The Scientific Challenges of Yellow River Study

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The Yellow River is famous for its complex and unique physical conditions which give great challenges to the river management. Based on the study and analysis of the existing problems and research progress, this paper indicated that the most significant challenges of Yellow River studies are: long term hydrological and morphological changes; the optimized hydrology and sediment conditions to maintain the healthy life of the River; and simulation of Yellow River through mathematical model and physical models.

Key words  Yellow River, Research, Challenges

1 Introduction

The Yellow River, the second longest river in China, originated from the Qinghai-Tibet Plateau, runs through nine provinces in North China and empties itself into the Bohai sea. Its total length is 5,464 km and the drainage area is 795,000 km$^2$.

1.1 Physical conditions

1.1.1 Less water and high sediment load

The total annual runoff of the Yellow River is 53.4 billion m$^3$, only 1/17 of the Yangtze River. The total annual sediment runoff amounts to 1.6 billion, which is 3 times of the Yangtze River. The average sediment concentration is 33.6 kg/m$^3$ which is the highest in the world. While 60% of the surface runoff is originated from the upper reach of Lanzhou, about 90% of the sediment runoff comes from the middle reach Yellow River.

1.1.2 Unique river morphology

The lower YR channel is actually 4~6 m higher than the ground level, and it is also the divide between the Hai and Huai River Basin. The upper section of the lower Yellow River is much wider than the lower section which means the flood discharge capacity is getting decreased in the lower section and causes substantial flood risk. The river channel is subject to frequent changes because of sedimentation caused morphological changes. Moreover, there are many human interventions built up in the floodplain and some 1,810,000 people still live right in the area between the embankments.

1.2 Existing Problems

In the past 55 years, lots of efforts have been made and great progress has been achieved aiming to control the Yellow River, such as dyke safety guaranteed, economic development sustained by limited water resources, 300 million ton silts intercepted by water and soil conservation projects every year, etc. But it has been noticed that the efforts of 55 years haven’t changed the Yellow River in a long run, some even making it worse. i.e. Firstly, even less water runs into the lower reaches because of increasing water consumption, especially in the flood season. Secondly, sediment concentration has increased while the total sediment runoff has decreased, and sediment deposition also increased. Thirdly, the water quality is getting worse, and some river sections downstream of Lanzhou are even worse than category IV. Meanwhile, the population pressure is getting bigger which sharpens the contradiction between human and river.
for example, embankment construction and river mouth training projects have improved flood safety, however, the sedimentation deposition is also limited within dykes which blocks up the river channel.

These changes lead to a series of new problems:

1) Growing suspended river and shrinking river channel

The Yellow River has been a suspended river for thousands of years. Embankment construction made the suspended river even worse because sediment deposition was restricted in the embankments. Now, the suspended height is normally from 4 m to 10 m, which has increased 50% than the 1950’s. Meanwhile, the Inner Mongolia and Ningxia Yellow River also become suspended river with height of 1 to 2 m. The secondary suspended river firstly appeared in the 1970s, which means as the riverbed growing, a new suspended river formulated right on the river bed of previous suspended river, and the transverse slope could cause lateral flow and attack the dykes on the two sides. The secondary suspended river is stretching to the lower reaches, its suspended height is normally 1 to 2 m, and some place has more than 4 m difference. Such a growing suspended river is an increasing thread to dykes and flood protection.

The river trough is the main transport channel of water and sediments, and its discharging capacity is often expressed by bankfull flow. From 1986 to 1999, the average sediment runoff of lower Yellow River is 760 million ton, however, 70% of sediments has deposited in the riverbed and leads to a shrinking river channel. At present, the width of the river channel above Gaocun shrinks by 40 %, the cross section area decreases by 50 %, and the height of riverbed increases 1.06 ~ 1.87 m while the average is 1.73 m. The bank full flow has decreased to (1800 ~ 3000) m$^3$/s by 2001. The main river trough shrink not only increases the probability of traverse flow and diagonal flow, but also decreases the transporting capacity of water and sediments, and deteriorates the situation of suspended rivers and increases the probability of the flood risk, threatening people’s livelihoods in floodplains.

2) River drying-up

In the recent 20 years, the annual runoff of lower Yellow River is getting decreased because of the construction of large-scale water projects. The utilization rate of water is over 80% after 1990, and the excessive water use has caused frequent river deple-

3) Water pollution

While the runoff decreased, the runoff decreased by 50% at Huayuankou in the past 20 years) the waste water pouring into the Yellow River has increased from 2.2 billion ton in the 1980’s to 4.2 billion ton nowadays. The result of these two impacts is the quick worsening of water quality. The river sections with water quality worse than category IV make up 51 % of the total Yellow River length and the minus category V river sections keep increasing year by year. Such a situation could also intensify the water scarcity since the polluted water is of low value to use, and it certainly influences human being’s life and health and also damages the ecosystem.

4) Ecosystem degradation

Soil erosion is one of the most prominent challenges in the Yellow River basin. Despite water and soil conservation achievements in the past 50 years in the Loess Plateau, we still have a long way to go for a sound soil erosion management, because the traditional controlling measures are losing efficiency and new technology needs to be explored.

The estuary wetland is a state Natural Reserve area for its important value to protect the precious migration birds. Because of runoff reduction, the delta wetland is shrinking rapidly in these 20 years, and the birds’ habitat and bio-diversity is at high risk.

Because of the river runoff reduction, water quality degradation and over fishing, the estuary ecosystem was greatly affected. The shore water salt concentration is getting increased while the nutrition decreases by 50%, which have already affected planktons’ growth and propagation. The fishery productivity is drastically decreased by 95%, shrimp farming has been stopped, and some fresh water fish and brackish water fish tends to die out.

Yellow River sources area (above Tangnaihai) is also subject to environment deterioration, where
there were plenty of dense vegetations before 1970s. However, in the past 30 years, surface vegetations has decreased by 30% ~ 70%, with grass varieties degenerating, grass productivity decreasing and rat nuisance increasing. Besides, the other environmental problems include lake/wetlands degradation and glacier/frozen earth melting, etc., and the most prominent problem is the dramatic surface runoff reduction.

2 Yellow River fundamental research and scientific challenges

2.1 Achievements of fundamental research

Water and sediment dynamics is always the main theme of Yellow River fundamental research, which includes water and sediments production, sedimentation and river morphology, water circulation and eco-environment variation, etc. It is also the driving force for scientific development and technical innovation in Yellow River management. In the past 50 years, the major findings of water and sediment dynamics are presented in following aspects:

(1) found out the source, quantity and temporal/spatial distribution of sediments in the Yellow River basin, key elements of soil erosion, and relations between particle size and sediments deposition. These findings are very important to formulate the strategies such as sediments interception, soil erosion control, and reservoir operation, etc.

(2) found out the source, quantity and temporal/spatial distribution of water in the Yellow River basin, especially the conditions of Yellow River floods, including the source, features and hydrodynamics of the floods. The achievement is significant for the formulation of the flood prevention strategy, flood controlling projects layout and operation rules, which is also important for water resources allocation in the Yellow River basin.

(3) Conceptual understanding of water and sediments dynamics in the lower Yellow River, including transportation of different size of silts, floods dynamics of different scales and different sediment load, and main factors influencing sediment transportation. The achievement has provided a solid theoretical foundation for the formation and practice of the scheme of "alleviate sediment deposition through water and sediment regulation" and river training works.

(4) Studied the impacts of human activities and climate change on water and sediment conditions of the Yellow River, including impact mechanism, qualitative influence and developing trend. The achievement is of great significance to the improvement of the river basin management approaches.

(5) The studies of Sanmenxia and Xiaolangdi reservoir operation have improved the knowledge of sediment dynamics in the Yellow River through development of numeric models and physical models. And the more important thing was forming an advanced theory of reservoir operation on high sediment laden rivers.

2.2 Scientific challenges

The first challenge: How much water and sediment can be produced in the future?

There average parameters of the Yellow River is well known, such as the average annual rainfall is 452 mm, the average annual sediment runoff at Tongguan is 1.6 billion ton, and the flood carrying capacity at Huayuankou is 22,000 m³/s. However, the hydrologic monitoring in recent years indicates that, water and sediment produced in the Yellow River basin has changed significantly.

(1) The major water resource of the Yellow River comes from the upper reach above Lanzhou, which is often called the water tank of the Yellow River. The annual runoff at Tangnaihai station was 21.3 billion m³ in 1956—1989, but it has decreased by 22% since 1990s while the rainfall has only decreased by 5.35%.

(2) The rainfall in the middle reach tributaries, Wei river, Fen river, Yiluo river and Qin river, has just decreased by 11% ~ 15% in recent 5 years, but the runoff has decreased 40% ~ 70%.

(3) In Sanmenxia station, the annual runoff is 24.5 billion m³ and the annual sediment runoff is 0.72 billion ton since 1986, which has decreased 41% and 47% respectively comparing to 1950—1985.

(4) There has been 10 floods bigger than 10,000 m³/s recorded at Huayuankou station since 1949, among which 8 occurred in 1949—1958, and no such big flood happened again after 1983.

The Yellow River water and sediment condition is essential to study the river morphology and sediment deposition, hydraulic structure planning and water allocation scheme, as well as the formulation of Yellow River basin management strategy. In this
case, many Chinese scientists have done a lot of research in this field since 1990s. The research shows that the rainfall variation and human intervention (rehabilitation, sediment interception, dam projects, groundwater abstraction, water harvesting and pasturing, etc.) are the two major influential factors of water and sediment production in the Yellow River Basin. Since human activities have changed the underlying surface and affected surface runoff generation and flow concentration, the runoff production becomes much less than the 1950s—1960s even from the same scale of rainfall. However, the quantification of human impact to the runoff production and developing trend still need further study. Therefore, the major task of scientific research is as following: What’s the tendency of water/sediment production if the rainfall keeps the same? What is the climate change and rainfall variation in the Yellow River basin? What’s the water demand, water consumption and available water supply in the future in consideration of social economic development?

The second challenge: Suitable water and sediment condition to keep the healthy life of the Yellow River

Keeping healthy life of river is the world’s trend in river basin management, especially for the Yellow River. The most important and urgent task nowadays for Yellow River health is as following: Restore flood discharging capacity in the lower Yellow River and remove the Secondary Suspended River; prevent functional river depletion while human’s water demand sustained; Recover river esthetics and bio-diversity; and improve water quality to sustain the ecosystem. Therefore, water and sediment condition study is very much important to achieve these objectives, including suitable runoff, sediment load, water, water depth, flowing speed and water quality etc.

The current bankfull flow of lower Yellow River is just 3,000 m$^3$/s, while the transverse slope is 3 m difference in height from the secondary suspended river to the outer embankments, which is very dangerous for flood control. The researchers indicate that it will be very difficult to recover bankfull discharge to above 6,000 m$^3$/s and completely remove the traverse flow based on the analysis of water and sediment situation in the future. Thus, the following questions need to be clarified: What’s the suitable bank full discharge required by the healthy Yellow River? What’s the suitable traverse slope? What’s the suitable water and sediment conditions required for a healthy riverbed?

The Yellow River is subject to high intervention of human beings, the river ecosystem is seriously affected since 1950s. However, the increasing water scarcity make it very difficult to restore the natural environment completely. In this case, it is necessary to study the ecosystem and bio-diversity so as to identify the endangered species for protection, especially the relations between river flow and habitat environment based on the river ecosystem investigation and variations in the past 50 years.

Along with the booming economy, water pollution is becoming a major problem of Yellow River, especially for the river downstream of Lanzhou city. It will be a very ambitious plan to restore the surface water quality of Category III in the whole Yellow River. In order to realize this target, it is very important to reinforce waste water treatment and upgrade industrial and agricultural production, and it is also an important task to keep a minimal environmental friendly flow.

After the implementation of the Yellow River integrated water allocation from 1999, the river hasn’t been drying up again for four years. However the discharge at Lijin (river mouth) was just (30 ~ 60) m$^3$/s at average, and some people believe although the river wasn’t fully dried, this flow can’t sustain the functions such as ecosystem protection, self cleaning and sediment transportation, so it’s called functional river drying up. Thus, our task is to study what the minimal river flow is to keep functions of ecosystem protection, self-cleaning, sediment transportation and water circulation?

In general, the above mentioned research is still in the primary stage.

The third challenge: Simulation and modeling of water and sediment dynamics

The mathematical modeling is a very important tool to study the Yellow River water and sediment dynamics, morphological changes, and water and sediment regulation, and it is the core of the Digital Yellow River Project. In the past decades, some dozens of hydrodynamics models have been developed and tested for the Yellow River, however, most of these models still need further improvement before it can be used in the real work. Therefore, it will be very necessary to focus on the following subjects in
the near future.

(1) Two-Dimensional water and sediment dynamics modeling of the middle and lower Yellow River

To study the key factors of sanding capacity and river bed roughness, which is very important for the mathematical modeling; to study and simulate of floodplain inundation, morphological changes, transverse flow, river scouring; data processing, input and output; numerical methods, etc.

(2) Water and sediment dynamics modeling of the middle reach reservoirs

To build the model which is used to simulate and optimize the reservoir operation strategy and sediment flushing scheme

(3) Rainfall-runoff-soil erosion modeling of the middle reach Yellow River

To study the rainfall-runoff-soil erosion physics and modeling techniques at different zone and different rainstorm; medium scale rainfall forecasting based on radar and satellite images; distributed hydrology and floods forecasting;

(4) Water pollution early warning and forecasting system

To study the integration of hydrological and water quality models.

(5) Morphological dynamics in the Yellow River Delta

To study and simulate sediment transposition, deposition and ocean dynamics.

Besides, physical models are also important tools to study the Yellow River water and sediment dynamics, morphological changes, and water and sediment regulation. So far, we have built the scaled models of Sanmenxia reservoir, Xiaolangdi reservoir, and lower Yellow River channel from Xiaolangdi to Dongpinghu, and we are working on the Yellow River delta and coastal model, and lower Wei river model. The simulation results of the scaled model is very much dependent on its conformity to the real one, so there are many problems to be solved, such as experiment material, stability of hydrodynamics simulation, verification and calibration, delta and ocean dynamics simulations, etc.

The Yellow River has very complicated physical conditions and very unique river morphology, which are the great challenges to river basin management and development, and there is still a long way to go for the Yellow River scientific research. The Yellow River is the mother river of the Chinese nationality, so we sincerely appreciate the concern and support of scientists from home and abroad, and we are looking forward to join our efforts and knowledge to push forward the scientific research of the Yellow River.