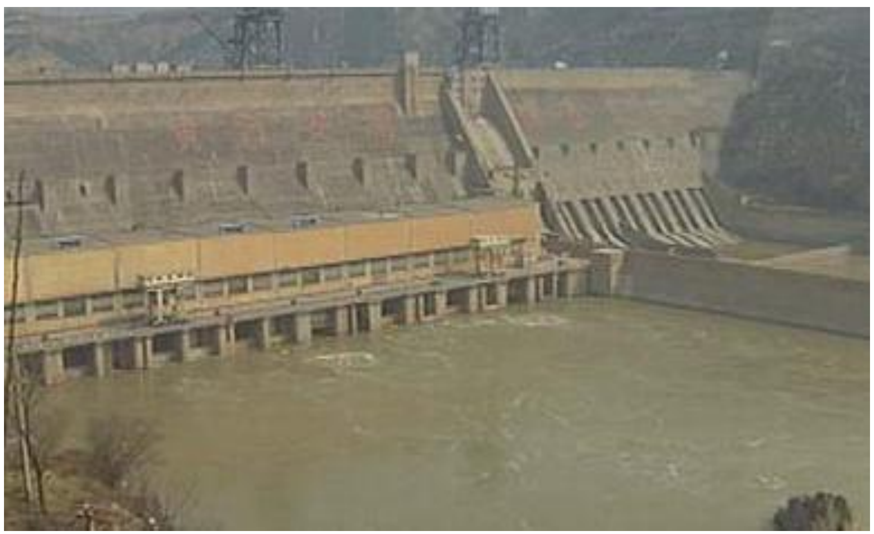
- The “Tongguan Elevation” is defined as the stage corresponding to a discharge of 1,000 m^3/s at Tongguan station, which is essentially the sill of Weihe’s confluence.
- Tongguan Elevation rose 4.5 m and reached 327.2 m in March 1962 because of reservoir sedimentation. This threatened the industrial and agricultural bases of the lower Weihe River, and more importantly the capital city of Shanxi Province Xi’an.
- Due to the unacceptable negative impact of rapid sedimentation in the lower Weihe River the Sanmenxia dam had to be reconstructed to provide high sediment releasing-capacity.

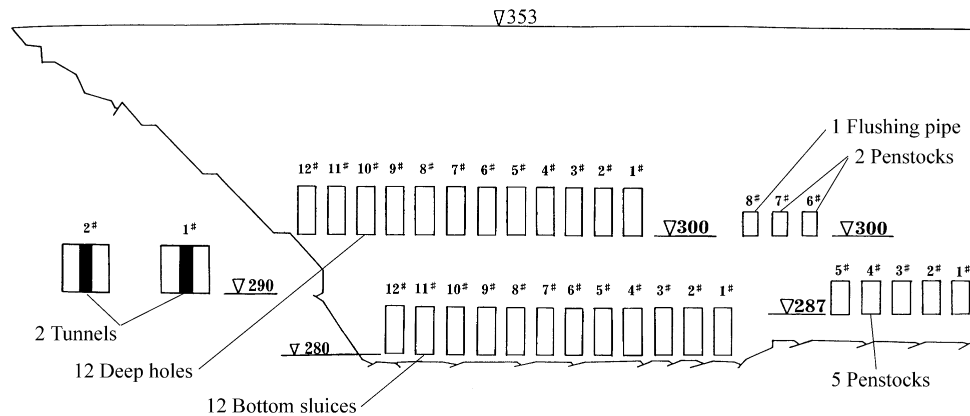


Tunnel 1-2
N
Bridge
R=65
R=65
287.0
290.0
290.0
262.0
Yellow River
287.0
262.0
280.0
Deep hole & bottom sluice
276.0
Scoured pit
260.0
Separation wall
293.5
289.5
Flushing pipe
God island
Zhongliu island
353.0
1:5
1:2.5
Unit 1-7
295.0
289.5
Railway
373.0
302.0
342.0
Ghost island
355.0



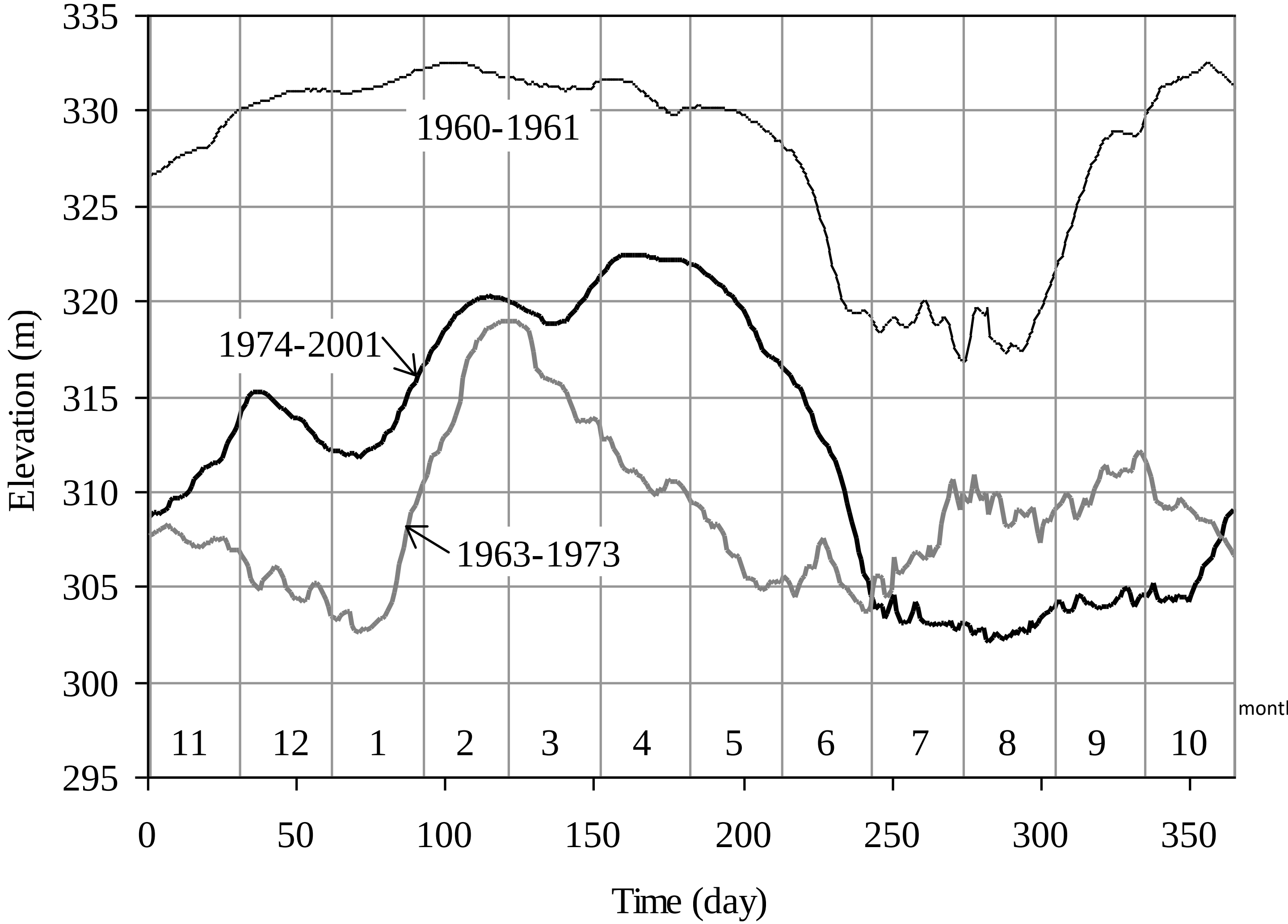






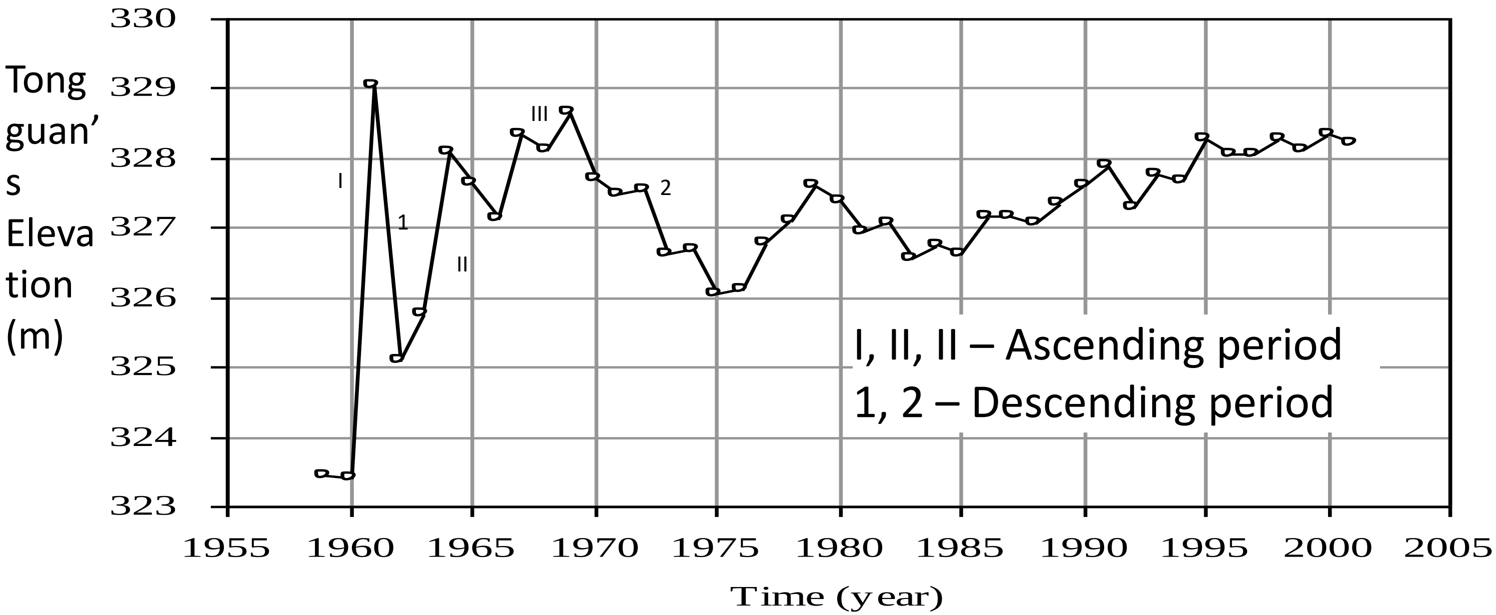
The outlet for water flow during construction was reopened (upper left); Sediment bottom outlets were added (b) Front view of original design; (c) Front view after reconstruction

Pool levels of the Sanmenxia Reservoir

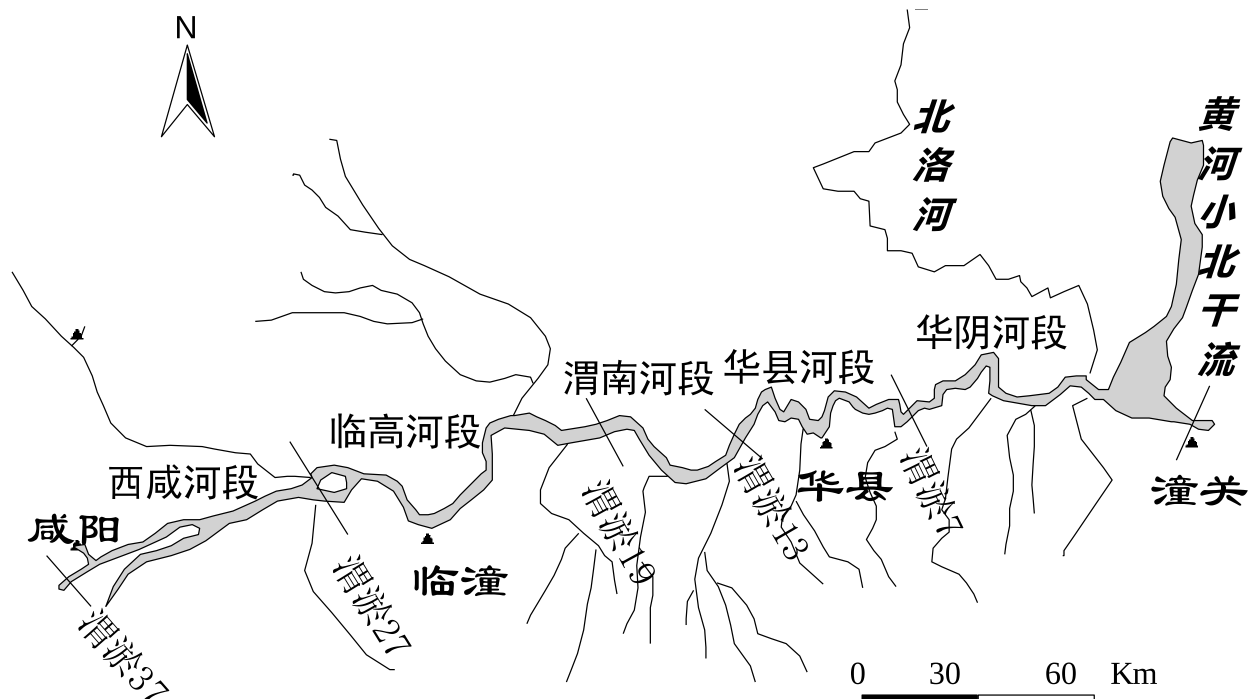


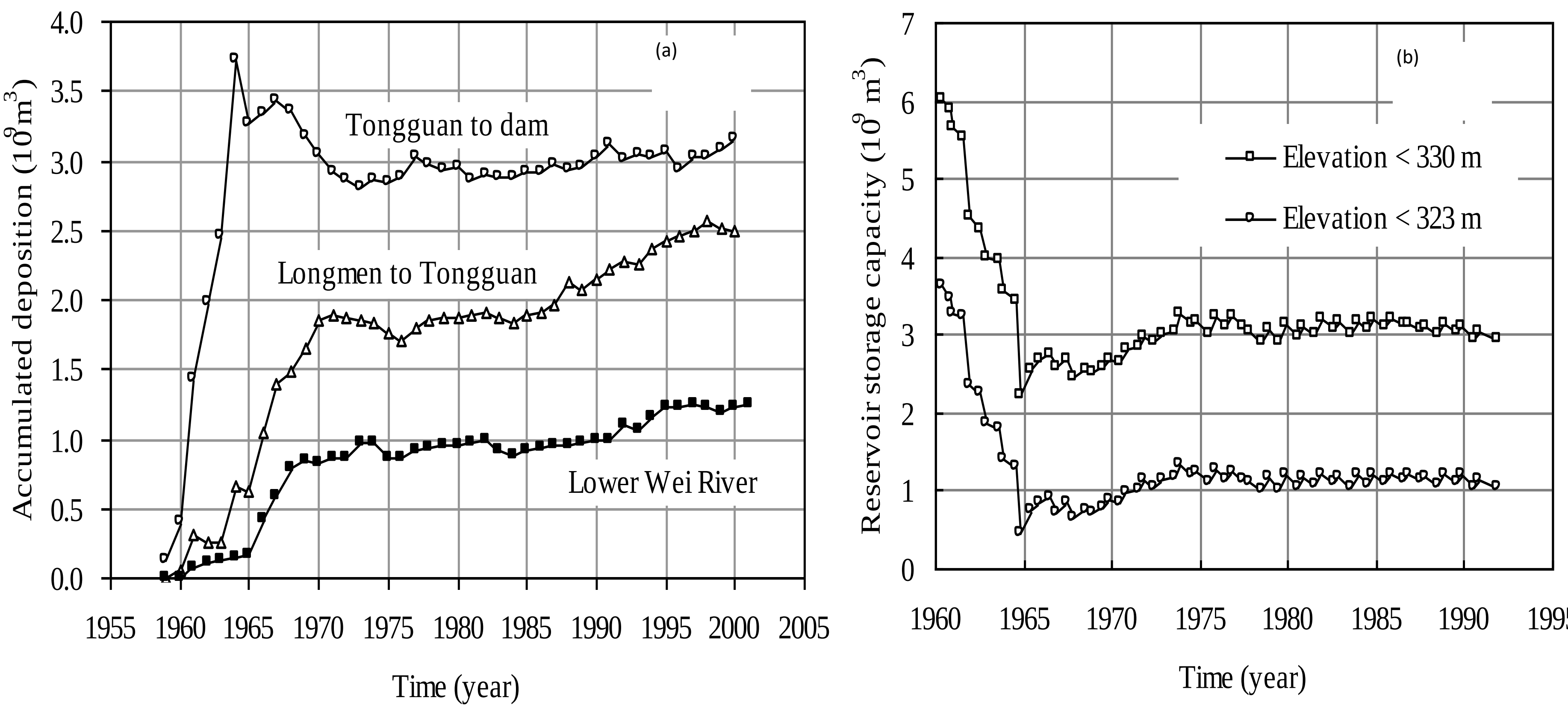
The operation of the reservoir experienced three period: 1960-1962 store water and trap sediment; 1963-1973 flood detention and sediment flushing; 1974-2010 store the clear and release the turbid

The lower Weihe River is in the backwater region of Sanmenxia Reservoir. The so called Tong-guan elevation is defined as the stage of flood discharge 1000 m^3/s at Tong-guan station.



Rising of Tongguan's elevation caused sedimentation in the lower Weihe River



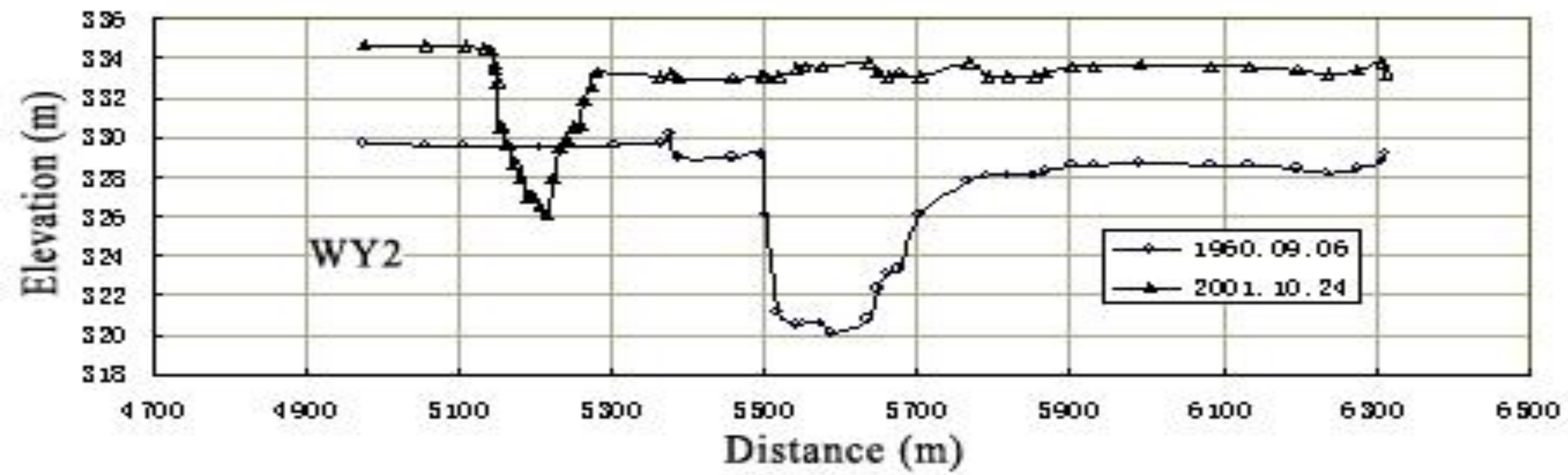


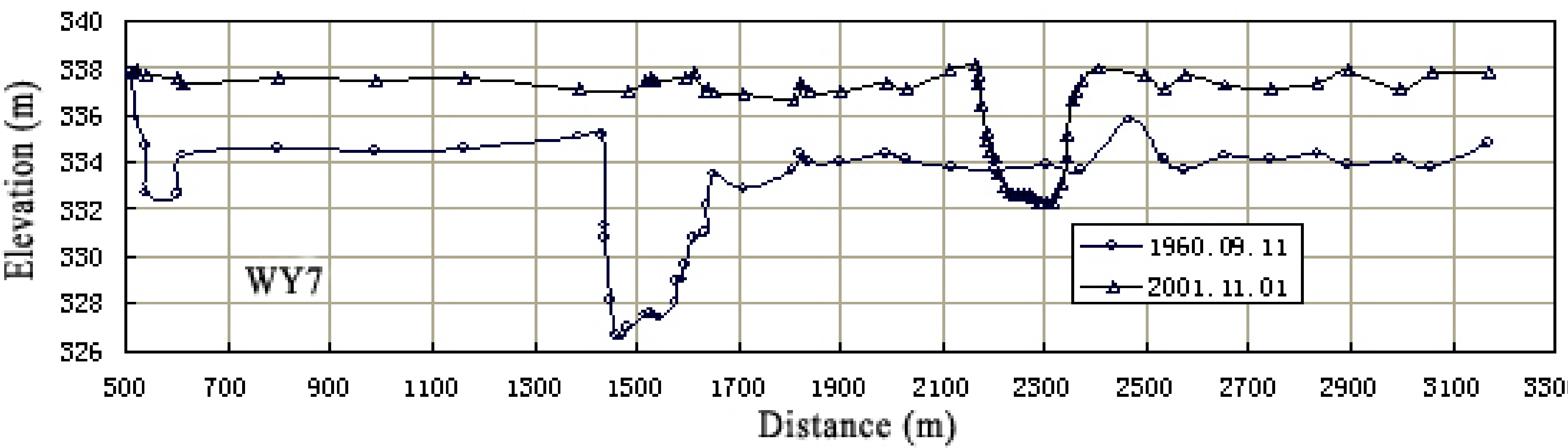
Variations of accumulated deposition and reservoir capacity in Sanmenxia Reservoir: (a) accumulated deposition; (b) reservoir storage capacity.

Sedimentation in the lower Weihe River

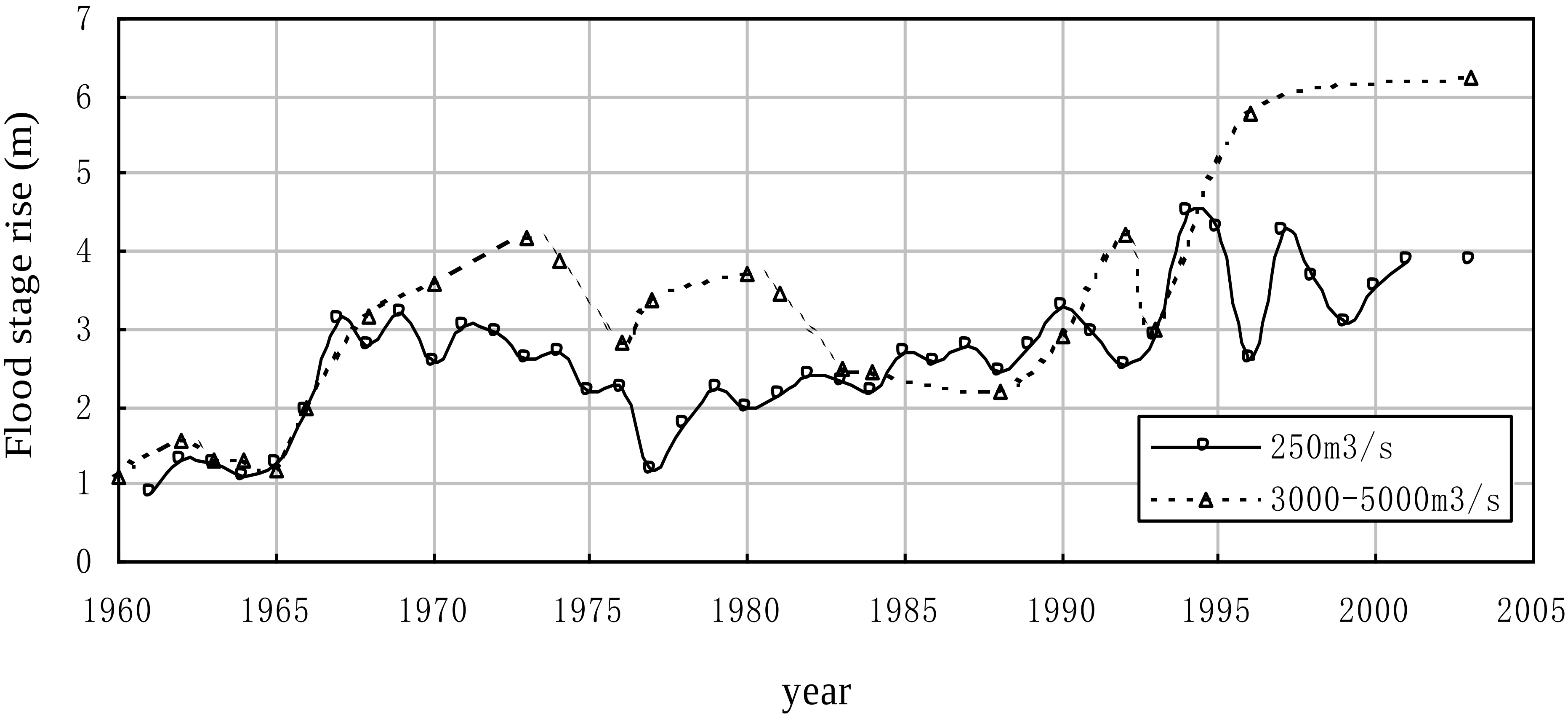
- The main problem of Sanmenxia is sedimentation in the lower Weihe River, which was known as 800li Qin Valley for its fertile land and high population.
- The raised Tongguan Elevation reduced the sediment carrying capacity of the flow from Weihe to the Yellow River and therefore resulted in quick sedimentation in the lower Weihe River.

Sedimentation in the lower Weihe River: WY2 .. are measurement cross sections on the Weihe River



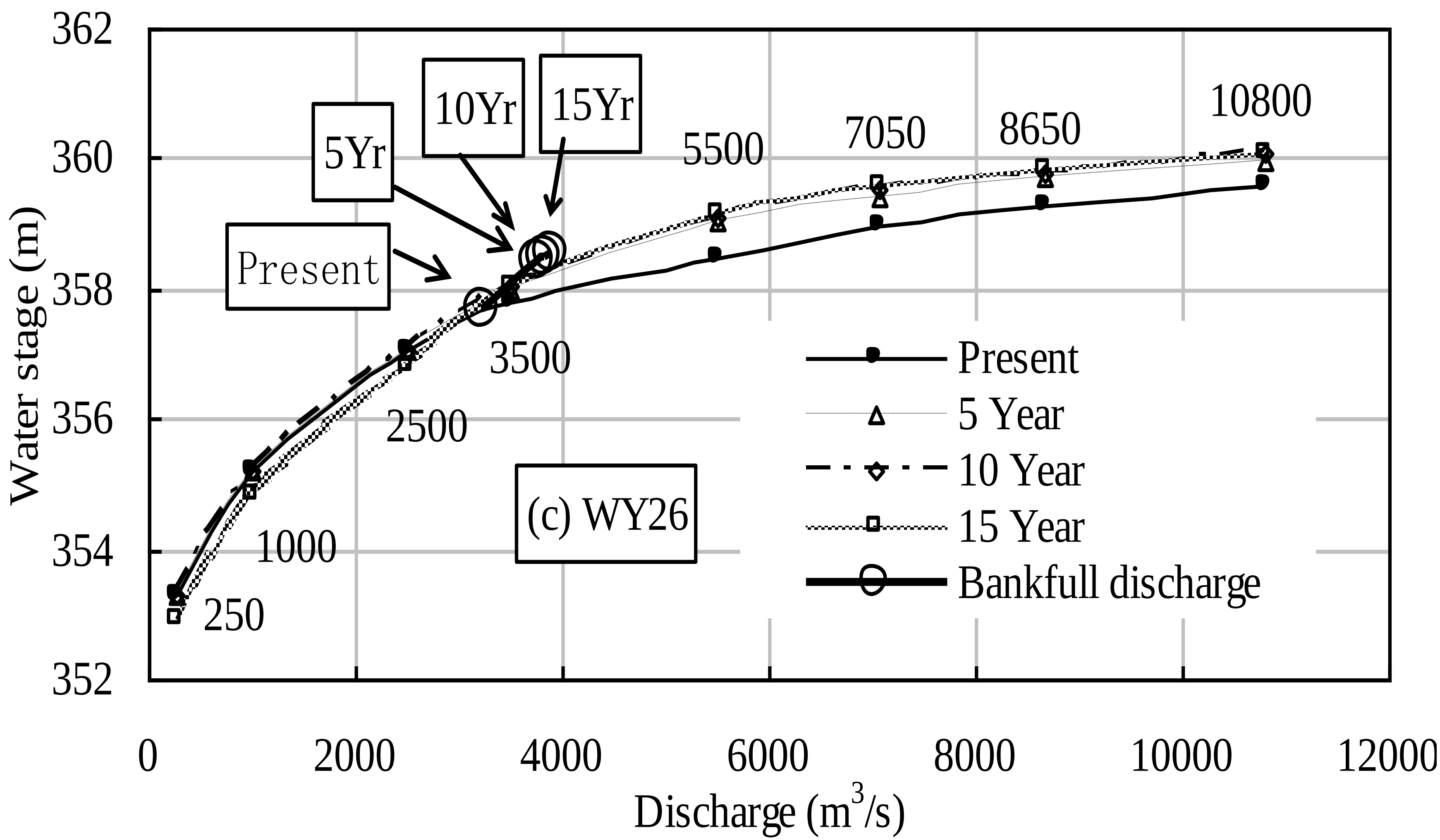


The bridge on a tributary of the Weihe River had to be raised because of sedimentation.
The lower Weihe River has been silted up and polluted by sewage water from towns by the river.



Flood stage rise (present flood stage minus the stage at the same discharge before the reservoir) due to sedimentation in the lower weihe river

- A flood in the Weihe River caused a lot of economic loss and thence rekindled the debate of decommission of the Sanmenxia Dam
- Because the problems of siltation and induced flooding risk to the lower Weihe river has not been solved, decommission of Sanmenxia dam is under discussion as an alternative strategy to eventually solve the problem.
- Assume the Tongguan's elevation will be reduced by 2 m, can the sedimentation and flooding in the lower weihe river be solved or mitigated?



Numerical simulation indicated that 15 years late after the reduction in Tongguan elevation the flood stage may reduce for small floods but not reduce for large floods

What are the mistakes of Sanmensia

- Dam construction is in accordance with the deposit sediment strategy for the Yellow River managameng.
- The mistakes of Sanmenxia are: 1) the site of the first dam on the YR should be Xiaolangdi or Balihutong rather than Sanme nxia. In Fact the Xiaolandi dam is operated in the same operation as that planned for Sanmenxia, which achieved great benefit and have no bad influence on Weihe River ; 2) the sediment load was greatly underestimated; 3) the emigrants were not well resettled.

Resettlement of emigrants

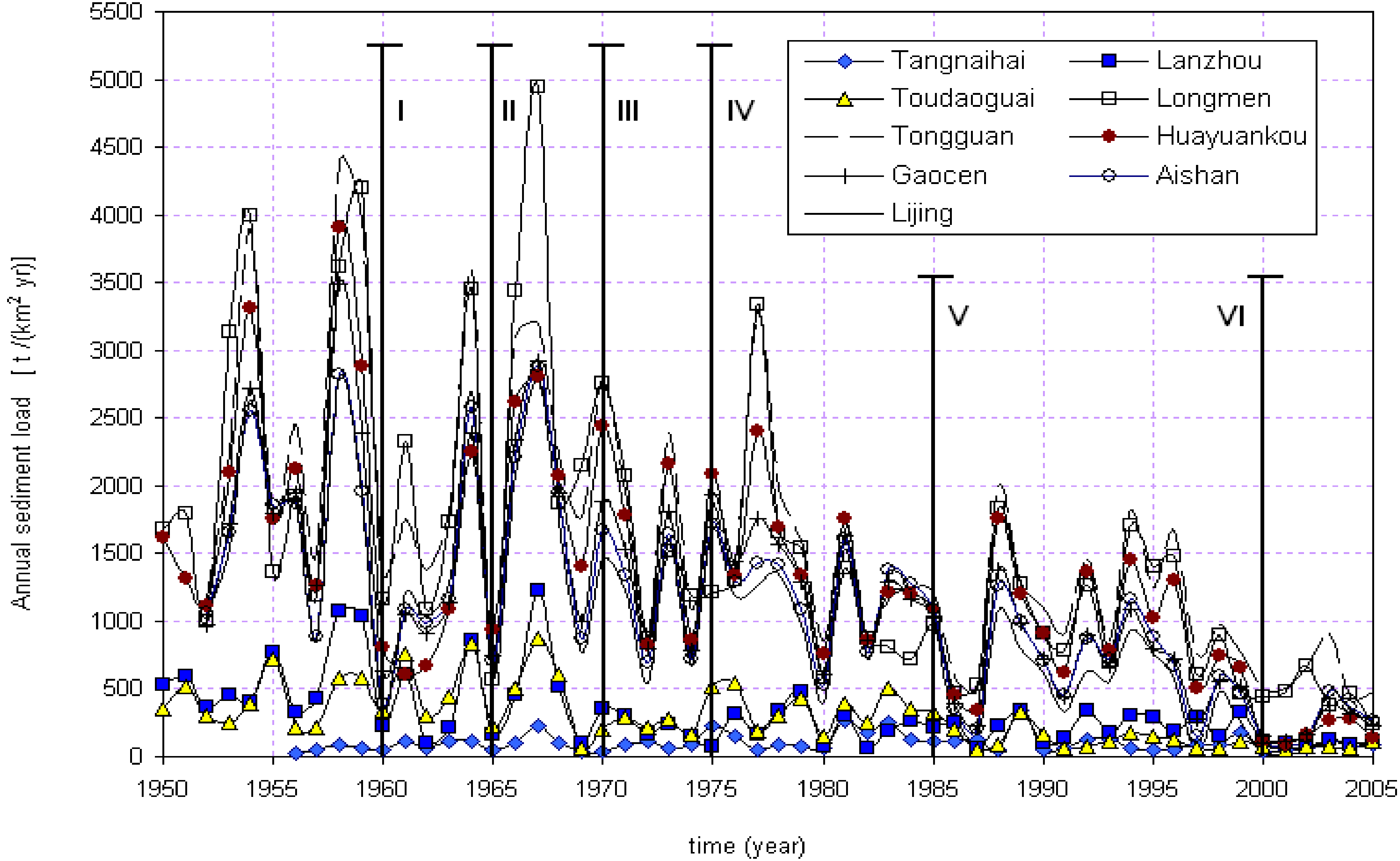
- 420000 people left their home and moved to the Gobi desert in Gansu, where they became very poor.
- Soon the emigrants learnt that the pool level reduced to 320m-325m， much lower than the planned 350m.
- The emigrants came back but their home land was occupied by military institutions， schools and factories. They struggled for 20-30 years and the central government partly agreed their return. However, their farmland were covered with sand and silt and the soil was salinnized.
- 套用张养浩的山坡羊：峰峦如聚，波涛如怒，秦川百里潼关路。望西都，意踌躇。伤心秦汉经行处，黄河渭河都做了土。离，百姓苦；归，百姓苦。

Future of Sanmenxia

- The sediment load from the middle Yellow river and Weihe River has been reducing in the past decade quickly.
- Sedimentation in the reservoir has been changed from siltation to erosion from 2004:

Year	2005	2006	2007	2008	2009	2010	2011	2012
Sanmenxia	-120	-33	+5	-20	-60	-134	-111	-82
Weihe R	-19	+14	-15	+3	-17	-102	-58	-17

In which –means erosion, +sedimentation



Sediment yield reduction at 9 stations on the Yellow River from 1950 to 2005

- Sanmenxia reservoir has become swan lake of China

Future of Sanmenxia

Sanmenxia has become the swan lake of Chine. More than 20000 white and black swans spent 6 months in the reservoir.

Great sediment reduction make it possible to operated the reservoir at higher level.

It is possible for the reservoir capacity to be restored and the operation mode may be adjusted to achieve its planned benefit.

onclusions

- The Yellow River carries heavy sediment load which deposits in the lower reaches and the estuary, causing continuously enhancement of the riverbed and extension of the river mouth.
- The lower reaches channel is unstable because of heavy sediment load. Scouring sediment with narrow channel was not a good strategy for long term river management and it had only short term effect for levee breach control.
- The strategy of wide river and depositing sediment successfully mitigated flood hazards. Erosion from the loess plateau has been minimized by check dams and reforestation. The risk of levee breaches has been reduced to the minimum.

onclusions

- Water and sediment load have greatly reduced in the past decades, which resulted in cutoff of flow and dramatic change in fluvial process. The Yellow River delta stop expansion and suffers land loss. The new problems may be eased with interbasin water transfer projects and artificial floods.
- Sedimentation in Sanmenxia reservoir caused the Tongguan elevation rising and change of the lower boundary of the Weihe River, consequently, retrogressive siltation in the lower Weihe River.
- Sedimentation in Sanmenxia reservoir has been changed from siltation to erosion from 2005 due to sediment load reduction. It is possible for the reservoir to restore its capacity.

Thank you

Questions are welcome

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Wang Zhao-Yin, J.H.W. Lee and S. Melching.2013. *River dynamics and integrated River Management*, Springer Verlag and Tsinghua Press, Berlin/Beijing. Pp. 1-800 ISBN 978-3-642-25651-6