FLOODING, FLOODPLAIN DEVELOPMENT
AND MANAGEMENT IN CHINA

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Abstract
Flooding is one of the natural attributes of rivers. This paper discussed the important roles of flooding on maintaining landscape and guaranteeing sustainable distribution of water resources in floodplain areas, and analyzed the PRED problem in floodplain areas in China. According to the present situation, management implications on flood and floodplain areas were put forward.

Keywords flooding, floodplain areas, sustainable development, water resources
Floodplains are lowland areas adjacent to rivers which subject to inundation during periodical floods. Flooding is vital to landscape maintaining and water resources sustainable utilization in floodplain areas.

1 FLOODING AND ITS IMPACTS ON FLOODPLAIN AREAS

1.1 FLOODING AND FLOODPLAIN ECOSYSTEM MAINTAINING

Flooding is a physical and hydrological feature of a river and it plays important roles in maintaining inputs and outputs of water, nutrients and energy flow in riverine ecosystems. Flooding plays critical roles as maintaining floodplain being sediment and nutrient filters, as contributor of pulses of nutrients and organic matter during floods, and providing habitats for fishes and waterfowls at certain live. The regular seasonal spring floods of the Nile River prior to construction of the Aswan High Dam, for example, were depended upon to provide moisture and soil enrichment for the fertile floodplains of its delta. Periodically inundated floodwaters provide significant habitat for fish to feed, spawn and reproduce, and floodwaters and vegetation in floodplain provide important resting, feeding and nesting areas or flyways for many waterfowl species. During inundation floodwaters deposit sediments rich in nutrients which keeps soils of floodplains productive, and periodical floodwater overbank flow and retreat exchange nutrients between river channels and floodplains. Thus biodiversity and ecoproductivity in floodplain areas are very high even comparable to rain forests and coral reefs which are the most productive ecosystems in the world. Flooding is vital to maintain a healthy ecosystem in floodplain areas. During a flood, the annual inundation and retreat of floodwaters onto the floodplain can bring water and particulate organic matter on to and out of floodplains and through these inflows and outflows riverine system health is maintained. Flooding not only provides hydrological continuity between tributaries and main stems, upstreams and downstreams, but guarantees the hydrological and ecological connections between river channels and floodplains.

1.2 FLOODING AND WATER RESOURCES SUSTAINABLE UTILIZATION IN FLOODPLAIN AREAS

Sustainable utilization of water resource is dependent on both spatial and temporal continuous
distribution of water. In China, cognition about flood is almost entirely based on its socio-economic calamitous effects, and flood generally is viewed as disaster, calamity and even evil. However, flood is intrinsically a kind of water resource and flooding is a form of water resource reallocation and it plays significant role in balancing and modifying distribution of water resources especially at basin scale\[1\]. China is listed as one of the 13 countries which lack water resources mostly, and water resource per capita is 2300 m$^3$ which accounts 1/4 of the world average. Arid and semiarid areas which accounts 52.5 % of area in China severely scarce of water resource with usable water resource less than 500 m$^3$ per capita. On the one hand, superfluous water in the flooding period in these areas is constrained between levees and prevented from overflowing to floodplain areas, and on the other hand, after the flooding period and the rapid floodwater recharge, these areas are extremely sort of water resource. While rivers without constructed levees can flood freely under their natural rhythm, and during the flooding period water in the rivers can be input into lakes and wetlands in floodplain areas and thus water resource spatial distribution pattern can be maintained. After the flooding, water in the lakes and wetlands can be recharged into the rivers, thus through the spatial pattern exchange water resource distribution can be available in the temporal pattern. Floodplains provide storage for floodwaters during a flood thus reduce the amount of water flowing downstream and release them to the river through hydraulic interactions after flood. The values and benefits of floodplains to the whole basin are important. During periods of flooding over banks, floodplains serve as natural roomage in storing floodwaters which is an important water resources in arid and semi arid areas and gradually release some of the floodwaters to river again.

2 MAIN FLOODPLAIN SOCIO-ECONOMIC AND ECOENVIRONMENTAL PROBLEMS IN CHINA

Regional sustainable development intrinsically equals intervolved and interdependent harmony of population, resources, environment and development. Composition elements of population (P), resources (R), environment (E) and development (D) interact with each other and links between them form the mechanism of regional development. Vulnerable regional PRED system model in China is shown in Fig 1.
Fig. 1. General adverse regional PRED system in China

Area of floodplains prone to frequent flood in China is about 1 million km², with most of the floodplains concentrate in middle and lower river basins. Unbalanced PRED system of floodplain areas accords with the general model as shown in fig 1 and has its own characters. Main PRED system problems in floodplain areas in China are as the following:

2.1 Large population and increasing growth in floodplain areas
Most of the more than 1.3 billion populations in China locate in floodplain areas that can be flooded with different magnitudes. More than 90% of cities and about 6 billion people live in floodplain areas. Vital statistics show that in floodplain areas there are 300~500 persons per km² with the highest as 1000 and the rate of population growth in floodplain areas continues to rise[2]. Large population put great pressure on resources and eco-environment and predaceous utilization of resources results in eco-environment degradation in floodplain areas. Eco-environment and resources are under strain subject to a variety of anthropogenic stresses primarily due to river flow regime modification and over land use in floodplain areas. Population is the most initiative component part of PRED system and it is the leading factor to system dynamics. Large population and large population growth rate are the main triggers that fuse disharmony in floodplain areas and the press from these will continue in the near future in China.

2.2 Over land utilization and water resource exploitation in floodplain areas
Flat topography and fertile soil appealed anthropogenic activities from high elevations in early stage to concentrate on floodplain areas. To develop floodplain areas is inevitable and
essential in historical process and nowadays especially in China which has a long history and is the most populous country in the world. To reasonably exploit land and water resources in floodplain areas under certain limits can bring great benefits to socio-economic development. But in order to provide sufficient provisions to large growing population agricultural activities intruded the floodplain excessively and occupied regular floodways in floodplains, thus natural or designed floodways used to carry and discharge flood waters of a given magnitude are invaded. In China, farm area in floodways and river bottomlands is about 930 000 hm², and regular residents in these places are up to 4 million. In the middle and lower reach of the Yangtze river, more than 800 000 hm² floodplains have been reclaimed and changed into farms and industrial areas in the last half century. Statistics of planned main floodwater storage in floodplains of large basins in China are shown as table 1.

<table>
<thead>
<tr>
<th>Floodplain</th>
<th>N</th>
<th>Ta</th>
<th>Fa</th>
<th>P</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle and lower rich of Yangtze river</td>
<td>40</td>
<td>118.66</td>
<td>54.86</td>
<td>568.57</td>
<td>63.68</td>
</tr>
<tr>
<td>Lower rich of Huang he river</td>
<td>6</td>
<td>91.69</td>
<td>60.49</td>
<td>470.74</td>
<td>7.75</td>
</tr>
<tr>
<td>Huai he river</td>
<td>27</td>
<td>39.12</td>
<td>23.98</td>
<td>162.06</td>
<td>8.61</td>
</tr>
<tr>
<td>Hai he river</td>
<td>25</td>
<td>95.60</td>
<td>56.95</td>
<td>414.34</td>
<td>17.03</td>
</tr>
<tr>
<td>Total</td>
<td>98</td>
<td>345.07</td>
<td>196.26</td>
<td>1615.71</td>
<td>97.07</td>
</tr>
</tbody>
</table>

N: Floodwater storage number; Ta: Total area of planned floodwater storage (10⁴hm²); Fa: Farm area in planned floodwater storage (10⁴hm²); P: population (10⁴); C: Floodwater storage capacity (billion m³)

2.3 Eco-environment deterioration in floodplain areas

In many floodplain areas in China, for the purpose of preventing the loss of life and property, engineering modifications such as artificial levees and dams were built. For instance, in order to protect property and life from regular flood, high levees were built along the Huang he River and the Huai he River. It is now well known in the world that Huang he river has been a hanging river due to its high silt and sand content in water and its river bed improves about 0.1 m yearly. The Huan he River is constrained completely within a narrow channel. Continuity of the river and its floodplains were cut off completely, and ecosystem along the river has long been changed and out of its natural regime. Levees, dams and other modifications prevented regular flooding, caused fragmentation of river-floodplain system.
and deteriorated the floodplain ecology due to less even no supply of water and nutrients to floodplain areas. Dynamics of flooding and its influence on maintaining floodplain health is altered, and links between rivers and floodplains are broken so that the role of connectivity of river and its floodplain in maintenance of the whole hydrosystem and ecosystem is nearly deprived. The result is that degradation of eco-environment in floodplain areas is inevitable and sometimes irreversible. Human activities have negative influence on eco-environment of floodplain areas and for a long period of time unreasonable development has been the leading reason to degradation of floodplain ecoenvironment system. Typical human activities and their impacts on eco-environment of floodplain areas in China are show in table 2.

### Table 2. Impacts of Human activities on Floodplain Areas

<table>
<thead>
<tr>
<th>Population</th>
<th>Purpose</th>
<th>Demanding</th>
<th>Conducts</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survival</td>
<td></td>
<td>Dwelling</td>
<td>Reclain lakes</td>
<td>Invasion of floodplains</td>
</tr>
<tr>
<td></td>
<td></td>
<td>agricultural activity</td>
<td>drain wetland</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Life and property protecting</td>
<td>Levees, dams construction</td>
<td>Floodheight rising, floodwater lost</td>
<td></td>
</tr>
<tr>
<td>Growth</td>
<td>hydropower irrigation</td>
<td>Reservoir construction</td>
<td>Flooding regimes alteration Eco-envionment demanding water decreasing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diversion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Development</td>
<td>Industry</td>
<td>Infrastructure</td>
<td>Landscape alteration</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Urbanlife</td>
<td>Sewage discharge</td>
<td>Contamination</td>
<td></td>
</tr>
<tr>
<td></td>
<td>recreation</td>
<td>Tourism</td>
<td>Habits disturbance</td>
<td></td>
</tr>
</tbody>
</table>

2.4 Risk and damage of flooding rising in floodplain areas

High levees keep flood water remaining in channel and cause the water surface elevation in channel rise compare with the level under natural phenomenon. However, due to constructions and other obstacle in the floodways decrease flood velocities. levees and dams, and development in the floodway restrain rivers unable to spread out in less rooms and increase normal flood height. Overbuilding on floodplains make the situation much more serious. Due to less room to spread, water has no place to go but straight to the rivers. On the one hand floodheight increase, on the other hand flood velocities decrease, thus the banks overflow is much more tend to occur and cause more serious disastrous flooding scenes. Under this regime, the risk of flooding rising in floodplain areas, and in order to protect property and life from flood or decrease the flood risk, higher levees were built.

In order to protect life and economy from flood caused damage, preventing and controlling flood through building levees and dams is the major theme of river water management in China. Flood is constrained between the levees, thus the hydrology rhythm of the rivers and
water cycle in the flooded areas are strongly changed, and these inversely impose negative effects upon the socio-economy and the eco-environment. Since in China rivers contain high concentration of bedloads, flood stays much longer time and remain much higher levels in the rivers than they can overflow into the flooded area, and thus the situation is: high levees-higher water levels-higher levees-more higher water levees. This is a vicious cycle (see Fig. 2).

![Vicious cycle of hydrology modification, hydrology regime and human activity](image)

Under control of the above vicious cycle, property losses caused by flood continue to rise in recent years and potential damages from flooding are getting more and more serious. Property losses caused by flood in floodplain areas in different decades in China is assessed and listed in table 3.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yangtze River</td>
<td>2223</td>
<td>3933</td>
<td>8130</td>
<td>11337</td>
</tr>
<tr>
<td>Huang he River</td>
<td>1500</td>
<td>3600</td>
<td>6000</td>
<td>9000</td>
</tr>
<tr>
<td>Huai he River</td>
<td>1613</td>
<td>2700</td>
<td>6000</td>
<td>10163</td>
</tr>
<tr>
<td>All over China</td>
<td>2190</td>
<td>3255</td>
<td>5880</td>
<td>12120</td>
</tr>
</tbody>
</table>

Unit: Chinese Yuan Per hm²

Despite inflation in the past and recent years, flood caused economic loss still increases. Since the last 10 years, large magnitude of flood occurs more frequently and flood peak endures longer time and damages are becoming more and more monstrous. Although flood of the Huang he River has not overflowed its high built levees and banks, flood risk is getting more and more serious due to the higher and higher bed of the river filled up by sands. More and
more experts acknowledge that the Huang he River from which Chinese civilization originated, has been a huge sword with sharp edge just hanging over China and once it falls horror calamity would be inevitable and irresistable.

3 IMPLICATIONS ON FLOOD AND FLOODPLAIN MANAGEMENT

Due to flat topography, fertile soil, convenient transportation and comparatively rich fresh water resource, floodplain areas that generally lie in middle or lower reaches of rivers inevitably appeal socio-economic activities concentrate in. In China, floodplain areas are the most populous and prosperous socio-economic regions, and in the prospective near future this situation would not be changed. Under the pressure of population overgrowth and economic development, people need more and more spaces and they occupy more and more floodplain areas. Hydrological process of rivers and floodplain areas is changed and becomes more and more unpredictable, and flood conditions are exacerbated. Ecosystem in floodplain areas deteriorates and the socio-economic damages caused by floods becomes higher and higher. Eco-environment needs flood to maintain its natural rhythm, and contrary to this socio-economy demands flood to be prevented. The extremely contrary needs to flooding between eco-environment and socio-economy reflects the severely maladjustment between human and environment. Corresponding and effective measures must be taken to solve this problem. The purpose of integrated management on floodplain areas should be to maintain eco-environment system health and reduce the loss of life and property caused by flood. According to the present situation in China, implications are as the following:

3.1 Floodplain zoning in flood-prone areas

First, experts from hydrology, cartology, geography and geomorphology must make integrated, detailed and veracious floodplain maps. Then according to the occurring frequency and magnitude of historic floods and modern flow features, define boundaries of different temporal and spatial scale floodplains and mark them in the floodplain maps. Likelihood of flooding and water covering degree under different magnitude floods at a given location should be clear in the map. Floodplain investigation and zoning would provide scientific basis for integrated floodplain management.
3.2 Development limiting in floodplain areas

The most effective way to reduce the costs of floodplain development due to flood is to strictly restrict floodplain development and exclude specific land uses in certain zones. With population growth and socio-economy development, human activity in floodplain areas is inevitable and will continue in China. What we need to do is limiting development in floodplain areas furthermore especially those most frequently inundated by flood. Any further land use and development activities within the 5-10 year floodplain should be prohibited. In areas between 10 year floodplain and 50-100 year floodplain special restrictions should be given on floodplain land uses. Give less permits for developers to enter floodplain, and to developed floodplains that have long been occupied and modified, it is necessary to relocate homes and businesses away from high risk areas to higher elevation lands in the floodplain areas. For mitigation of potential agricultural flood losses farmers must be restricted and encouraged to improve tillage practices to reduce the rate at which water moves off the landscape and grow flood-tolerant crops which can withstand and adapt to periodic flooding in floodplain areas. To guarantee the above measures effectively be taken, floodplain laws, ordinances and guidance must be adopted.

3.3 Controlling population growth in floodplain areas

Population growth should be strictly controlled in floodplain areas. To floodplains inundated yearly or several years a time, residents should be removed to higher elevations. Shangdong province government decided to remove all the housing estate in the Huang he River watercourse and compensate the residents for their leaving the floodways occupied since their ancestors. In the last 3 years, 304 villages, 160 thousand residents were relocated from Huang he Rever river bottoms to higher and safer ground outside of the levees, but still there are 487 villages, 450 thousand residents sparsely populated in the river bottom floodplains. Occupants (Residents) in the river bottoms have to restore their vulnerable homes damaged by flood in no more than 7 years, and the only way for them to reduce the risk of flooding forever is relocation. The provincial government decided to move repeatedly flooded homes outside the levees within 3 years and elevate homes which are difficult to move within 3 years due to insufficient funding. The best way to reduce and minimize life losses due to flood is strictly control population growth and remove residents in floodplain areas.
3.4 Establishing floodplain reservations and reducing pollution
Floodplain wetlands intercept, purify and store floodwaters. To protect this kind of drinking
water fountainhead, it is effective to install vegetated buffers along the fringe of floodplains
and it is necessary to establish reserves to retire and restore those strained floodplains.
Establishing natural reserves in floodplain areas is beneficial and effective for floodplain
protection. Effective remedial measures should be taken to conserve contaminated floodplain
eco-enviroment, and strict laws and regulations should be enacted to reduce all kinds of
floodplain pollutions.

3.5 Definition of rights and responsibilities of integrated management
Rights to protect and develop floodplains and responsibilities for flood losses between
agencies share in floodplain management are not clearly delineated nowadays in China.
Operational decisions from different management sections are not integrated, and sometimes
partnerships is not so friendly that related managing parties mainly consider interests of their
own segmentations especially when profits or responsibilities are concerned. It is necessary to
delineate clearly which agency should own rights and be responsible to different floodplain
management tasks. On the basis of scientific research and investigations, the authoritative
management agencies should make overall plans and take comprehensive factors into
consideration and implement comprehensive floodplain management measures to guarantee
beneficial functions of floodplains and their sustainable utilization.

To flood and floodplain, adaptative management strategies maybe better than alternative
management strategies and sometimes the best way to manage is to let flood and floodplain
be. Anyway, nature has its own law and humanbeing is not the arbiter of this world.

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