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# Practices of Using Spreading and Detention Areas (SDA) to Mitigate Extraordinary Flood Damages in China

*by*

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Four thousand years ago, ancestors of China had used the spreading measure to mitigate flood damages in the Yellow river. Later, this measure formed an effective system in flood defense together with levee projects. Nowadays, many reservoirs have been built for flood control. However, it is difficult to build reservoirs in the middle and downstream of main rivers in China. The utilization of spreading and detention areas (SDA) are an effective way to mitigate extraordinary floods, but this is accompanied with the severe social problems. For the tradeoff of SDA is difficult to estimate, this measure is still in argue. This measure has been practiced for many years and still be used in China. In recent years, with the advance of flood forecasting and reservoir operation, SDA got effective. This study focus on the SDA in 4 main rivers of China, a comprehensive study is made concerning with the historical, the geographic, the climatic and the social conditions. Major problems of SDA are discussed.

Keywords: Spreading Area (SA); Detention Area (DA); 4 Major Rivers of Yangtze, Yellow, Huaihe and Haihe

## INTRODUCTION

Prior to 1949 no reservoirs were built to control extraordinary floods in main rivers of China. Government took an active role in building flood control reservoirs with the economic development in fifties and sixties, over 60% of existing reservoirs (86,000) were built in that period. General floods of P>5%–10% are controlled. However, the functions of structural measures are limited for the flood volumes or peak discharges are too big, and rainstorms mainly concentrate on both middle and downstream of main rivers. Non-structural measures such as SA and DA have long been the major methods to prevent catastrophic floods in plain areas.

Despite the utilization of SA and DA, catastrophic floods have still resulted in severe damages. The flood of the Yangtze river in 1954 killed 33169 people, 3.17 million hectares of cultivated land submerged and over 4277 houses destroyed [1]. The floods of the Huaihe river cause 80,000 people's deaths in 1975 [2]. A large flood happened again in the Huaihe river in 1991 and nearly 3000 people died [3]. Moreover, the most dangerous floodplain is the Jinjiang section of the Yangtze river. Xue pointed out that if the levees of this section were destroyed by the flood like 1870, over 500,000 people will be killed. The estimated economic loss will be over hundreds billion yuans [4][$1 US = 5.5 yuan].

Planning Spreading Area (SA) is the area that, in the case of flood discharge is over the protection ability of downstream, is used to temporally SCATTER peak discharge by opening a levee mouth. SA is suitable for hurry flood currents and multi-branch river systems when suitable areas exist. The floods are usually diverted to the another river channel (Fig. 1). This measure generally contains no sluices.

Planning Detention Area (DA) is the area that, in case of flood discharge is over the protection ability of downstream, is used to temporally STORE peak flood by the controlling sluices. The stored floods are recharged to the river by natural return or by pumping after the recession of flood level. DA is suitable for a river of enough flood forecasting period to response.

The difference between SA and DA is that SA is only used to *scatter* peak flood but DA is mainly used to *store* peak flood. This division sometimes is not clear. If the floods occur in several rivers at the same times, the SA is also used to store floods.

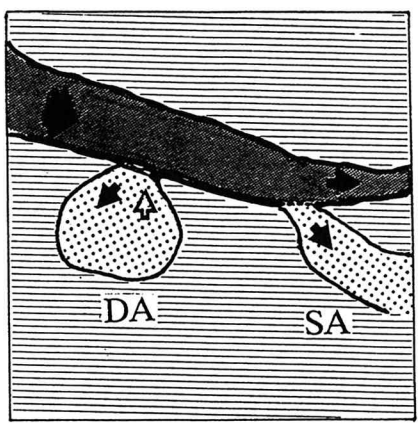


Fig. 1 Conceptual Map of SDA

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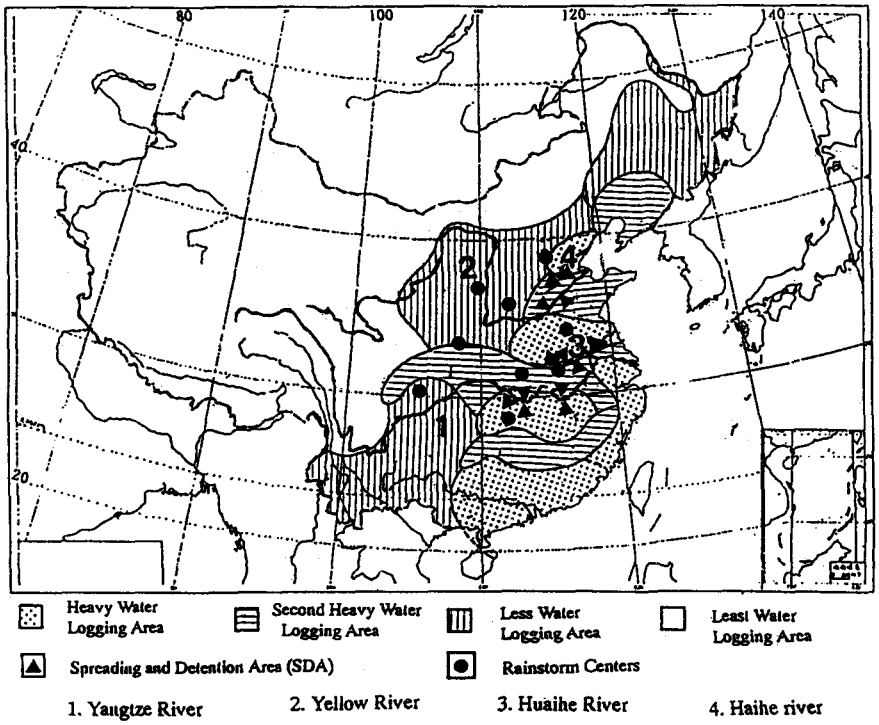


**Fig 2. Distribution of Rainstorm Centers, SDA and Water Logging Areas**

## HISTORY OF SDA

Rich experiences of nonstructural measures have been accumulated in Yellow river over 4000 years. According to legend, there were severe floods and sea freshest in the Yellow river basin in old time, ancestors of China had to select hills as the living place to settle down. Ordered by emperor Yao, Song used simple levees enclosing the inhabitant areas, but this measure failed. God Yu, the son of Song, learned the experience of his father in about BC 2200. He realized that water is always flow from higher place to the lower and then he used the methods of channel dredging and flood spreading to mitigate damages. For the lower production ability in that time, flood damages were still severe [5]. Feng Jun is the man who clearly used the measure of flood spreading in Xihan dynasty (B.C. 95–112). He suggested to use an old river channel as the spreading route to diver floods. Also in that period, Wang Jin developed a theory that combined the channel dredging, levee strength and flood diversion to control flood. Natural lowlands were used to spreading floods. In Song Dynasty (969–1134), a SA was planned in north part of the Yellow river to prevent the capital from the floods in south part. Manpower measure was adapted to diver floods.

## BASIC CONDITIONS OF 4 MAIN RIVERS

SA and DA have been planned for emergency use in 7 main rivers of China. However, for the specialities of weather, geography and social conditions, flood damages mainly concentrate on 4 rivers: the Yangtze, the Yellow, the Huaihe and the Haihe. Table 1 shows the basic conditions of 4 rivers and Fig. 2 shows the distribution of rainstorm centers, SDA and water-logging areas (1950–1980). This figure is made based on the data of reference [2] and [6], etc. From these we can see that the water-logging areas of heavy and second-heavy mainly locate in the middle and downstream of above 4 rivers. SDA is also concentrated on these rivers [6].

From *social* point of view, one third of China's territory is included in these river basins but the percents of population, crop output and irrigation areas are as high as 74%–84%. Moreover, the floodplains of China mainly located on the east plains and coastal line areas. The percentage of land area is only 8% of territory, but the percentages of populations, the cultivated land and the production value are separately 40%, 35% and 60% [7]. Nowadays, 43,600 km of main levees are used to protect the population of 173.5 million in these areas [8][9].

Table 1 Basic Condition of 4 Main Rivers in China

| Items \ Rivers | Yangtze | Yellow | Huaihe | Haihe | Rate of China's% |
|---|---|---|---|---|---|
| RIVER BASIN AREA ($km^2$) | 1808500 | 752443 | 269150* | 26464 | 32 |
| Upstream | 1007530 | 367898 | 30000 | | |
| Midstream | | 362138 | 128000 | | |
| Downstream | | 22407 | 30000 | | |
| LATITUTE (m) | 5600 | 5200 | 200 | 1000 | |
| Upstream | 40-5600 | 980-5200 | 24-200 | 50-1000 | |
| Midstream | 14-40 | 90-980 | 2-24 | | |
| Downstream | 0-14 | 0-90 | 0-2 | 0-50 | |
| RIVER LENGTH (km) | 6300 | 5464 | 1000 | 1090 | |
| Upstream | 4450 | 3461 | 360 | | |
| Midstream | 1000 | 1235 | 490 | | |
| Downstream | 847 | 768 | 150 | | |
| RIVER SLOPE (m/km) | | | | | |
| Upstream | 1.25 | 1.01 | 0.6 | | |
| Midstream | 0.03 | 0.73 | 0.05 | | |
| Downstream | 0.02 | 0.12 | 0 | | |
| PLAIN LENGTH OF RIVER (km) | 1847 | 1535 | 640 | 600 | |
| PLAIN SLOPE (m/km) | 0.024 | 0.12 | 0.034 | 0.1 | |
| YEARLY RUNOFF (bil.$m^3$) | 97.93 | 5.6 | 5.3 | 2.84 | 41 |
| RUNOFF DEPTH (mm) | 526 | 83.2 | 225 | 91 | |
| YEARLY RAINFALL (bil.$m^3$) | 1936 | 369 | 283 | 178 | |
| AVERAGE RAINFALL DEPTH(mm) | 1071 | 464 | 860 | 560 | |
| TOTAL POPULATION (mil.) | 385.8 | 93.8 | 143.7 | 101.0 | 80 |
| ARABLE LAND (mil.ha) | 23.4 | 12.2 | 12.3 | 10.3 | 74 |
| TOTAL STORAGE (bil.$m^3$) | 137.2 | 57.7 | 40.7 | 24.4 | 73 |
| EFFECTIVE STORAGE(bil.$m^3$) | 79.6 | 15.2 | 14.6 | 9.0 | 71 |
| TOTAL LEVEES | | | | | |
| Length (km) | 54236 | 10072 | 48987 | 24627 | 79 |
| Protected Land (mil.ha) | 5.7 | 1.6 | 9.4 | 6.1 | 83 |
| Protected Population(mil.) | 90 | 11 | 93 | 45 | 84 |
| MAIN LEVEES | | | | | |
| Length (km) | 13240 | 5513 | 13527 | 11300 | 25 |
| Protected Land (mil.ha) | 3.7 | 1.1 | 6.7 | 5.3 | 61 |
| Protected Population(mil.) | 60 | 7.9 | 66.7 | 38.9 | 61 |

Note: 81,000 $km^2$ of Huaihe river basin area is not included for this area has an indepentent river month.

From *geographic* point of view, these river sources from 1000 to 6500 m above sea level, 81%–99% of latitude differences and 30%–70% of river lengths concentrate on upstream. The latitudes of alluvial fans in midstream are only 24–90 m but the distances from alluvial fans to the river months are as long as 500–1500 km. The channel slopes in middle and downstream are only 0.002–0.07%. Flood levels are usually 3–10 m higher than that of farm lands at the downstream rivers because of the sand deposition.

From *climatic* point of view, these river basins are affected by the monsoons from Pacific and Indian oceans, and by the special geographic conditions of Huangtu loessial plateau and Himalaya mountains. The monsoon characteristics of cold and drought in winter but warm and moist in summer are highly contrasted. Over 50% of yearly rainfalls in most areas are concentrated on 4 months from April to September (difference in regions) and thus form some rainstorm characteristics. (1) rainstorm centers usually locate on the midstream areas (Fig. 2). (2) regional medium floods are the major catastrophic floods. The flood periods are usually 3–7 days and rainstorm areas are 100,000–200,000 $km^2$. (3) floods sometimes happen in one or several river basins at the same time and this kind of flood usually causes severe damages [Ref. 1, P18].

## THE ESTABLISHMENT AND ADVANCE OF SDA

The efforts of flood control through structural measures are limited in middle and downstream areas. The first reason is that the floods mainly occur in midstream and the function of reservoir operation in upstream is less. The second reason is that no suitable site exists to build reservoirs in big plain areas. The third reason is that there are impossible to wide, raise or dig new channels for the rivers are too long to cost. On the other hand, many big lakes and lowlands exist in the plain areas. These areas have natural functions to regulate floods. As for the populations in SDA have increased rapidly during this century, many lakes have been cultivated and natural flood regulation functions have greatly decreased. Example of this is the Dongtinghu lake, this lake is one of the largest lakes in the Yangtze river but the lake area has decreased 50% during this century [Ref. 10, p320]. This reduction is one of the important reason for severe flood damages of China in thirties and forties.

After 1949, China government has selected several lakes and lowlands as SDA in middle and downstream areas. These areas have provided places to diver floods and to limit future encroaching to the lakes. DA was used to prevent extraordinary floods of P>5%–10% in the Yangtze and the Yellow rivers. Both SA and DA were built to prevent ordinary or extraordinary floods in the Huaihe and Haihe rivers. These areas have played an important role in defense extraordinary floods during past 43 years.

Table 3 shows the basic conditions of SDA in these 4 rivers and table 4 show the elements of SDA. Comparing with protected areas, the percents of populations and cultivated lands of SDA are only 5.9% and 6.7%. Regression analyses show that a liner relation exists between the areas, the cultivated lands, the populations and the storage volumes. This is because (1) the cultivated lands original from natural lakes and lowlands; (2) the populations increasing rapidly for the lower education level and got new lands in SDA.

Table 4 The Elements of SDA

| | | |
|---|---|---|
| Population Density (Per ha.) | 6–97 | Average 17.4 |
| Water Depth (m) | 0.5–4.2 | Average 3.8 |
| Percent of Cultivated Lands to the Total Areas | 50%–82% | Average 64% |

1. *The Yangtze River*

The Yangtze river is the third longest river in the world and the biggest river in China. The numbers of branch rivers are 3600. The percents of mountains, hills and plain areas are separately 65%, 22% and 13%. The yearly runoff is about twenty times higher than that of the Yellow river. For the good natural condition, the Yangtze river basin has been the most important river basin of China. However, flood damages are severe for the uneven of the rainfalls.

The Yangtze river basin belongs to subtropical zone and has two thunderstorm areas. One is the mold rain area all over the downstream during May to June. The another area in the Northeast of Sichuan province is near the alluvial fan and rainstorms concentrate on the period of July to August. Regional strong rainstorms and regional big precipitation are the major sources of flood. Generally, these two source areas not meet at the same time, but the whole river basin floods may be happened if the former rainstorms delayed or the latter rainfalls ahead.

The plain areas of the Yangtze river are 126,000 $km^2$ and 15% are lakes and lowlands. The river connects with some famous lakes such as Panyanghu, Dongtinghu and Taihu, etc. Six DA have been planned on these lakes since 1949, but only Jinjiang and Dujiatai were used. Jinjiang levee is a famous section of the Yangtze river. This levee was first built in Xijin dynasty among B.C. 205–95 and located on the base of sands and graves. The levee was strengthened for many times during past 1600 years. However, the levee quantity is still poor for the natural defects such as ant nest, brick dregs, snail shell and crested within levees. The Yangtze river has been silted for over 2000 years and flood level is general by 3–10 meter higher than the land along river.

The safety discharge of Jinjiang section is only 45,000 $m^3$. In 1870, a flood discharge of 105,000 $m^3$ occurred at Sashi city section of Jinjiang levee and broken the south levee. Over 30,000 $km^2$ was submerged and 8,000,000 people affected. Big volume of floods made it impossible to completely control in this river. The Gezhouba reservoir is the only reservoir built on the principal river of the Yangtze but 2.7 billion $m^3$ of storage is too small to regulate the floods. Three Gorge reservoir, well-known in the world, will be built within five years to control peak floods in the Yangtze river. One purpose of this project is to mitigate flood damages in Jinjiang section. To control extraordinary floods of P<1%, some SDA are needed to take reservoir operation cooperated with Three Gorge reservoir [4].

To keep the safety of Jinjiang areas and Wuhan city–the largest city in middle China, central government built Jinjiang DA and Dujiatai DA in 1952 and 1956. Levees, inlet sluices, regulating gates and discharge projects were built. Flood protection standards raised from original 4–5 years to 10–20 years. Combined with some temporally measures, the protection standard can raise to about 40 years. If combined with Three Gorge reservoir, the flood defence ability will be over 100 years.

2. *The Yellow River*

The Yellow river basin is famous for the human civilization and this river is also famous for the high sand contents and flood damages. Flood disasters happened 1590 times during past 2540 years but no catastrophic damages happened in

Table 2 Characteristic Values of Flood Near SDA in Four Rivers

| River Name | River-basin Area ($km^2$) | Max. Measured Flood | | | | Max. Inves. Flood | |
|---|---|---|---|---|---|---|---|
| | | Peak Discharge ($m^3/s$) | Flood Volume (mil.$m^3$) | Period (day) | Occured Year | Peak Discharge ($m^3/s$) | Occured Year |
| 1. Yangtze | | | | | | | |
| Yichang | 1005501 | 71100 | 244800 | 60 | 1896 | 105000 | 1870 |
| Hankao | 1488036 | 76100 | 322000 | 60 | 1954 | | |
| 2. Yellow | | | | | | | |
| Huayuankao | 730036 | 22300 | 10100 | 15 | 1958 | 32000 | 1761 |
| 3. Huaihe | | | | | | | |
| Zhengyi-angguan | 91620 | 12800 | 32700 | 30 | 1950 | | |
| 4. Haihe | | | | | | | |
| Miyun | 15790 | 10650 | 2885 | 15 | 1939 | | |
| Huangbi-zhuang | 23272 | 13100 | 3024 | 15 | 1956 | 20000-27500 | 1794 |
| Lingmin-guan | 2326 | 12300 | 1074 | 15 | 1963 | 6680 | 1917 |

Sources: this table is abstracted from p19, China History Big Flood.

Table 3 Basin Conditions of SDA in Four Rivers

| River | Number | Area ($km^2$) | Cultivated Land (1000 ha) | Population (1000) | Storage Volume (million $m^3$) |
|---|---|---|---|---|---|
| 1. Yangtze | 6 | | 473.3 | 4780 | Over 50,000 |
| Jinjiang | | | 58.7 | 670 | 5,400 |
| Honghu | | | 90.7 | 980 | 32,000 |
| Wuhan | | | 138 | 1,200 | 6,800 |
| Dongting | | | 208.7 | 1,550 | |
| Panyanghu | | | 19.3 | 180 | |
| Huayanghu | | | 24.6 | 200 | |
| 2. Yellow | 4 | 3162 | 206 | 1611 | 4590 |
| Beijinti | | 2316 | 162 | 1260 | 2000 |
| Dongping | | 623 | 31 | 260 | 2000 |
| Qihebei | | 100 | 6 | 42 | 390 |
| Kenlinan | | 123 | 7 | 49 | 200 |
| 3. Huaihe | 22 | 3110 | 1,500 | 380 | 6,700 |
| 4. Haihe | 32 | | | | 19,100 |

Table 5 Practices of SDA

| Name | Period | Used Times | Diverting Discharge ($m^3/s$) | Rate of Peak Q Reduction (%) | Flood Level Down in Downstream (m) | Flood Storage (mil.$m^3$) | Flood Stored Rate (%) |
|---|---|---|---|---|---|---|---|
| 1. Yangtze | | | | | | | |
| Jinjiang | 1954.7 | 3 | | | 0.47 .64 .96 | 12500 | |
| | 1981 | 1 | | | | | |
| Dujiatai | 1956-78 | 20 | | | | 15000 | |
| | 1956.7.2 | | | | | | |
| | -6(142hm) | | 3120 | | 0.9 | 837 | |
| | 1958.7.8 | | | | | | |
| | -8.27 | 4 | 4800 | | 0.47-2.53 | | |
| 2. Yellow | | | | | | | |
| Dongpinghu | 1949-58 | 5 | | | | | |
| | 1957 | 1 | 800 | 7 | | | |
| | 1958 | 1 | 3300 | 20.8 | 1.62 | | |
| | 1982 | 1 | 2970 | 28.6 | 1.1 | | |
| 3. Huaihe | 1950-91 | 165 | 800-1000 | 33-61 | 0.2-0.8 | 10-950 | 13-15 |
| Fangqiuhu | 1954 | 1 | 860 | | 0.39 | | |
| Panlingwa | 1954 | 1 | 1190 | | 0.15 | | |
| Chenxihu | 1968 | 1 | 10630 | 60.57 | | | 15.28 |
| | 1991 | 1 | | | 0.81 | 520 | |
| Jingshanhu | 1982 | 1 | 2210 | | 0.47 | | |
| Dongfenghu | 1982 | 1 | | | 0.81 | | |
| Menwa | 1982 | 1 | 1380 | 33.47 | | | 13.57 |
| | 1991 | 2 | | | | 965 | |

past 43 years. The successful theory is to store floods and sands in the way of step by step. Two methods were used: (1) building cascade reservoirs in principle river and (2) water conservation. A hundred and seventy reservoirs have been built in upstream and tributary during past 43 years.

The upstream of the Yellow river belongs to the arid and semi-arid areas. The precipitation is less and the short duration storms and ice prisms are the sources of floods. Several thunderstorm centers exist. (1) Gorge region among Shanxi and Shaanxi provinces. (2) Middle plain area. Several big stream influxes into the Yellow and river basin area suddenly increase by 185,000 $km^2$. (3) The regions between the Shanmengxia reservoir and Huayuankao. The characteristics of floods are short duration and high velocity.

In history, many SDA existed in the Yellow river. A comprehensive tech-economic planning for the improvement of the Yellow river was made in 1954 and many reservoirs were planned for flood control. DA was considered as a temporal measure to mitigate extraordinary floods before these reservoirs completed. This planning was later changed. Experts found from the practices and analysis to the historic data that extraordinary floods are possible to happen in downstream and the estimated peak discharge in Huayuankao station is 46,000 $m^3/s$. This discharge is far over the safety discharge of 22,000 $m^3/s$ [11].

Structural measures are impossible to be effectively used to control such a flood and DA were planned again as a main measure to mitigate this kind of flood. Beijingti DA was the largest area and was temperately planned as a flood detention area in 1951. In August 1975, after the big flood damage happened in the Huaihe river, this area was enlarged. Dongpinghu DA was a natural regulation lake in history and this lake was enlarged to 2 billion $m^3$ in 1958. The purpose of this DA is to reduce the flood discharge and delay the peak time. A big regulation sluice was built in 1963 and flood diversion capacity raised. Kenlinan DA was built to diver milted-snow floods in spring period for the ice floods often cause the damages to downstream areas.

3. *The Huaihe River*

The Huaihe river locates in the area between the Yangtze river and the Yellow river. In 1128, a big flood destroyed the south levee of the Yellow river, and then the Yellow river aggressed the Huaihe river as long as 727 years. About 10 billion tons of sand silted in the downstream area [12]. These sediments changed the geography of the Huaihe and resulted in severe flood damages. Both June and July are the mold rain seasons in this river. Affected by the geography, the southwest part is the central thunderstorm area and is the biggest rainstorm area of China. Continue thunderstorms often occur.

Two special canals were built around 1949. Part of floods can be directly discharged into the sea, but main floods have to discharge to the Yangtze river through the Hongzehu lake. In 1950, China government issued the principle of improving the Huaihe river based on the combination measures of reservoirs and SDA. After 40 years, the total reservoir storage reaches to 25 billion $m^3$. The 22 SDA were built in plain areas and diversion ability is about 28 billion $m^3$. These combined measures have raise the flood protection standards to 20–40 years in main levee areas. For the population increased 125%–178% during 1953–1986 in the major SDA of the Huaihe river, it takes big social problems to use the SDA.

4. *The Haihe river*

The Haihe river basin locates on the north part of the Yellow river and belongs to the semi-arid area. This area includes some big cities such as Beijing and Tianjing. The percents of mountains and plains are separately 60% and 40%. The yearly rainfall is 375–808 millimeter. During July to September, 75%–85% of yearly rainfall mainly occur in the form of flood. Big difference exists between mountains (1000 m) and plain areas (50 m). The thunderstorms distribute in the direction of north-south along the Taihang mountains and west-east along the Yanshan mountains. Rainstorms concentrate on the steep windward areas. Several streams can happen the floods at the same times and one rainstorm can be followed by another thunderstorm.

In history, the Yellow river aggressed the Huaihe river for 3 times in the years of B.C. 602, 11 and 1048. Formed by the sand sediment, many lowlands, lakes and small channels remain and water logging is heavy. After 1949, 50 canals have been dug and 21.86 billion $m^3$ of reservoir storage have been formed. Flood discharge ability has increased from original 2,420 $m^3$ to 24,680 $m^3$. Flood protection standards increase from less than 10 years to 50 years. Thirty-two SDA were planned and total detention capacity is 12.3 billion $m^3$.

## THE EFFECTIVENESS OF SDA

The effectiveness of SDA on flood mitigation is difficult to describe in quantity but it is ease to see in qualitative analysis. From economic point of view, flood damage transferred from the high-loss areas to the lower-loss areas, the difference is the benefit. This benefit is usually a positive. The benefit shows in the aspects of the lower of flood level, the reduction of flood discharge and the increasing of flood regulation ability (combining with reservoir operation). The lower of flood levels can also reduce the levee strength cost and delay the arrival time of flood in downstream areas. The problems of unclear protected areas and instability of floods result in the difficult to the benefit-cost analysis.

China has practiced SDA about 200 times in 4 main rivers during past 43 years. The 80% concentrated on the Huaihe river; 10% on the Hanjiang branches river of the Yangtze river; and rest 10% on other rivers. Table 5 shows the operation practices of these SDA.

1. *Practices in the Yangtze river*

A flood of P=2.5% happened in the Yangtze river in 1954 just after 2 years the Jinjiang DA project finished. Jinjiang DA was used for 3 times to mitigate the peak floods in that

year and the flood levels down 0.47–0.96 m in Sashi city. In 1981, flood happened in Sichuan province, this area was used again to mitigate flood.

The project cost of the Dujiatai DA was equal to a medium-year flood damage in the fifties. Before this project, the downstream levees were destroyed 7 times during 1934–1952 and catastrophic discharges were 10,250–17,200 $m^3/s$. This project was used 7 times during 1956–1958 and 13 times during 1959–1978. The flood discharges in 1956–1958 are 12,850–17800 $m^3/s$ and these discharges are the same amount of the past catastrophic discharge. No sections of levees were destroyed even after the project built within 36 years. The effectiveness of flood control is obvious. The Danjiangkao reservoir was built in upstream in 1973. The cooperation of this reservoir with the Dujiatai DA has raised the flood control capacity to 10 billion $m^3$. Flood damages are controlled [10][14].

2. *Practice in the Yellow river*

In the Yellow river, Dongpinghu DA was used 6 times in past 43 years. During 1949–1958 this area belonged to a natural flood regulation pool and the peak reduction rate was 7%–20% [15]. The early filling of storage before peak flood reduces the flood regulation ability of DA. In 1982, the flood was not so big but with the function of sluice, the peak reduction is obvious. Other DA were not used for the general floods have been controlled by reservoirs. Dongpinghu DA consists of 3 sub-areas and the uses of these areas depend on the flood discharge [5][14].

3. *Practices in the Huaihe river*

In the Huaihe river, total operation times of 22 SDA were 165 during 1950–1991 and accumulated submerged area was 813,000 hectare. The diversion frequency is 2–18 years and in most areas the operation standards are only 3–5 years. The major practices concentrated on 1954, 1982 and 1991. In 1991, a big flood (P≈3%–1%) happened in the Huaihe river. Three DA (75%) and twelve SA (67%) were put into use and total diversion volumes reach to 6.61 billion $m^3$. This volume is far over the reservoir storage volumes in upstream (2.45 billion $m^3$). Through the combination of reservoir operation and SDA, 80% of peak discharge were reduced [16]. Important cities, railways and 407,000 hectare of cultivated lands have been protected. The estimated avoided loss is 14.7 billion yuans (2.7 billion U.S. dollars)[17][18][19].

4. *Practice in the Haihe river*

SDA were used when a big flood happened from August 2–8 in 1963. The daily rainfall area of over 50 mm is 80,000 $km^2$ and the rainfall area that over 100 mm is over 150,000 $km^2$ during 7 days. Total rainstorm volume is 33.3 billion $m^3$. Eight SDA has been opened by manual. The diversion discharges are 805–2,740 $m^3/s$ and the total diversion flood amount is 3.1 billion $m^3$. The time of flood remained in the SDA was as long as 1–2 months in these areas [20].

5. *Summary*

From above practice we can see that the operation standards of SDA are 10–40 years in the Yangtze, the Yellow and the Haihe rivers, 2–15 years in the Huaihe river. Peak reduction rates are 20%–30% and flood levels down 0.2–2.5 m in downstream. Flood stored rate is about 15%. In addition, DA is effective than SA because DA usually has sluices to outage and have suitable places to escape and live. The effect of SA is not ideal because there are generally no special discharge systems in SA and levee repairing works are hard.

## PROBLEMS AND IMPROVEMENT WAYS OF SDA

Severe social problems and some technical problems exist in SDA:

(1) *How to deal with the tradeoffs between SDA and protected areas?* For the historical reasons, people in upstream encroached the lake and reduced the regulation areas, thus increased the flood damages of downstream. Nowadays, it is impossible to regress to the original areas for the populations in SDA areas have double. SDA is a way to balance the benefits between upstream and downstream areas, and between provinces and regions. Flood diversion resistance exists in some rivers.

(2) *How to carry on an economic compensation*? As for the protected areas are usually not clear, it is difficult to ask protected people to pay some money to the SDA. The problems are how to pay and how much to pay? Flood insurance was carried on in the SDA in China but this measure is not popular for the people in SDA are not enough ability to pay the insurance fees [21]. In addition, how to balance the benefits between regional and provinces and how to objectively estimate the flood damage both in planning SDA and protected areas are still not solved.

(3) *How to effective reduce the flood damages in a comprehensive way and how to guarantee the people living and recovering during flooding period?* The recession times of DA are usually as long as 1–5 months in big DA and the flood water depths are 3–5 meters. Many people have to crowed on a small area (2–5 $m^2$ per person) and for a long time. The assistance of food supply and disease prevention are not easy. In addition, the tasks of flood spreading and recovering are hard works to the local people.

(4) *How to manage the floodplains effectively*? There are absent the effective laws to limit population increasing and land use in SDA. The fast increasing of population causes the difficult to future use of SDA.

Some improvement ways are suggested.

(1) *Raising the flood control standards of rivers*. The basic problems of SDA in China are the low standards of SDA. The operation frequencies should be improved for the operation frequencies are only 2–5 years in most areas of the Huaihe river. This improvement is possible to do by the combination of flood forecasting and reservoir operation. The practices in the Huaihe river show that the major levees in downstream are able to against 40 year flood, early flood

diversions exist both in the Huaihe river and the Yellow river. Other ways such as reservoir construction, levee strength and diversion channel construction should be considered.

(2) *Strength the land management and increasing the pumping system.* The wheat harvest should be guaranteed for the winter wheat is the major crop in SDA and harvest period is early in May and June. It is possible to take some agriculture technology to ahead harvest time. The improvement of pumping system will also reduce the wet time and will benefit to replant.

(3) *Building safety projects in SDA.* Gradually reduction of the utilization times of SA and development the DA are the aims in the future. SA is prepare only for the extraordinary floods and people in this area should have enough times to escape and safety places to living. The people in DA need to immigrate to safety areas and DA should be changed to a no-inhabitant farm and flood diversion places.

## CONCLUSIONS

(1) The measure of using SDA to mitigate peak flood is an effect way to control extraordinary flood in China, but result in severe social problems. The characteristics of geography, climate and social conditions limit the function of structure measure. However, suitable conditions exist for utilization of SDA. The use of SDA has also a close relation with the history and sand problems of the Yellow river.

(2) SDA are mainly planned on the middle and downstream areas of big rivers and are mainly used for mitigating extraordinary floods. The 43 year practices of SDA show that the operation standard is 20–40 years in the Yangtze, the Yellow and the Haihe rivers, 2–15 years in the Huaihe river. The peak reduction rate is 20%–30%. Flood level down 0.2–2.5 m in downstream and flood stored rate is about 15%. In addition, DA is effect than SA because DA has sluices to outage.

(3) SDA is economic in qualitative analysis, but it is difficult to take a benefit-cost analysis in quantitative for the protected areas are usually unclear and flood damages are irregular. Flood damage data are not easy to collect for the modeling and evaluation of SDA.

(4) Severe social problems exist in SDA. First, the absent of adequate laws, policies and regulations have resulted in the diversion resistant. Second, the compensations to the planning SDA is a complex problem for the effective compensation methods of flood diversion are absent. Flood insurance has been carried on in the SDA of Huaihe river for several years, but this business not gets widely developed yet. Third, the settlements and withdrawing of inhabitants in SDA are difficult because of too many people, long distant of withdrawing road and long time of flood detention. SDA is a complex measure related with nature, history, social and environment. It also has obvious regional characteristics. In addition, flood forecasting and reservoir operation together with SDA can form an effective system to defense flood.

## REFERENCE


[1] Weng Fube, *Position and action of the Yangtze river basin planning in economic development*, Journal of Water Resources Planning, 1988.1

[2] *China historical big floods*, China Book Shop Press, 1989

[3] China disaster reduction press, January 7, 1992

[4] Xue Shiyi, *The flood control benefit of Three George project*, Journal of China Water Resources, 1987.5

[5] Yellow River Water Conservancy Committee, *Flood control and development of the Yellow river* (translation), Kokin Shoin limited company (Japan), 1989.5.2

[6] Feng Peizhi et al, *China major weather disasters analysis* (1950–1980), China Weather Press, 1985.11

[7] Liu Xiaoling, People's Daily (overseas edition), 1992.11.12

[8] *China yearbook of water conservancy (1990)*, China Water Resources and Electric Power Press, 1991.12

[9] *China yearbook of statistics (1991)*, China Statistics Press, 1992

[10] Koide, Hahu *The Yangtze river, natural and comprehensive development*, Tsukiji Shokan limited company (Japan), 1987.7.20

[11] Weng Chongde, *Practice and development of comprehensive planning in the Yangtze river*, Journal of Water Resource Planning, 1988.1

[12] Liu Shukun, Chen Xiaotao, *Big flood damage of the the Huaihe and the Taihu river basins in 1991*, Journal of the Japan Society of Civil Engineers, Vol. 7 1992.7

[13] Aya Shiroo et al, *Flood damage and control of the Huaihe river*, Proceeding of the 47th Annual Conference of the Japan Society of civil Engineers(2), 1992.9

[14] Xiu zhengpu, *Benefit analysis of the Yangtze river flood control project*, Journal of Economics of Water Resources, 1985.3

[15] Pen Yinren, *Flood control measures and practices of Dongpinghu flood division project in the downstream of the Yellow river*, Journal of Water Resources and Hydroelectric Power, 1985.4

[16] Tan Huafeng, *Flood control and two suggestions on the Huaihe river*, Anhui province, Journal of Anhui Water resources, 1991.3–4

[17] Lin Yiran, *Flood and control of the Huaihe river in 1991*, Journal of Anhui Water Resources, 1991.3–4

[18] Xiu Yinchong, *Operation of spreading and detention areas in midstream of the Huaihe river*, Journal of Anhui Water Resources, 1989.1

[19] Shan jingzhang, *Operation of spreading and detention areas and nonstructural measures in the Huaihe river*, Journal of Water Resources and Hydroelectric Power, 1985.4

[20] Yao Qingnong, et al, *Some experiences on the Huaihe river basin planning*, Journal of Water Resources Planning, 1988.1

[21] Yamada, K, Fan Zhen, *Practice of Flood Insurance in China*, 29th Scientific Symposium of Japan Society for Natural Disaster Science, 1992.11.4–6