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Environmental Impacts of the Yangtze Three Gorges Project: An Overview of the Chinese-German Research Cooperation

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ABSTRACT: The construction of the Three Gorges Dam on the Yangtze River in China has a great influence on the ecosystems involved. In order to investigate these environmental effects in the Yangtze catchment area as well as downstream of the dam, Forschungszentrum Jülich has organized a research network for the Chinese and German partners. In the research fields of (1) interaction water/sediment/contaminants, (2) vegetation/biodiversity, (3) changing land use/erosion/mass movements, and (4) atmosphere, the partners have accumulated a great deal of expertise in handling major issues and also in developing models and recommendations for action. The following provides an overview of the research network and the research tasks. On the German side, five projects in research field (3) have been in operation since 2008. The results are reported in contributions by Ehret et al., Jaehnig and Cai, Schönbrodt et al., and Seeber et al.. Another five projects in research field (1) have started by September 2010. The research tasks undertaken in these five projects are presented below.
KEY WORDS: Three Gorges Dam, Yangtze River, environmental research, ecosystem.

INTRODUCTION

This article gives an overview of current research activities in the Chinese-German collaboration known as the Yangtze Project. In the Yangtze Project, Chinese and German scientists collaborate closely in investigating environmental impacts following the construction of the Three Gorges Dam. In the four research fields, namely, (1) interaction water/sediment/contaminant, (2) vegetation/biodiversity, (3) changing land use/erosion/mass movements, and (4) atmosphere, they work on proposals for the sustainable management of the Yangtze River and its reservoir.

This overview provides an introduction to the project network and research activities. Detailed information, especially on the recent results of working groups in research field (3), can be found in the respective articles by Ehret et al. (2010), Jaehnig and Cai (2010), Schönbrodt et al. (2010), and Seeber et al. (2010).

BACKGROUND

No other river governs the lives of so many people as the mighty Yangtze, whose course divides the People's Republic of China into two almost equal halves from north to south. Even the catchment area of the Nile is home to only 280 million people, in comparison to the 400 million people who live in the Yangtze basin. For thousands of years, the river has influenced the economy, communications, and agriculture in China, as well as its culture. The Yangtze River was indeed always both a curse and a blessing

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for the country. In the same way as the Nile, its sediment-rich waters helped increase the fertility of the adjacent agricultural regions by regular flooding. However, in the 20th century, the flooding also caused the death of some 320 000 individuals (Jackson and Sleigh, 1998).

The first concrete plans to dam the Yangtze River in the Three Gorges area, situated on the middle reach of the river, date back to the beginning of the 20th century (Ponseti and López-Pujol, 2006; China Three Gorges Corporation, 2002). In the year 1993, the decision was made to build the dam. When the building project was finished in 2009, the final water level in the reservoir region was nearly reached.

The Chinese government is pursuing four major objectives with the reservoir project (State Environmental Protection Administration, 2006): (1) Preventing flooding. The catastrophic floods on the Yangtze River are to be prevented by a reservoir system whose keystone is the Three Gorges Reservoir (Yangtze Valley Water Resources Protection Bureau, 1999). (2) Ensuring water supply. The Yangtze River provides (drinking) water for the majority of people living in its catchment area. At the same time, a system of pipes (South-North Water Transfer Project) transports water to the dry northern area and thus enables new agricultural areas to be exploited (Berkoff, 2003). (3) Securing navigation. The aim of the Chinese policy to develop the western part of the country is linked to better navigation of the Yangtze River and an expansion of Chongqing harbor. As a consequence, ocean-going ships of 10 000 GRT are able to reach Chongqing (Yangtze Valley Water Resources Protection Bureau, 1999). (4) Generating electric energy. The International Energy Agency (IEA) calculates an increase in the demand for electric energy from 2000 to 2030 of about 260% in China (Waltenberger, 2008). The major proportion of this demand will continue to be satisfied by fossil fuels (Harmeling, 2007). In order to satisfy the rising demand for energy by the booming Chinese economy, additional numerous hydropower plants will be installed on the Yangtze and its tributaries. The Three Gorges Dam is by far the biggest of these. Its installed capacity roughly equals that of 15 nuclear power stations (Worsley School Online).

PARTNERSHIP

At the request of Chinese research institutions, and in particular also motivated by its own interests, Forschungszentrum Jülich GmbH has organized a research network in order to perform scientific work under these unique research conditions on the Yangtze River.

About 30 Chinese and German partners have joined together in the Yangtze Project. The German side is represented by universities, Helmholtz Centres and private companies, according to their special expertise. On the Chinese side, leading universities, CAS institutions and government establishments are participating in the project under the overall control of the Three Gorges Project Construction Committee, representing the State Council, which acts as the coordinator for the Chinese side.

On the basis of its interdisciplinary composition, the Chinese-German Yangtze Project provides considerable expertise for dealing with major issues and also for developing models and recommendations for action. The involvement of universities, nonuniversity research institutions, industry, and public authorities means that all the necessary competences can complement each other. Also, the gain in knowledge can be transferred to similar problem areas.

The central element of the partnership is the current bilateral cooperation between Germany and China, which is based on a strategy that is closely coordinated and which is under continuous further development. To this end, Forschungszentrum Jülich GmbH has already signed extensive agreements with Tongji University, Shanghai, and the ministry responsible for the Three Gorges Project.

All efforts by the partners have the objective of long-term cooperation, which is necessary due to the complexity of the issues to be dealt with.

RESEARCH FIELDS

Interaction Water/Sediment/Contaminants

The pollution of the Yangtze River with a wide range of problem substances is often underestimated since in many cases, attention is only paid to the low measured concentrations. However, the large volumes of water (annual water discharge rates of the upper Yangtze River at Yichang are between 5 000 m^3/s in

January and 40 000 m^3/s in the rainy summer months) lead to appreciable loads, and thus, the danger that an accumulation of pollutants may even reach the human food chain (Zhang et al., 2005; Martens et al., 2000). Moreover, the Yangtze River represents the major, and in some cases indeed the only, source of drinking and domestic water for the population.

Since, due to the damming of the Yangtze River, the residence time and the water depth in the reservoir have both considerably increased, great significance is attached to identifying and monitoring the conversion of substances within the water body and in the sediment. The nature of the transformation changes both quantitatively and also qualitatively depending on the varying conditions (oxygen, temperature, light, and redox potential). The sediment load of the river and the completely different dynamics of the sedimentation and suspension lead to waves of sediment and pollutants resulting in a complex system of new chemical conversions. This causes changes in bioaccumulation, biotransformation, and bioavailability.

It also must be assumed that there continues to be considerable pollution of the water in the reservoir (State Environmental Protection Administration, 2004) by direct inputs of municipal effluents, industrial waste water treatment plants, diffuse inputs of substances from areas used for agriculture, inundation areas, existing installations that have not been properly refurbished and also waste deposits, and navigation.

To keep the long-term impacts and the side effects under control as far as possible, the challenges of long-term security of the drinking water supply and sustainable development of the waters (fishery, biodiversity, and tourism) are being tackled under difficult and continually changing conditions according to the state of the art. These priority tasks are listed as follows: (1) determination of the transport behavior of problem substances and the dynamics of the turbid matter up to and including the sediment; (2) examination of key biological and chemical processes on the river banks, in the water column and sediment; and (3) modeling of conversion and transport processes and also the development of monitoring concepts.

Research tasks

Physico-chemical aspects and transport of particulate matter Many dams function as large sediment traps (Higgit and Lu, 2001). As a consequence, a considerable change in the ratio of dissolved-to-particulate substances due to sedimentation and suspension within and below the reservoir is to be expected with the Three Gorges Reservoir. The particulate substances, which adsorb some of the pollutants and withdraw them from the water column into the sediment, are reduced by retention and settling in the reservoir. At the same time, this increases the fraction of dissolved organic compounds, which makes the pollutants complex and thus transport them over long distances. Pollutants are also remobilized from the sediments during the degradation of particulate compounds, especially from the riparian zones that are only intermittently inundated.

The mass transfer of important components, such as nutrients, heavy metals, and xenobiotics, in heterogeneous bodies of water can also result from their binding to colloids, which have a large sorption capacity for substances contained in water.

Shift from oxic to anoxic conditions In the course of fluctuations of the water level, polluted sites may be subjected to both oxic and anoxic conditions. An essential question is therefore determining when anaerobic microorganisms have been established in previous oxic sediments and thus become able to initiate further anaerobic degradation.

Modeling Modeling is necessary in order to be able to understand and assess the interaction of the individual processes as well as the dynamics of sediment and pollutant transport (Jacoub, 2004). The use of models makes it possible to draw up balances for sediments and pollutants and to make estimates of variables, such as deposition, mobilization, movement, and discharge. Furthermore, the application of hydrodynamic transport models (water and suspended matter transport) is an essential requirement for predicting the water quality. For sediment transport, the description of the processes mainly concentrates on the chemical interactions of suspended sediments with the pollutants. Attention is also focused on another ele-

ment in a model description of the water quality, namely, the conversion of nutrients as well as the build-up and degradation of phytoplankton.

Water use A large number of new aspects and challenges arise with respect to drinking water recovery along the Yangtze River, both in the region of the reservoir and also below the new dam up to the point where the river finally flows into the East China Sea. This concerns the influence of the change in the flow rate of the Yangtze River on the groundwater level and also the resulting water purification requirements. Consideration must also be given to the treatment of waters with high concentrations of turbid matter (suspended matter, colloids). A factor of major significance for designing drinking water recovery plants is also the impact of the shift in the fresh water/salt water interface in the lower reach of the Yangtze River.

The nutrient input into the East China Sea via the Yangtze River is modified by construction of the dam. For example, due to an increasing stratification in the reservoir region, the proportion of nitrogen elimination processes (denitrification) increases with anoxic water bodies close to the bottom, thus having a positive effect for the coastal waters. On the other hand, the fraction of silicates in the water may be reduced due to the sedimentation of the suspended matter leading to a shift in the plankton species (decrease of diatoms in comparison to green algae and cyanobacteria, some of which are poisonous) with far-reaching negative consequences for the use of the coastal waters for aquaculture and fishery.

Vegetation and Biodiversity

The water level in the reservoir reveals the dramatic change in contrast to the natural inundation regime. In the past, the flood events on the banks of the Yangtze River and its tributaries occurred in the summer months. The plants in the water fluctuation zone (WFZ. riparian zone) were previously inundated during the warmer time of year (28 ℃ July/August) and the terrestrial phase of the WFZ was characterized by cool temperatures (3–5 ℃ January) that permitted only little plant activity.

Nowadays, within the impounded section of the river, water level fluctuations of up to 30 m result in the course of the seasons. The highest water levels occur in winter upstream of the Three Gorges Dam and also in the tributaries. The plants in the WFZ experience considerably improved climatic conditions with higher temperatures during their physiologically active season in the summer months. This reversal of the flood pulse in the course of the year exerts an enormous influence on the fauna and flora and the associated processes.

Other parameters resulting from the management of the reservoir are the sediment deposits and their varying extents in the different zones of the WFZ. The locally different thicknesses of the sediment body will be decisive for the emergence of plant shoots through the sediment. In areas of high flow rates, in contrast, habitats will be established that are strongly characterized by the dynamics of the pebbles and boulders.

The Three Gorges Project will thus bring about a significant change in habitat conditions for vegetation in the WFZ; the consequences of which cannot yet be predicted with any certainty. This also concerns the potential and long-term impacts of changed vegetation on the local population, who exploit the plant resources, and on the hydro regime and the sedimentation in the reservoir. Sustainable plant cover along the various regions of the WFZ must, on one hand, have mechanisms, enabling it to survive submersion lasting in some cases several months, and on the other hand, the vegetation must also be capable of tolerating other extreme environmental conditions.

Different vegetation types develop depending on the time and intensity of the so-called “flood pulse” (Junk et al., 1989). Not only are the conditions during inundation of central significance for the consequences of submergence but also the conditions for the plants during the phase in which the vegetation in the WFZ is not submerged (White and Jentsch, 2001). The vegetation in the WFZ is of major significance for the water quality, the binding and degradation of pollutants, the reduction of erosion, and the agricultural land use in the region.

The vegetation of the region was not affected by glacial superimposition and is therefore characterized by a high level of biodiversity. According to the latest census, commissioned by the municipal government of Chongqing, 14% of the endangered Chinese plant

species are found in the region and 36 of them are endemic. The region is also the area of origin of a number of cultivated species that are now found throughout the world (e.g., Kiwis) and is the area of distribution for numerous crop plants (Chinese medicinal plants, plants for raw materials). The biodiversity of the region is therefore an important resource (Chen et al., 1994) that must be protected.

Research tasks

Water quality The envisaged research activities focus on the vegetation of the riparian regions and the sedimentation areas directly affected by construction of the dam. The contamination of the water and sediment with organic and inorganic pollutants is an important constraint for the establishment of vegetation in the WFZ. At the same time, the fluxes in the sediment body caused by plants (transport of oxygen and organic carbon into the sediment body) make a decisive contribution to the self-purifying capacity of the sediment by promoting microbial activity in the root zone. However, plants also transport gases from the subsoil into the atmosphere and themselves represent degradation paths and storage capacities for pollutants. In particular, in view of the expected use of the vegetation by local people, the question also arises of the role of vegetation in the WFZ with respect to the input of pollutants into the aquatic and terrestrial food chains.

Plants under stress conditions Stabilizing the intensity of erosion and sedimentation behavior can be profoundly influenced by plants in the WFZ. In particular, long-lived shrubs, trees, and also belts of reed are of special significance here. The adaptation of plants to conditions in the WFZ is strongly characterized by the storage organs available to these plants during the inundation phase and whether they can efficiently fill these organs during the vegetation phase. In heavily sedimented regions, rapid planting with annual species will prevent the formation and drifting of dust from the sediments.

Ecosystem functions The vegetation in the WFZ will be significantly influenced by differences in the disturbance regime. The emergent vegetation forms will supplant previous formations unable to adapt adequately to the new regime. Active measures for managing the WFZ will increase the stability of the ecosystem functions and assist in more rapidly establishing sustainable dynamics in the WFZ.

Changing Land Use/Erosion/Mass Movements

Landslides and rock falls are the major geological events in the Three Gorges region. The mud and debris avalanches formed during such landslides represent a danger both for areas of settlement and also for land used industrially and agriculturally, as well as for infrastructure facilities, and can also considerably obstruct navigation. Furthermore, the analogous mass movements are one of the reasons for the silting up of the Yangtze River and many of its tributaries.

More than 2 000 large-scale landslides have been discovered so far along the banks of the reservoir. Since 1982, more than 70 landslides, cave-ins, and mud flows have occurred, also representing a direct danger for the population. For example, in June 1985, a landslide of about 30 million m^3 was experienced near the town of Xintan (Hubei Province), of which about 2.6 million m^3 ended up in the river. Even if this landslide has now been stabilized, it is nevertheless to be feared that rises in the water level of the newly created reservoir and the tributaries of the Yangtze River could cause a renewed mass movement. If more elevated hillside slopes, which have previously remained dry, are now flooded and in view of the regular changes in water level of the new riparian zone, it can be expected that further mass movements will be triggered.

In addition to natural causes, anthropogenic impacts must also be taken into consideration as the initiating factors for these events. This may, for example, concern the use of erosion-sensitive areas for agriculture or development and building measures for residential housing and transport infrastructure. Furthermore, the mass of the water body changes continually during the periodic impounding and discharge of the water, and thus, pressure conditions in the reservoir also change, leading to a build-up of stresses, which may then be relieved via cracks, landslides, local earthquakes, etc..

The impoundage is also associated with the reset-

tlement of millions of people, and the expenditure for regional planning is correspondingly high. Land development measures, such as the construction of roads and the use of areas endangered by erosion for agriculture, increase the hazard potential. As a whole, it must therefore be feared that instability along the riparian zones of the Yangtze River and its tributaries will tend to increase as the level of the impounded water is now raised to 175 m.

Research tasks

Risk assessment and evaluation of changed land use In close cooperation with their Chinese partners, five German research groups as mentioned above are investigating the risk assessment of changing land use, mass movements, soil erosion, and the input of material and agricultural chemicals into the rivers in the Xiangxi catchment area as an example. The Xiangxi River flows from the north into the Yangtze River. It enters the reservoir about 37 km upstream of the Three Gorges Dam. This subcatchment area of the Yangtze River is particularly affected by the loss of area due to the impoundage, thus making it a very suitable test field. Due to the lower fertility of the land remaining after construction of the dam, more extensive areas of this region with steeper slopes is now being used for agriculture. Consequently, an increase in the area affected by erosion phenomena is expected.

Therefore, the scientific and technical prerequisites are being created by the research groups for a monitoring and hazard forecast plan. The research results will make a major contribution to assessing the dangers and thus provide indications of the possible usefulness of the riparian regions of the Yangtze during and after the period of impounding the river.

Diffuse input of pollutants In the analysis of the significance of diffuse sediment and phosphorus inputs in the Three Gorges Area, an eco-hydrological model is used to assess the impact of large-scale land use change on water quantity and quality (Arnold et al., 1998).

Neuronal networks and remote sensing techniques

For the timely recognition of landslides, approaches based on a geographic information system (GIS) are combined with methods based on neuronal networks. In combination with innovative remote sensing methods, it will thus be possible to further develop the methodology for the investigation and monitoring of such extensive areas that can otherwise only be explored on the ground with an unacceptably great effort. In this way, hot spots with especially active and dangerous mass movements can be recognized and identified for monitoring.

The results of all the studies will be used in a risk analysis for the geohazards of erosion and landslides in the whole area under consideration. This analysis will provide indications for the usefulness or endangerment of the area of settlement in the region of the impounded bank and thus represent a starting point for regional planning, giving due attention to the abovementioned natural dangers.

STATUS AND FUTURE ACTIVITIES

Due to the very nature of the project, the overarching goals are oriented to the objectives formulated in the framework program of the German Federal Ministry of Education and Research (BMBF) “Research for Sustainability”. Starting with one partner organization in Germany and six universities in China, today, about 15 institutions from each side have submitted project applications. The project applications from the German side have received assurance of funding for three years from the German Federal Ministry of Education and Research. The BMBF also supports the exchange of scientists and PhD students on short-term (International Bureau) and long-term contracts (German Exchange Service, DAAD). Similar support is provided by Chinese ministries (MOE, MOST) and the China Scholarship Council. In addition, Forschungszentrum Jülich GmbH promotes the scientific training of Chinese PhD students by scholarships from its own basic funding.

The principal goal in the short term is an improved understanding of local conditions, the creation of a reliable data basis and harmonizing the scientific methods of all partners involved. The high standards of German environmental research are to be transferred in order to ensure compliance with international standards. The education and training measures mentioned above will contribute to this process.

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