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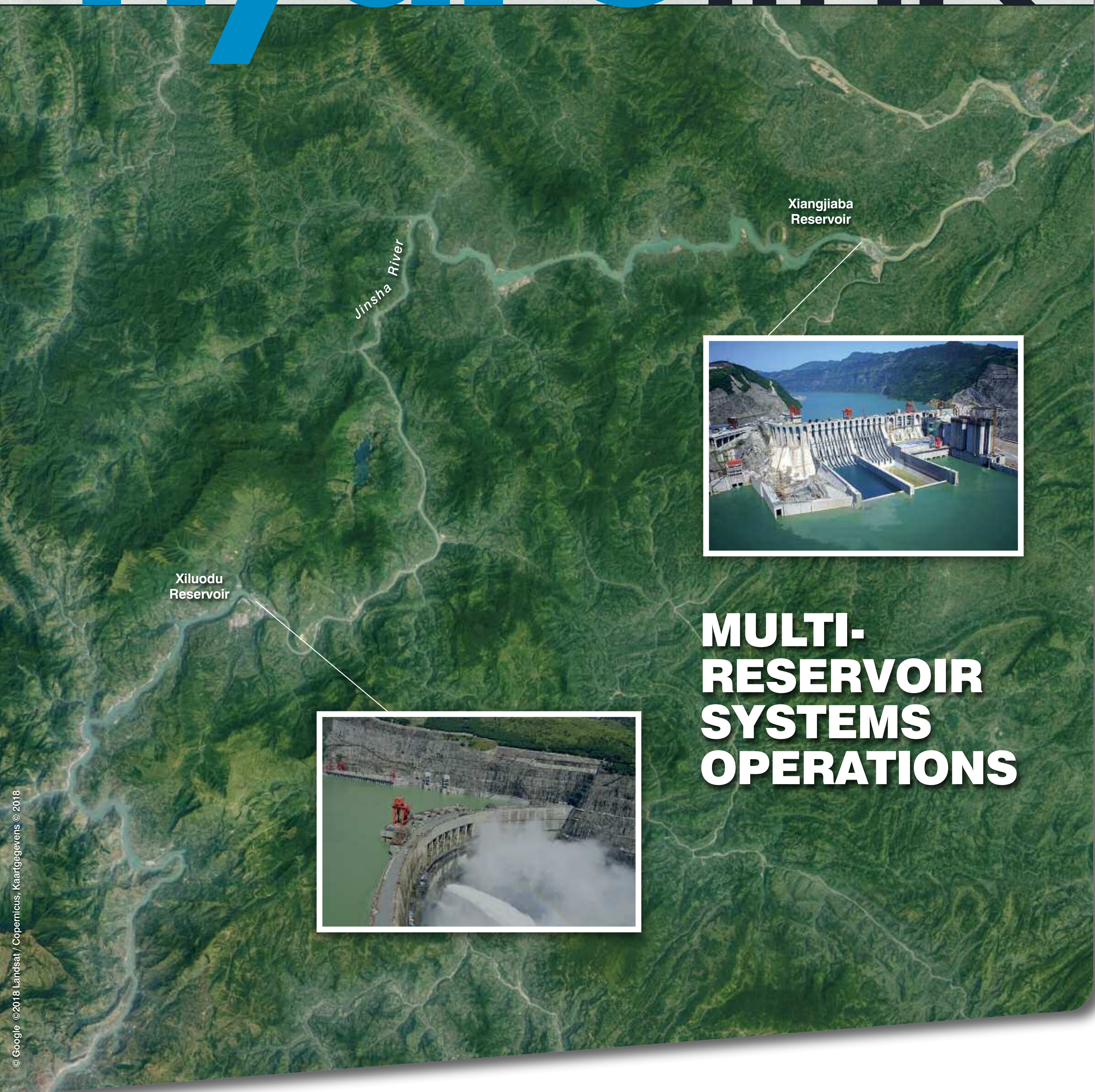

MULTI-RESERVOIR SYSTEMS OPERATIONS

A TOOL OF WATER RESOURCES MANAGEMENT IN CHINA SEE PAGE 102

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OPERATIONAL MANAGEMENT OF MULTI-RESERVOIR SYSTEMS

EDITORIAL BY ANGELOS N. FINDIKAKIS & MINGNA WANG

The management of multi reservoir systems has become progressively more complex over the years. The challenge faced by the operators of such systems is finding the right balance between their benefits and their potential negative impacts as they are often trying to satisfy multiple competing water use requirements, while taking into account water rights and a broad range of environmental, socio-economic and other factors.

Angelos N. Findikakis
Hydrolink Editor

Mingna Wang
Guest Editor

In many river basins, especially in Europe, the United States and Australia, the most suitable reservoir sites have already been developed. The questionable economic feasibility and environmental concerns about dam construction at any remaining sites limit the potential for adding new storage capacity in these areas. This has created the need to optimize the operation and maximize the efficiency of the existing reservoirs systems. At the same time, there is significant dam construction activity in Asia and to a lesser extent in Africa. There planners and managers are trying to use lessons learned from past projects and make adjustments to address any problems that arise when new projects start operating.

The present issue of Hydrolink includes eight articles addressing different recent issues in multi-reservoir systems. The majority of these articles relate to projects in China, which provide some interesting insights into the evolving approach to water and environmental management in this country, which is now leading the world in the number of new dams under construction.

An interesting insight in the current water policy in China is given in the article by Zongzhi Wang, Liang Cheng, Kelin Liu and Xia Hu which describes the development of a computer tool designed to support its implementation. This policy is defined in terms of "Three Red Lines", resource development, water use efficiency and pollution control. The tool presented in this article is a combination of a regional macroeconomic model and models estimating supply and demand, pollution discharges and compliance to water quality standards under different scenarios. These models work together to help assess whether specific control targets, such as total water consumption, added value to the industry by water use, and water use efficiency in agriculture are met in each area.

An overview of an approach to the operational management of multi-reservoir systems, which sometimes involve inter-basin water transfers, such as the South to North water transfer project in China is presented in the article by Xiaohui Lei, Xu Wang, and Mingna Wang. The article describes the integrated technical framework for long-term, short-term and real-time operations in both the donor and the receiving basin, supported by a combination of models at different spatial and time scales. The application of this approach as part of a decision support system was illustrated in the multi-reservoir system of the Middle Route of the South-to-North Water Transfer Project.

Optimizing the real time operation of multi-reservoir systems is the subject of two more articles in this issue. Henrik Madsen and Anne Katrine Falk present a new approach for real-time optimization of multi-reservoir systems using a combination of high-fidelity hydrological-hydrodynamic simulation models and simpler surrogate control models, which reduces the computational requirements for running the models making it possible to use them in real time. The new approach is demonstrated in the Murrumbidgee River system in New South Wales, Australia.

Soon-thiam Khu, Xu Wang, and Qiaofeng Tan, using the water-supply system of the Li River in China's Guangxi Province, show how the use of hedging rules for the operation of a multi-purpose, multi-reservoir system produces superior results to those obtained with conventional operation rules, by minimizing maximum deficits and maximizing the reliability of both water supply and hydropower generation.

A special challenge in many river basins is flood control, especially in view of changing conditions due to development. The article by Zhipeng Ma, Sen Wang, Donghui Wan, Kang Zhang & Huazhi Zou discusses this problem in the Pearl River basin, the second largest in China. The analysis of a large number of flood events from different stages of reservoir development in the basin using a model accounting for both the flow in the river channel and the overflow in the floodplain helped develop new insights into the response of the system to different types of flood events and improve its management. This led to the development of a flood control operation model optimizing the use of the limited flood control storage and increasing hydropower generation.

Indicative of the increasing attention paid to environmental concerns arising from the reservoir development in China are three articles published in this issue. The first of these articles by Jijian Lian, Chao Ma and Ye Yao discusses the development of operation rules for the Three Gorges Project designed to modify the hydrodynamic circulation in the reservoir reducing this way the occurrence of algal blooms and improving water quality in the reservoir arms in several tributaries of the main river.

The article by Jin Chen, Jijun Xu and Zheng-Jie Yin discusses the effect of two hydropower reservoirs on the Jinsha River on the spawning and breeding of different species of fish species and the development of a model designed to optimise the operation the reservoirs taking into account the ecological and hydrological water demand for the fish, including the high flow pulses required for spawning and breeding.

The article by Zhifeng Yang, Yujun Yi, Xuan Wang and Xinan Yin presents an overview of the major problems in shallow macrophytic lakes caused by changes in the natural hydrologic regime as the result of the construction and operation of reservoirs and other human activities upstream. The article discusses the use of a two-dimensional hydrodynamic and water quality model to determine the quantity and rate of water that must be provided to such lakes in order maintain their ecological health. This approach is demonstrated in Baiyang Lake, the largest freshwater lake in northern China.

Even though all but one of the articles published in this issue are based on work for multi-reservoir systems in China, the lessons learned from this work can be useful to similar systems in other parts of the world. To advance further the sharing of knowledge on this subject between academic researchers and practitioners the recently established IAHR Working Group on Water Systems Operations is sponsoring the First International Symposium on Cascade Reservoirs and Water Systems Operations to be held in Beijing on October 19-23, 2018.

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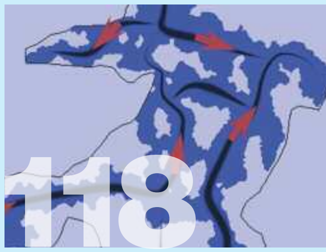

OPERATIONAL TECHNOLOGIES AND PRACTICES OF WATER RESOURCES SYSTEMS

BY XIAOHUI LEI, XU WANG & MINGNA WANG

The operation of water resources systems is characterized by multi-objectives, multi-levels and high uncertainties, and thus these systems should be considered as a whole from multiple perspectives and levels. The basic principles and theories of hydrology, hydraulics, economics, operations research and mathematics, as well as new theories and techniques such as cybernetics and heuristic algorithms, need to be taken into account in the simulation and optimization of hydrological, water supply, water use and consumption and water drainage processes. Here, we proposed a technical framework for the operation of water resources systems, which was then illustrated using the Middle Route of the South-to-North Water Transfer Project.

What is a water resources system?

A water resources system can be considered as a unit consisting of various water bodies such as rivers, lakes, reservoirs and groundwater in a given region that are connected hydrologically and hydraulically and can be potentially exploited for the benefit of mankind, as well as of related engineering projects for different purposes. It is evident that the individual water bodies in a water resources system are highly interdependent and mutually influential, thus forming a unit with an integrated function and a unique hierarchical structure.

The middle route of the South-to-North Water Transfer Project (STNWTP) in China is mainly composed of four sectors: the water source project, the compensation project in the middle and lower reaches of the Hanjiang River, the water conveyance project in the middle route and the matching project in the water receiving area. It consists of 27 reservoirs, 88 separate gates and 165 water units. Water in the middle route of the STNWTP is extracted from the Danjiangkou reservoir located in the Hanjiang River of Yangtze River tributary, then through Henan and Hebei Provinces, and finally arrived into Tianjin and Beijing. It consequently provides industrial and domestic water for the towns and also meets agricultural and ecological water demand in some areas.

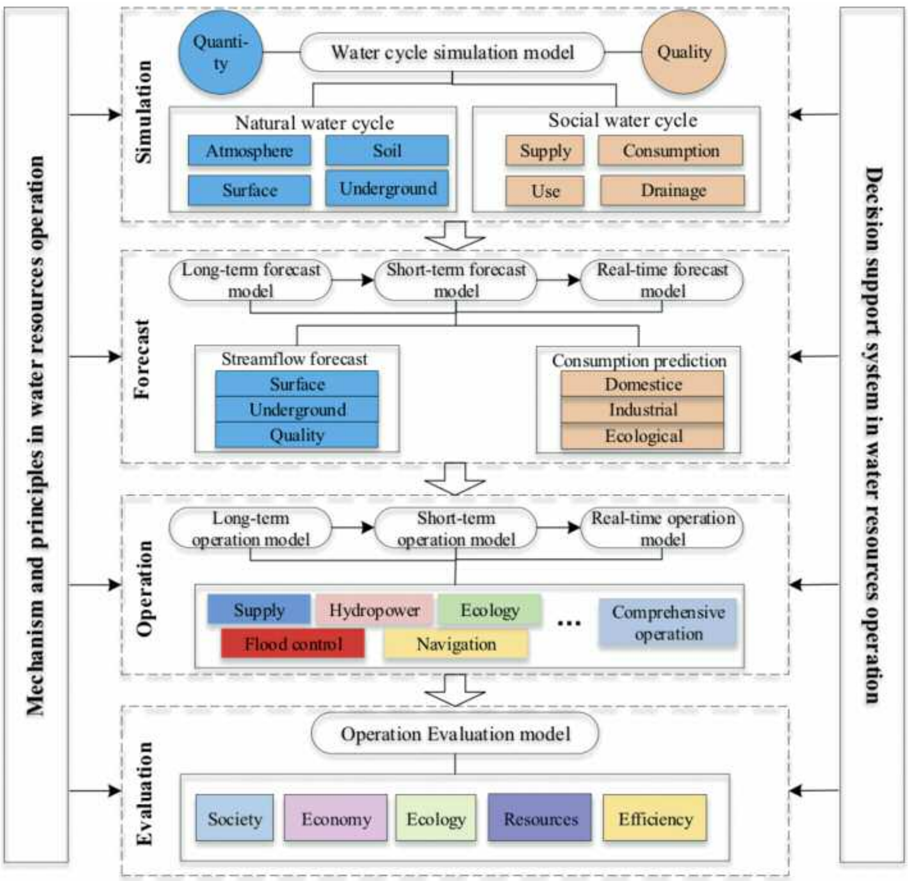

Figure 1. An integrated technical framework for water resources operation

Basic concepts in water resources operations

Water resources operations should abide by the principles of fairness, high efficiency and sustainable development One of its primary objectives is to balance the interests of different regions and parties (e.g., flood control, water supply, irrigation, electricity generation, ecological environment, navigation and tourism) on the premise of ensuring flood control safety. Consideration should also be given to historical and current domestic, industrial and ecological water uses and demands. Accordingly, there is a need for unified management of water resources in the basin or region according to the current availability of water resources and the forecast of future water inflows and demands. Efforts should be made to obtain an optimal spatiotemporal allocation of water resources by engineering projects and by the implementation of other measures, so that the water demand of various uses in the basin and region can be better satisfied. An important consideration in water resources operations is the competitive, sometimes even conflicting, water demands from different sectors (e.g., flood control, water supply, irrigation, electricity generation, ecological environment, shipping and tourism), making water resources operations a complex multi-objective group decision-making problem. However, the major objective of water resources operations is largely determined by the actual demands in the basin and region. From a spatial perspective, water resources operations can involve a single water storage project or multiple projects in the region, or the whole basin and inter-basin transfers; from a temporal perspective, water resources operations can be long term, short term or real time; From the perspective of operational targets, water resources operations can involve a single water source, or the combination of several or all water sources in the basin and region; From the application perspective, water resources operations can be applied to water transfer projects, urban water supply and drainage systems, rural irrigation and water supply and drainage systems, etc.; From the perspective of operational measures, water resources operations are made possible by the use of engineering projects and other measures, such as the control of total water intake, water quota, water quality, water conservation, and water pricing.

Figure 2. A schematic of the middle route of the STNWTP

An integrated technical framework for water resources operations

As China was working on the middle route of the South-to-North Water Transfer Project (STNWTP), we proposed an integrated technical framework for water resources operations in the basin, which consisted of four closely interrelated hierarchical levels, including simulation, forecast, operation and evaluation. The simulation of water cycles in the basin can have a direct effect on subsequent forecast, operation and evaluation, and thus it is the basis for the proposed hierarchical technical framework for water resources operations. The forecast model should have the capacity of long-, medium- and short-term forecast, real-time updating and self-correction, so that the parameters or structures required in forecast models can be appropriately adjusted and the existing runoff forecast can be corrected promptly. The operation model plays a key role in the adaptive operation of water resources systems, which includes the determination of operational criteria and objectives, development of models of different time scales, solution methods, and conversion of models of different time scales. It is closely related to the actual problems in the utilization of water resources and their management. The purpose of evaluation is to qualitatively and quantitatively evaluate possible impacts and the efficacy of different operational strategies, which can contribute significantly to preventing the ineffectiveness and irrationality of water resources operations resulting from subjective preferences and incomplete information.

The application of the proposed water resources operations approach to the middle route of the STNWTP

At the technical level, we investigated some key techniques involved in the operation of the middle route of the STNWTP, such as the simulation of distributed nature-social water cycle system, forecast of medium and long term runoff, inter-basin water resources operation, reservoir operation, multi-objective optimization, evaluation of water resources operation, decision support system for inter-basin water resources operation. At the application level, we developed various dynamic water resources operation models for the simulation and optimization of the middle route of the STNWTP, including the simulation of distributed nature-social water cycle system, water resources operation models for water source regions, water receiving regions and the main routine, the combined water resources operation models, and decision support system for water resources operation. We also integrated inter-basin simulation for nature-social water cycle system, forecast, operation and evaluation using system integration techniques, and developed a decision-making support system for water resources operations in both water source and water receiving regions, which can assist annual, monthly, ten-day and weekly water resources operations and provide technical support and a management tool for operation negotiation to maximize the profits of the middle route of the STNWTP. ■

Xiaohui Lei, **professor of the China Institute of Water Resources and Hydropower Research (IWHR), chairman of the IAHR cascade reservoirs and water system operation Working Group-member of the Executive Committee of the 5th International Association for Hydro-Environmental Engineering and Research in China, vice secretary general of the Water Division Committee of the Chinese Hydraulic Engineering Society. He has been engaged in the forecast and operation of complex water resources systems, and has published over 50 Science Citation Index (SCI) papers, 34 Engineering Index (EI)papers and 16 treatises. Now, he holds 32 patents and more than 20 software copyrights. He hosts over 50 national research projects and has been awarded the first prize of the national science and technology progress for one time, first prize at ministerial and provincial-level for six times and second prize for two times.**

Xu Wang, **a senior engineer of the China Institute of Water Resources and Hydropower Research (IWHR), has been engaged in joint operation of cascade reservoirs, optimization and utilization of basin water resources, and high efficiency solution algorithms. He has published 23 peer-reviewed papers, including 6 SCI papers and10 EI papers, and 2 treatises. He holds 2 patents and 10 software copyrights. He has been awarded for three times, including two second prizes at the ministerial and provincial-level.**

Mingna Wang, **senior engineer in China Institute of Water Resources and Hydropower Research (IWHR), member of the IAHR cascade reservoirs and water system operation Working Group. Her major includes cascade reservoirs operations, urban water systems design and simulation, and integrated management of water quality and quantity.**

MSWRMS-LAB: A TOOL OF WATER RESOURCES MANAGEMENT IN CHINA

BY ZONGZHI WANG, LIANG CHENG, KELIN LIU & XIA HU

The Chinese government came up with the Most Stringent Water Resources Management System (MSWRMS) in 2011 in order to realize sustainable water resources utilization and support sustainable social and economy development. The core of the system is the 'Three Red Lines' which set control targets on four key management indicators, including total water use, industrial water use per ten thousand Chinese Yuan, irrigation efficiency and the percentage of water functional zones complying with the water quality standards up to 2015, 2020, and 2030, designed to set limits on water use, water use efficiency and water pollution.

MSWRMS is a new approach in Chinese water resources management. Issues including the dynamic change and interannual variability of management indicators with socioeconomic development and water resource, the feedback between indicators, setting dynamic annual management target, changing water use behavior and adjusting industrial structure to fulfil control target must be addressed in the MSWRMS implementation. The Most Stringent Water Resources Management System Lab (for short MSWRMS-Lab) is an effective tool that supports addressing the above issues.

Principle and function of MSWRMS-Lab

The MSWRMS-Lab tool consists of four models, including a regional macroeconomic model, a water demand and pollutant emission projection model, a water supply and demand balancing model at basin scale, and a model estimating the percentage of water functional zones complying with the water quality standard, as shown in Figure 1. The macroeconomic model is mainly used to simulate and predict the economic and social development index including industrial added value, urbanization rate, population, income of urban and rural residents under different fixed asset investment scenarios. Water demand for each region and pollutant discharges into each water functional zone is projected by the water demand and pollutant emission projection model using the forecasted economic and social development index. The total water use of each region is determined by balancing water supply and demand and water allocation between different users. The pollutants discharged into a water functional zone include pollutants transmitted from upstream zones which are in excess of its assimilative capacity and pollutants discharged within its own corresponding water demand region. When pollutants are less than the corresponding assimilative capacity, then the water functional zone is complying with the water quality standards. We have built the MSWRMS-Lab in the Shandong province and the Beijiang river basins by using browser/server (B/S) software architecture.

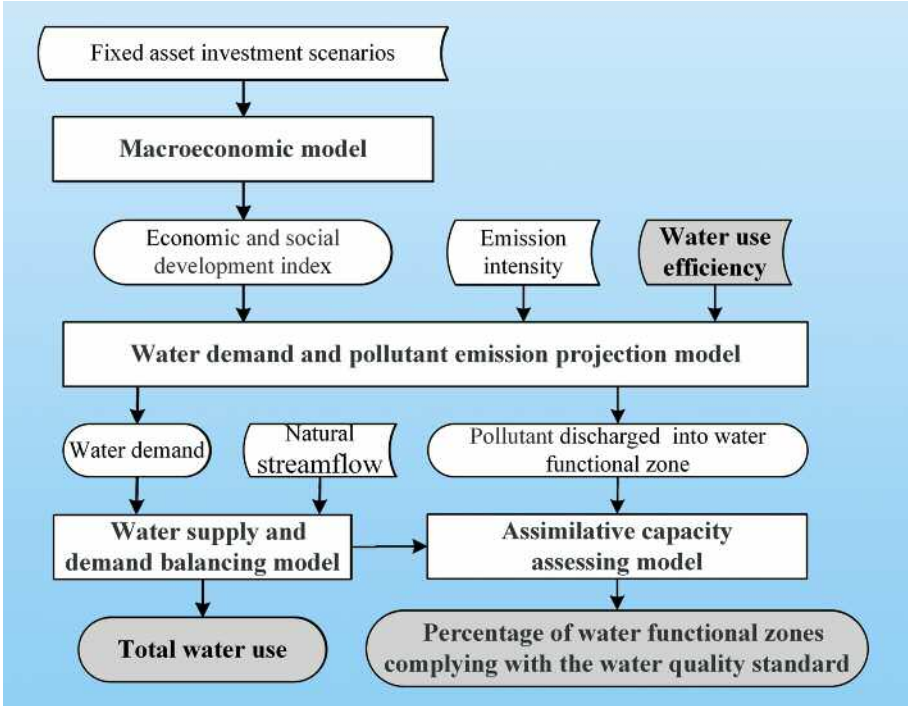

Figure 1. Components of MSWRMS-Lab

The main interface of the MSWRMS-Lab application in Shandong province is shown in Figure 2. This lab has many functions, such as system simulation, scenario prediction, dynamic regulation and implementation evaluation. The lab supported the development of dynamic annual management targets for Shandong province and the assessment of whether the control targets of the 'Three Red Lines' for each city of the Shandong province were met at the end of 2015 and 2016.

MSWRMS-LabApplication 1: simulating dynamic change of management indicators

Using the model system, we can simulate how management indicators change with socioeconomic development accounting for the inter-

Figure 2. Main interface of MSWRMS-Lab in Shandong province

annual variability of precipitation. The feedback between management indicators can be simulated too. Figure 3 shows how the total water demand and total water use of Shandong province in 2015 varies with three different socioeconomic scenarios and the exceedance frequency of annual precipitation. The Gross Domestic Product (GDP) and the irrigated area of the Business as Usual (BAU) scenario was forecasted based on the trend of the fixed asset investment during 2011～2014, while the fixed asset investment of low or high development scenario was 20% smaller or larger than the BAU scenario. The exceedance frequency of annual precipitation was based on the annual precipitation from 1956 to 2000. The total water demand increases with the frequency the level of socioeconomic development in terms of the GDP and the irrigated area as shown in Figure 3. In wet years, water demand can be guaranteed and total water use increases with the frequency and the level of socioeconomic development up to a point. Beyond that point, i.e. in dry years, satisfaction of the water demand cannot be guaranteed and the total water use decreases with the exceedance frequency. The total water used under different socioeconomic development levels is very small, almost the same.

MSWRMS-Lab application 2: calculating dynamic management targets

The control targets of the 'Three Red Lines' are based on an average number of historical water inflow in terms of annual precipitation or natural streamflow. In the assessment of whether the control targets are met at the end of a year, the dynamic management targets corresponding to the frequency of water inflow of this year are needed. A method to calculate the dynamic targets is established based on the lab. In this method the average number of dynamic targets is equal to the control target. Figure 4 shows the control target of total water use of Shandong province in 2015 and its dynamic management targets under annual precipitation for the period 1956 to 2000. In wet years when the exceedance frequency of the annual precipi-

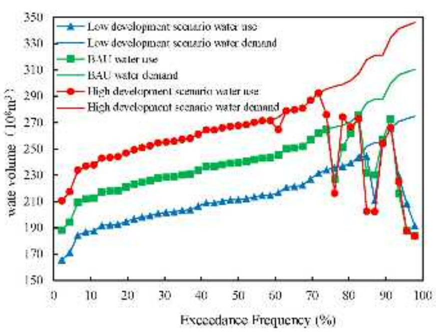

Figure 3. Total water demand and total water use of Shandong province in 2015 under three different socioeconomic scenarios and annual precipitation of 1956 to 2000

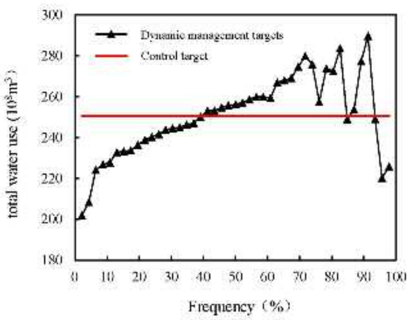

Figure 4. The control target of Shandong province in 2015 and its dynamic management targets

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Kelin Liu **is a senior engineer in Nanjing Hydraulic Research Institute (China). He is mainly engaged in research on reservoir optimal operation, flood resources utilization and hydrological forecast. He is or has been involved in numerous research and consulting projects supported by National Natural Science Foundation of China (NSFC), Ministry of Science and Technology (China) and Ministry of Water Resources (China).**

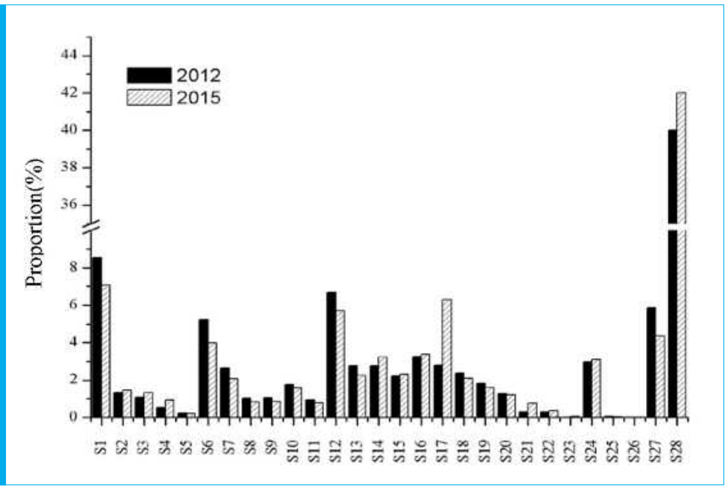
Xia Hu **is a master student in Nanchang University, Jiangxi province. and is a guest student of NHRI now who mainly engaged in research on water resources planning and management and water management policy analysis.**

tation is less than 40%, the dynamic management target is less than the control target. When the exceedance frequency is in the range 40%~94%, the dynamic management target is mostly higher than the control target. But when the exceedance frequency is larger than 94%, the dynamic management target is less than the control target.

MSWRMS-Lab application 3: adjustment of industrial structure

The unreasonable development of the industrial economy is one of the important reasons for China's resource and environmental issues. Adjustment of the industrial economy and improvement of water use efficiency are important measures for the implementation of MSWRMS. An optimization model based on the simulation model system was developed to adjust the industrial structure. The economy was divided into 28 economic industries, including primary industry, construction, tertiary industry and 25 other industries in the model. The objective in the model is to maximize GDP. The decision variable is the industry added value of these 28 industries. The control targets of the 'Three Red Lines', industry diversity, employment, consumption and investment are set as constraints. The adjusted industrial structure of Shandong in 2015 is obtained by the model. The initial industrial structure in 2012 is chosen as baseline. The changes in the proportion of GDP contributed by each of the 28 industries in 2012 and 2015 is shown as Figure 5. The model shows that the relative contribution to the GDP of high water consumption industries , such as primary industry, food industry, textile industry, paper industry and oil processing and chemical industry, decreases, while the relative contribution to the GDP of the tertiary industry, general equipment industry and special equipment industry increases.

Figure 5. Relative contribution to the GDP of each of 28 industries in 2012 and 2015



DERIVATION OF OPTIMAL JOINT OPERATING RULES FOR MULTI-PURPOSE MULTI-RESERVOIR WATER-SUPPLY BY SYSTEMS

BY SOON-THIAM KHU , XU WANG & QIAOFENG TAN

The derivation of joint operating policy is a challenging task for a multi-purpose multi-reservoir systems. The study proposed an aggregation-decomposition model to guide the joint operation of multi-purpose multi-reservoir systems, including: (1) an aggregated model based on the improved hedging rule (HR) to ensure the long-term water-supply operating benefit; (2) a decomposed model to allocate the limited release to individual reservoirs for the purpose of maximizing the total profit of the facing period; and (3) a double-layer simulation-based optimization model to obtain the optimal time-varying HRs using the non-dominated sorting genetic algorithm II, whose objectives were to minimize maximum water deficit and maximize water supply reliability.

The water-supply system of Li River in Guangxi Province, China, was selected for the case study. The results show that the operating policy proposed in this study is better than conventional operating rules and aggregated standard operating policy (SOP) for both water supply and hydropower generation due to the use of hedging mechanisms and effective coordination among multiple objectives.

What is the problem?

For a multi-reservoir water-supply system, the downstream water demand can be satisfied by any one or several reservoirs. In most cases, these reservoirs are operated independently without a joint operating rule. Meanwhile, reservoirs in China usually serve multiple purposes, such as flood control, hydropower generation, navigation, and recreation [1-2]. Therefore, the joint operating rule is expected to be able to coordinate not only individual reservoirs but also different water use purposes. Li River is a tributary of Xi River in the Pearl River Basin, which is located in the northeast of Guangxi Province of China. As shown in Fig. 1, the water-supply system of Li River consists of six reservoirs, including the Fuzikou Reservoir (FZK), Chuanjiang Reservoir (CJ), Xiaorongjiang Reservoir (XRJ), Qingshitan Reservoir (QST), Sianjiang Reservoir (SAJ) and Wulixia Reservoir (WLX). These reservoirs supply water for the 83 km reach from Guilin City to Yangshuo City (GL-YS), which is a famous tourist area in China. The highest priority is assigned to water supply. The water released is used to generate hydropower and then delivered to GL-YS. Although these reservoirs serve a common water supply objective, each reservoir releases according to its own operating rule curve predetermined in the design stage without considering the coordination of reservoirs. How to build a joint operation rule as well as coordinate multi-objective relationship is always a big challenge for the reservoir managers in Li River basin.

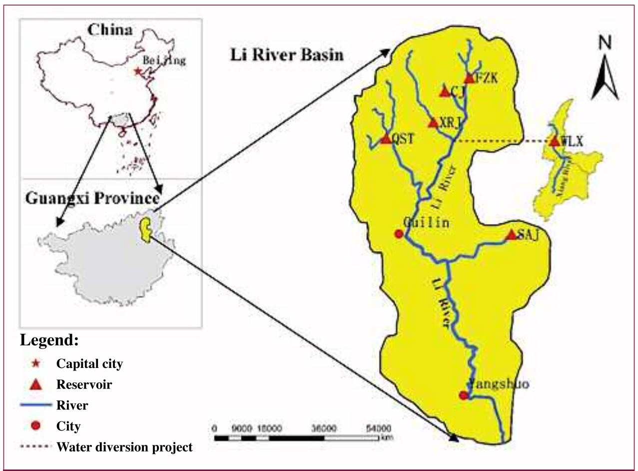


Figure 1. Location of Li River Basin in China

What kinds of reservoir operation rules were used to achieve joint operation?

To guide the multi-reservoir operation with joint water demand, the aggregation technique is used to simplify multi-reservoirs into a virtual reservoir and the type of corresponding operating rules is based on the hedging mechanism. Then a decomposition technique is used to guide the operation of each individual reservoir.

The problem of how much water to withhold from immediately beneficial deliveries, retaining that water in storage, is known as "hedging"[3]. The philosophy behind a hedging mechanism is that hedging is triggered to conserve water for future use when the reservoir water-supply capability falls into a specified range. For the widely used two-point HR, it consists of two parameters, namely the starting water availability *(SWA)* and ending water availability *(EWA)*. When water availability *(WA)* is between *SWA* and *EWA*, the HRs are triggered; Otherwise, SOP is used [4-5]. To adapt to the uneven-distributed runoff between months, time-varying HRs are used. Each month has its own HR. Meanwhile, considering the limited maximum damage depth constraints, another parameter called the damage depth index *(DDI)* is introduced into the HRs to control the acceptable level of damage. Correspondingly, there are two cases of HRs in month t: (1) Case I occurs when $0 \le (1-DDI_t) \cdot D_t \le SWA_t$ (Fig. 2(a)); while Case II occurs when $SWA_t < (1-DDI_t) \cdot D_t < D_t$ (Fig. 2(b)).

Case I:

$$R_t = \begin{cases} WA_t & \text{if } WA_t < SWA_t, \\ D_t + (SWA_t - D_t)\dfrac{WA_t - EWA_t}{SWA_t - EWA_t} & \text{if } SWA_t \le WA_t \le EWA_t, \\ D_t & \text{if } EWA_t \le WA_t < D_t + C, \\ WA_t - C & \text{if } WA_t \ge D_t + C. \end{cases} \quad (1)$$

Case II:

$$R_t = \begin{cases} WA_t & \text{if } WA_t < (1-DDI_t)D_t, \\ (1-DDI_t)D_t & \text{if } (1\text{-}DDI_t)D_t \le WA_t \le EWA_t - DDI_t \cdot D_t \dfrac{SWA_t - EWA_t}{SWA_t - D_t}, \\ D_t + (SWA_t - D_t)\dfrac{(WA_t - EWA_t)}{SWA_t - EWA_t} & \text{if } EWA_t\text{-}DDI_t \cdot D_t \dfrac{SWA_t - EWA_t}{SWA_t - D_t} \le WA_t < EWA_t, \\ D_t & \text{if } EWA_t \le WA_t < D_t + C, \\ WA_t - C & \text{if } WA_t \ge D_t + C. \end{cases} \quad (2)$$

where R_t is the total release of the aggregated reservoir at time t; SWA_t and EWA_t are the starting and ending water availability of the aggregated reservoir at time t; D_t is the water demand for the water-supply system at time t; and DDI_t is the damage depth index, indicating the rate that the water demand are not satisfied. The range of DDI_t is [0, 1], where $DDI_t = 0$ indicates that no hedging is allowed and SOP is used to guide the operation, while $DDI_t = 1$ indicates that no water is released. $C = \sum_{i=1}^{n} c_i$ is the total active capacity of all reservoirs.

How to coordinate multi-objective relationship?

The aggregation-decomposition technique is used to guide the joint operation of the multi-purpose multi-reservoir system, and a hierarchical multi-objective optimization model is proposed according to the priorities of different objectives. The outer optimal model based on the aggregation technique is used to decide the total release of the system, and thus the objectives with high priorities are considered in this model to ensure the long-term benefit of the primary operating task; while the inner optimal model based on the decomposition technique is used to allocate the limited total release to individual reservoirs to maximize the secondary objectives. For the reservoir operation problem in Li River Basin, the outer optimal model is used to ensure the priority of the water supply, the objective of which is to minimize maximum water deficit and maximize water supply reliability. This is a typical multi-objective optimization problem that can be solved using Non-domination Sorting Genetic Algorithm (NSGA-II). The inner optimal model is used to maximize the total profit of individual reservoirs for each period, which can be solve by (Genetic Algorithm) GA or Dynamic Programming (DP).

Reservoir joint operation for Li River water-supply system

To demonstrate the advantage of the proposed operating rules, the results of aggregated HRs are compared with those of aggregated SOP and conventional rules (CRs) in terms of the water supply reliability (WSR), maximum water deficit (MWD) and hydropower generation.

Table 1 shows the results of the three rules in the training and testing periods. The selected aggregated HRs could improve the two water-supply objectives of CRs, and decrease the MWD of the aggregated SOP significantly by slightly sacrificing WSR in both the training and testing periods. In addition, the total annual power generation of the reservoir system is improved by the aggregated HRs in both periods. The power generation obtained by the aggregated HRs is always higher than that obtained by the aggregated SOP; and the power generation obtained by the aggregation-decomposition model (aggregated HRs or SOP) is higher than that obtained by CRs for all reservoirs except for XRJ and SAJ. Fig. 3(a)-(b) show the monthly average storage and output process of the aggregated reservoir. Fig. 3(a) clearly shows that the storage of the aggregated HRs is always greater than

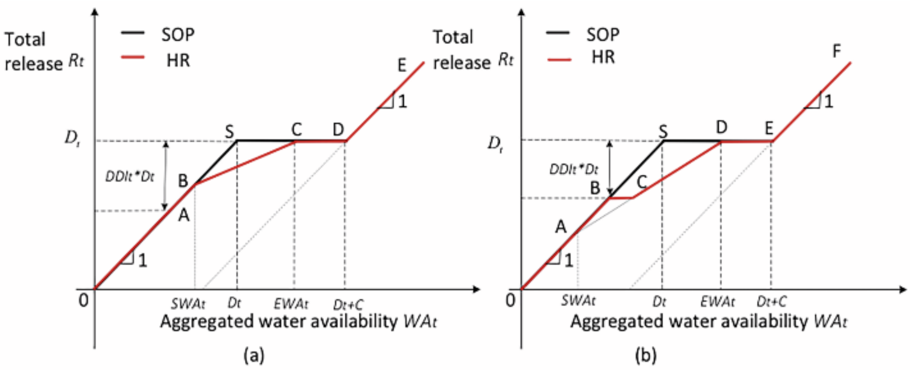


Figure 2. Improved HRs of aggregated reservoir considering the damage depth: (a) case I; (b) case II

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Xu Wang, **a senior engineer of the China Institute of Water Resources and Hydropower Research (IWHR), has been engaged in joint operation of cascade reservoirs, optimization and utilization of basin water resources, and high efficiency solution algorithms. He has published 23 peer-reviewed papers, including 6 SCI papers and10 EI papers, and 2 treatises. He holds 2 patents and 10 software copyrights. He has been awarded for three times, including two second prizes at the ministerial and provincial-level.**

Qiaofeng Tan, **PhD student from Sichuan University. She has been engaged in joint operation of cascade reservoirs, optimization and utilization of basin water resources, and high efficiency solution algorithms.**

that of the aggregated SOP and CRs due to the use of hedging mechanism which could retain water for future use. Generally speaking, the more the water is stored in reservoirs, the more the hydropower may be generated in the future because of the higher water head. Thus, the output of the aggregated HRs is higher than that of other schemes in most months (see Fig.3(b)).

In conclusion, the aggregated HRs are superior to the other two rules for both water supply and hydropower generation because of the use of the hedging mechanism and the optimal water allocation of the release among reservoirs. ■

Option		Training period CRs	Aggregated SOP	Aggregated HRs	Testing period CRs	Aggregated SOP	Aggregated HRs
Water supply reliability(%)		91.04	98.95	95.00	91.23	98.68	94.30
Maximum water deficit (m3/s)		30.98	39.28	8.23	31.21	41.04	9.89
Annual power generation (10^8 kw.h)	FZK	0.4931	0.5305	0.5382	0.4935	0.5355	0.5378
	CJ	0.2631	0.2673	0.2692	0.2632	0.2662	0.2684
	XRJ	0.6414	0.5928	0.5980	0.6399	0.5939	0.5965
	WLX	0.2622	0.2806	0.2830	0.2610	0.2790	0.2794
	QST	0.6568	0.6673	0.6680	0.6570	0.6650	0.6717
	SAJ	0.2322	0.2135	0.2180	0.2340	0.2130	0.2172
	System total	2.5488	2.5520	2.5744	2.5486	2.5526	2.5710

Table 1. Comparison of operation results of different operation rules

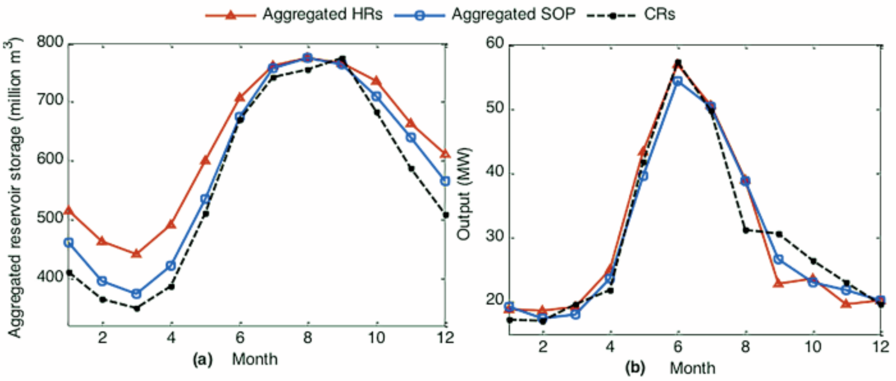

Figure 3. Monthly average operating process of the aggregated reservoir: (a) storage; (b) output

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CO-OPTED COUNCIL MEMBERS

IAHR would like to welcome the new co-opted Council Members for the term 2017-2019

Dr. Damien Violeau
Senior Scientist, Laboratoire National d'Hydraulique et Environnement, EDF R&D
FRANCE

Damien Violeau has been working since 1997 at the Laboratoire National d'Hydraulique et Environnement of EDF R&D, where he was appointed Senior Scientist in 2013. He is also involved in the Laboratoire d'Hydraulique Saint-Venant, created in 2006. His main activities are the development of the Smoothed Particle Hydrodynamics (SPH) numerical method and the design of coastal waterworks, with an additional contribution to turbulent processes in the environment. He compiled his work on Theoretical fluid mechanics, SPH and its application to waterworks in a 600+ page book published by Oxford University Press in 2012. Besides his research activities, he developed a long and fruitful teaching experience, as lecturer in several engineering colleges in France, in particular Ecole des Ponts ParisTech, where he has been teaching Fluid Mechanics since 1998. Damien was introduced to IAHR in 2003, first as a member of the Hydroinformatics Section, then as a member of the Maritime Section (now Committee on Coastal and Maritime Hydraulics) where he was secretary from 2006 to 2007. He participated to the Biennial congresses since then, as well as many other IAHR congresses, as speaker, chairman and organizer of special sessions. He is also a regular reviewer of JHR, and was appointed Associate Editor in January 2015. He was co-opted member of the Council in 2013 and participated to the Council meeting in Porto that year. Since then, he started to think about the way to improve the links between Industry and Academia in IAHR. He also built a new YPN, the Paris IAHR YPN, officially started at the end of 2014; he is the YPN advisor.
Damien has also been member of ERCOFTAC and is member of the French Hydro Society (SHF). In 2005, he created the SPH European Research Interest Community which he chaired until 2009.

Hajime Nakagawa
Professor of Disaster Prevention Research Institute and Director
Kyoto University
JAPAN

Hajime Nakagawa is the Professor and the Director of the Disaster Prevention Research Institute (DPRI) of Kyoto University and is also the Director of the Ujigawa Hydraulics Laboratory attached to DPRI. He currently serves as the Secretary General of the Japan Chapter of IAHR. He has been involved in development of hazard maps for overland flood flow and debris for the prevention and mitigation from the water and sediment related disasters. He also currently serves as a Vice-President of World Association for Sedimentation and Erosion Research (WASER).

Nor Azazi Zakaria
Director and Founder of River Engineering and Urban Drainage Research Centre (REDAC)
Director of Engineering Campus, University Sains Malaysia
Professor of Civil Engineering
IAHR-APD Executive Committee
Scientific Expert Panel for Prime Minister's Science Advisor
Professional Congress Organiser of 37th IAHR World Congress
MALAYSIA

Nor Azazi has served in Universiti Sains Malaysia (USM) since 1994. He then established the River Engineering and Urban Drainage Research Centre (REDAC) in 2001 and has since remained as the Director. REDAC is the first research centre in USM Engineering Campus accorded as the Higher Institution Centre of Excellence (HICoE) in Service Thrust on Stormwater Management niche area.
Nor Azazi's main research interests are Sustainable Urban Drainage Systems and River Management. He is the leading researcher in the innovation of Bio-ecological Drainage System (BIOECODS), and is now an established figure in the field of stormwater management at national and international level. He is the Executive Committee for Malaysian National Committee on Irrigation and Drainage (MANCID) and Malaysia Stormwater Organization (MSO), as well as IAHR APD.

COMPREHENSIVE OPERATION OF RESERVOIRS AND SLUICE-PUMP GROUPS IN THE PEARL RIVER BASIN

BY ZHIPENG MA, SEN WANG, DONGHUI WAN, KANG ZHANG & HUAZHI ZOU

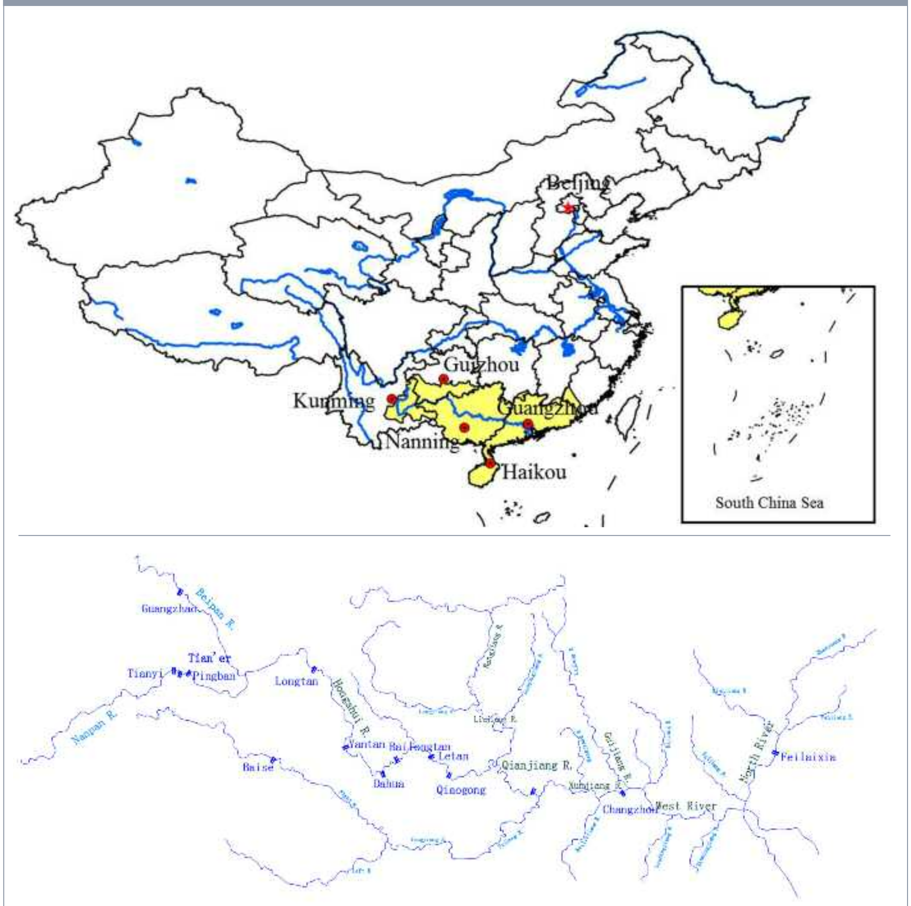
In order to prevent flood and drought disasters, cascade reservoirs and embankments have been constructed in the main river, and numerous sluices and pumps have also been installed in the delta of the Pearl River. These manmade projects have caused substantial changes in the hydraulic regime in the Pearl River basin. We propose a 1D/2D coupled flood model to precisely characterize flood flows accounting for how the water flows out of and then returns to the main channel.

In order to better satisfy the various water demands in the Pearl River basin, such as flood control, power generation, water supply, suppression of saltwater intrusion, navigation security, and eco-environment protection, we have developed a multi-objective comprehensive management model, which takes into account the flood control operation of key cascade reservoirs, the storage of water at the end of the flood period, water releases in the dry period, and the combined operation of sluice-pump groups. Significant social, economic, and environmental benefits can be achieved from the comprehensive operation of the sluices in the Pearl River basin.

Introduction

The Pearl River is the second largest river in China next to the Yangtze River in terms of discharge. In order to generate power, control flooding, and supply fresh water, numerous reservoirs have been constructed in the upper and middle reaches of the Pearl River, and the embankments in the middle and lower reaches of the river have been strengthened, resulting in substantial changes in the hydraulic regime in the Pearl River basin. A major problem is that the control and use of water resources for multiple purposes, such as flood control, power generation, water supply, salinity suppression, satisfying ecological and environmental constraints and navigation, should be well coordinated, which can be complicated by the large drainage area with no reservoirs providing river flow regulation and long water transfer distance (about 1000 km from the upstream Tianyi Reservoir to the estuary).

Figure 1. The geographic location of the Pearl River basin

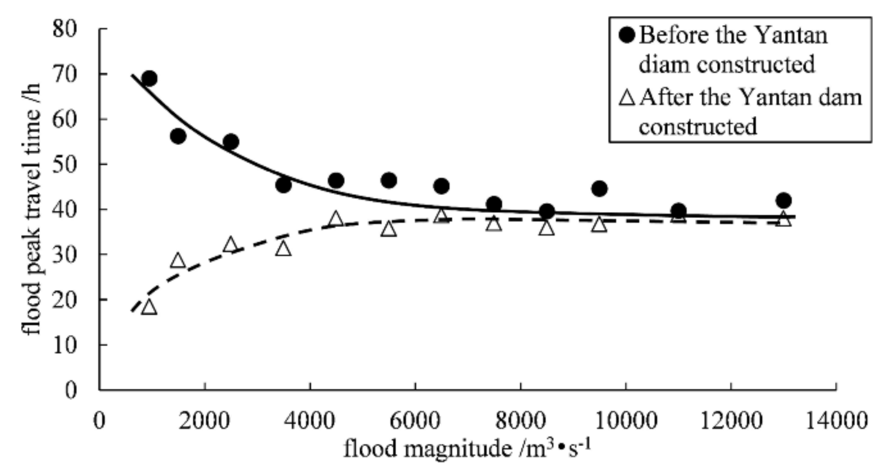


Obviously, the existing operation rules may not be adaptable to such dramatic changes in the Pearl River basin. The Pearl River Delta is a low-lying area surrounding the Pearl River estuary with a dense network of cities and a large population, and it is now one of the three largest economic zones in China. The river system of the Pearl River Delta consists of thousands of river branches with numerous sluices and pumps The hydrodynamics and mass transfer in the Pearl River Delta can be affected simultaneously by multiple factors such as runoff, tides and hydraulic structures. Thus, the Pearl River Delta is considered to be one of the most complex delta water systems in China, making it extremely difficult for the multi-objective operation of sluices and their pumps.

Changes in hydrologic regime

A total of 257 flood events of different magnitudes in the river section with cascade reservoirs were measured, and changes in their travel time before and after the construction of cascade reservoirs in the upper reach were comprehensively compared by statistical analysis, hydrological methods and hydrodynamic models. The results of this comparison showed that the speed of propagation of moderate and small floods increased after the construction of the cascade reservoirs, resulting in a decrease in the average travel time over the reach from Longtan Reservoir to Qiaogong Reservoir (about 422 km) by about 13 hours. This comprehensive comparison approach uses the hydrological method and the hydrodynamic model mutual verification method to calculate the flood propagation time, which can make full use of available data and information and improve the computational efficiency without compromising accuracy compared with traditional hydrological method. For the middle and downstream part of the system with numerous embankments, in order to deal with the problem of needing to estimate empirically main channel outflows in the hydrological method, we propose a 1D/2D coupled flood model to precisely describe how part of the flood waters flows out of and then returns to the main channel, which can be solved by the Riemann problem-based method. The peak flood flow that returns to the main channel is increased by about 10.4% on average compared with the natural flood flow, and the higher the flood magnitude, the more pronounced the phenomenon of water returning to the main channel. This contributes to better understanding of the variation and evolution parameters of flood events of different magnitudes, and thus provides valuable insights into the water control for the complete or partial returning of water to the main channel, flood control in the Pearl River basin, and the construction of key water conservancy projects.

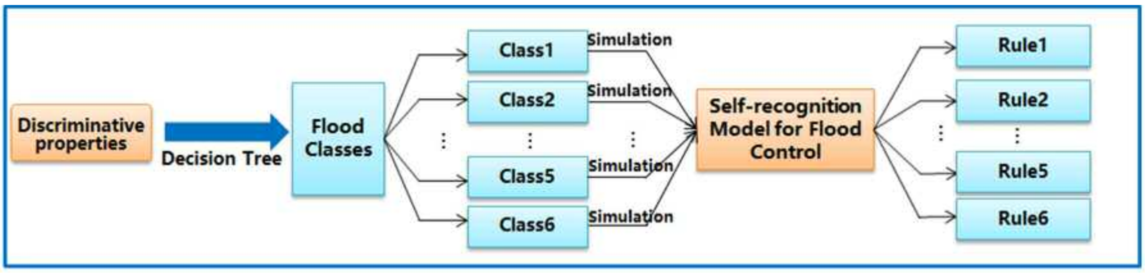
Figure 2. Changes of flood travel time and flood hydrograph in the Pearl River basin

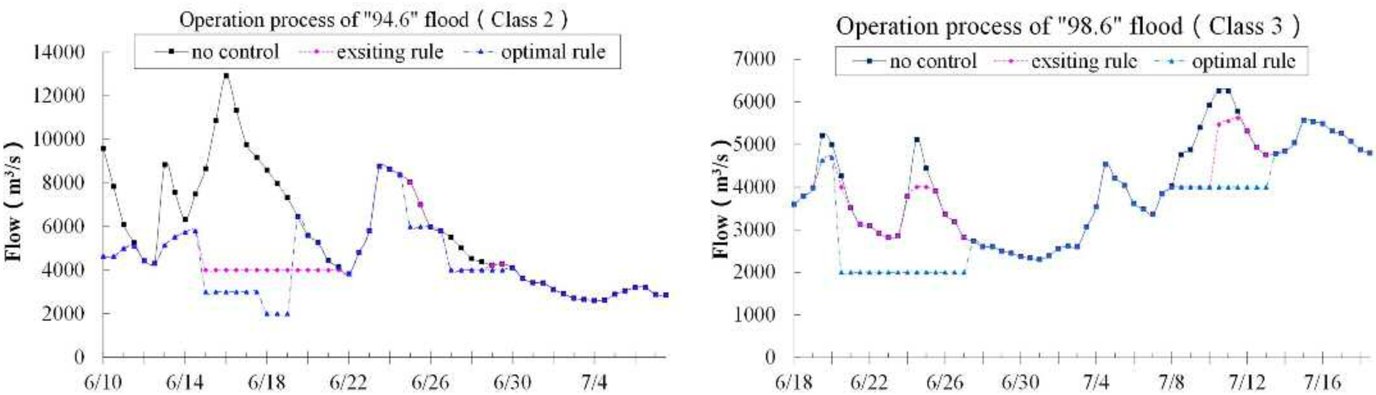


Flood control operation

Considering the complex flood scenarios and limited flood control capacity, we propose a method for classifying flood events based on their discriminative properties, such as the stage of flood, the difference in the occurrence time of flood peak, and the ratio of flood volume between upstream and downstream. We developed a flood control operation model based on the self-recognition of flood classes, and the discrimination of different flood events and corresponding discharge of reservoirs. This enables the dynamic self-recognition of flood classes and real-time control of discharge, making it possible to make full use of limited

Figure 3. Self-recognition of flood classes and operation process of typical floods

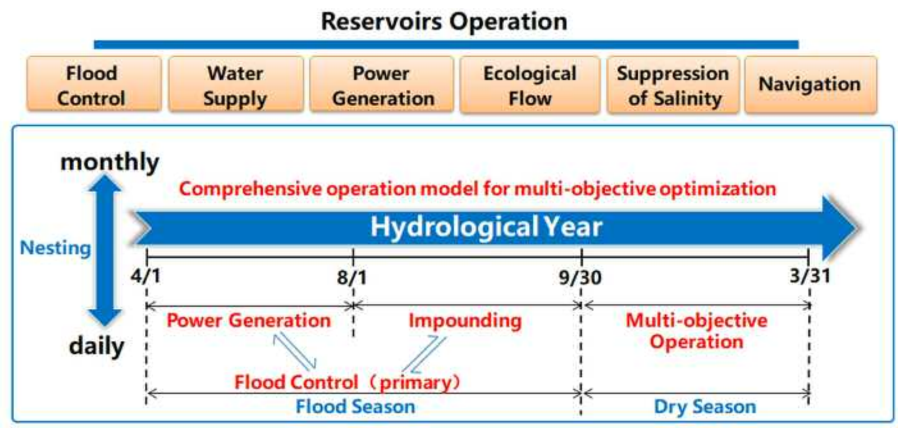


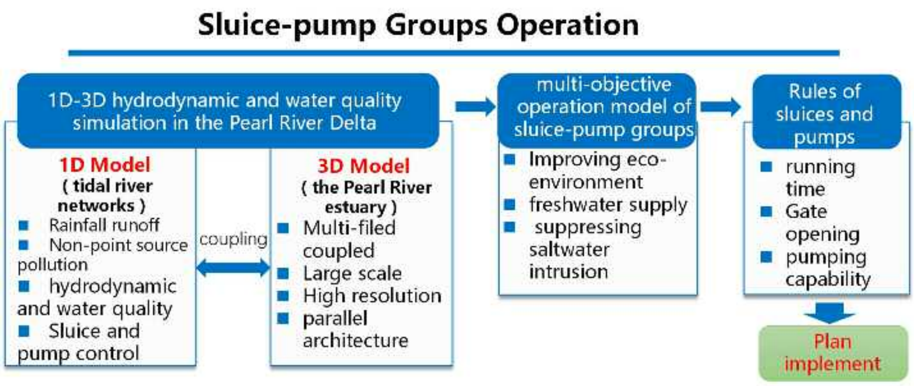


flood control storage. As a result, the flood control capacity can be significantly improved in cases of floods occurring in the basin, or in the middle and lower reaches of the river. Compared with the existing method, the peak flood flow occurring in the basin in June 1994 is reduced by 1600 m³/s, and its probability of occurrence is reduced from once in 200 years to once in 60 years; whereas the peak flood flow occurring in the middle and lower reaches of the river in June 1998 is reduced by 2300 m³/s, and its probability is reduced from once in 200 years to once in 100 years.

Comprehensive management

In order to better satisfy the diverse water demands in the Pearl River basin, we developed a multi-objective comprehensive management model consisting of both mid-and-long term scheduling and short-term scheduling. This model can serve multiple purposes such as flood control, power generation, water supply, satisfying ecological and environmental constraints, navigation, and suppression of salinity by integrating monthly multi-objective operations in the flood and dry seasons and daily flood control and power generation operations, the impounding of water at the end of the flood period, and the water storage in the dry period. Attempts have also been made to ensure reliable interconnection and switching between different tasks under different hydraulic conditions. As a result, the total power generation of the cascaded hydropower stations increased by 0.9 billion kWh over the period from 2014 to 2016, and the daily reliability of ecological flow and discharge for the suppression of saltwater intrusion in the control section have respectively reached 95% and 85% respectively over the period from 2015 to 2016. In addition, the water storage increased by 0.85 billion m3 with an increase rate of 8.6% in 2015. A simulation platform was used for mass (e.g., pollutants and salts) transfer and for the operation of sluices and their pumps, taking into account various dynamic factors such as runoff, tide and wind. This makes it possible to produce high-precision simulations of hydrodynamics and mass transfer in the Pearl River Delta. The coordinated operation of sluices and their pumps contributes to improved management of the cascade reservoirs in terms of the opening and closing timing of sluices and their pumps, salinity suppression and freshwater supplement. The results show that some hydrological indexes, such as the pollutant concentration in river branches and water storage and supply can be effectively improved. ■





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REAL-TIME OPTIMISATION OF LARGE RIVER AND RESERVOIR SYSTEM OPERATIONS

BY HENRIK MADSEN & ANNE KATRINE FALK

We present a new approach for real-time optimisation of large river and reservoir systems that combines physically-based hydrological-hydrodynamic models with surrogate control models within a Model Predictive Control framework. The approach is demonstrated in the optimisation of storage operations of the Murrumbidgee River system in New South Wales, Australia. This system consists of multiple reservoirs with pronounced travel times between the reservoirs. The test shows a large potential for improving operational efficiency of large water systems.

Real-time optimisation

There is a large potential for improving the operation of multi-purpose, large-scale river and reservoir systems by real-time optimisation. Reservoir operation rule curves have traditionally been optimised using a simulation-optimisation approach in which a high-fidelity, i.e. a detailed hydrological-hydrodynamic simulation model of the system is coupled with an optimisation algorithm (e.g. Ngo et al., 2007). However, for real-time optimisation of large systems such an approach is infeasible due to the curse of dimensionality and high computational requirements.

To facilitate real-time optimisation of very large water systems, we have developed a Model Predictive Control (MPC) framework that combines high-fidelity hydrological-hydrodynamic simulation models with simpler surrogate control models. The surrogate model is a computationally fast emulator of the high-fidelity model, which is sufficiently accurate for predicting the change in the system state due to changes in system operations and uncontrolled inflows and extractions. We apply linear surrogate models, which allow formulation of a fast-solvable optimisation model with 10,000s of optimisation variables.

Model predictive control framework

A central element of MPC is that it optimises the current operation while taken into account also the operation over a future time horizon. This is accomplished by optimising the operation over the full time horizon but only implementing the optimised operation for the first part. The optimisation is then repeated with new initial conditions and a new forecast of the system boundaries.

In our framework, a surrogate model is used as the internal dynamic model of the MPC. The surrogate model is derived and calibrated from the high-fidelity hydrological-hydrodynamic model of the river and reservoir system. The surrogate model is schematised using different building blocks as illustrated in Figure 1. The reservoir block describes reservoir storage as a function of inflows and outflows. The reach block describes water flow in a river reach using

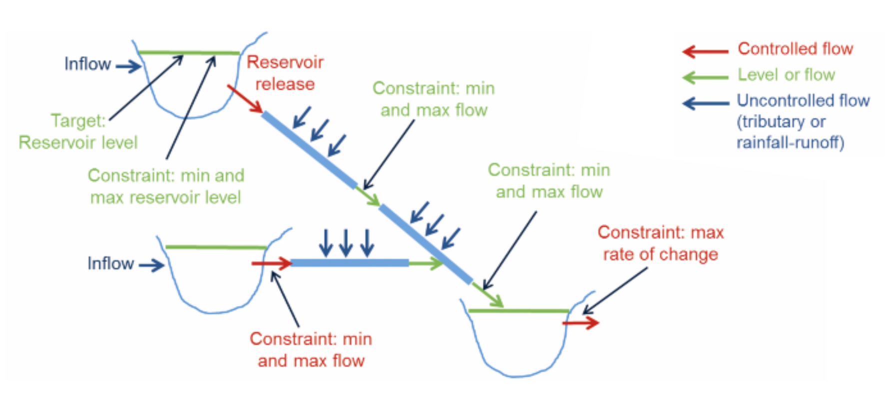

Figure 1. Example of schematisation of surrogate model and definition of constraints for the MPC optimisation model

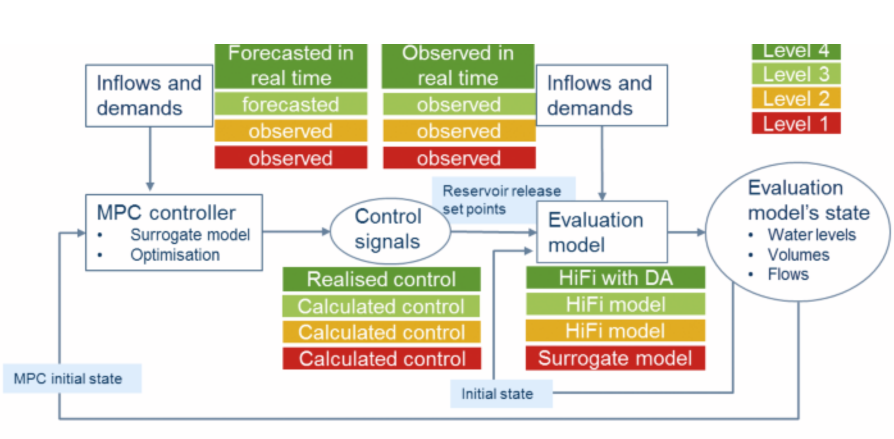

Figure 2. Closed loop test hierarchy for tuning and evaluation of the MPC controller. The colours from red to green illustrate the four test levels with use of different data for inflows and water demands for the MPC controller and evaluation model, control signals, and evaluation model (HiFi: high-fidelity, DA: data assimilation)

a linear routing model and takes into account inflows and extractions along the reach. Figure 1 also illustrates constraints that are defined for the MPC optimisation model, including both physical constraints (e.g. minimum river flow and maximum reservoir level) and operational goals (e.g. reservoir level target, and maximum river flow). Physical constraints are implemented as hard constraints (i.e. are not allowed to be violated), whereas operational goals typically are implemented as soft constraints (i.e. are allowed to be violated, but with an associated penalty).

An important element of our MPC framework is the dynamic interaction between the high-fidelity model and the surrogate models. For testing, the high-fidelity model is used as evaluation model to tune and evaluate the performance of the MPC controller. The high-fidelity model provides initial conditions to the surrogate model when a new MPC optimisation is initiated, which ensures that the surrogate model is not drifting away from the true state of the system. In the real-time implementation, water level and discharge observations are used to update the high-fidelity model using data assimilation.

A test hierarchy for tuning and evaluation of the MPC controller in a closed-loop test environment is illustrated in Figure 2. The test hierarchy includes four levels, which gradually increase the discrepancies between the surrogate model and the evaluation model. At Level 1, the MPC controller is evaluated against the surrogate model itself, whereas at Level 2 it is evaluated against the high-fidelity model. For both Level 1 and 2, observed inflows and water demands are used as input to the MPC controller and the evaluation model. At level 3, the MPC controller is forced with forecasted inflows and water demands to evaluate its robustness to forecast errors. Finally, at Level 4, the MPC controller is tested in a real-time environment where the MPC controller is forced with real-time forecast data. The high-fidelity model uses the realised control, real-time data of inflows and water demands, and water level and discharge measurements for data assimilation.

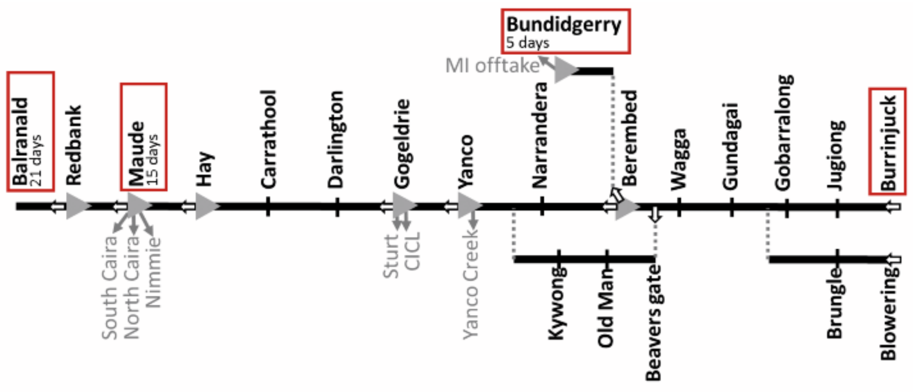

Figure 3. Surrogate model schematisation for the Murrumbidgee River system. The figure shows the river reaches (black lines), inline reservoirs (grey triangles), controllable gates (white arrows), and major offtakes (grey arrows). Tributary inflows and individual water users distributed along the river are not shown. For the selected locations shown in Figure 4 approximate travel times from Burrinjuck Reservoir are shown. Adapted from Falk et al. (2016)

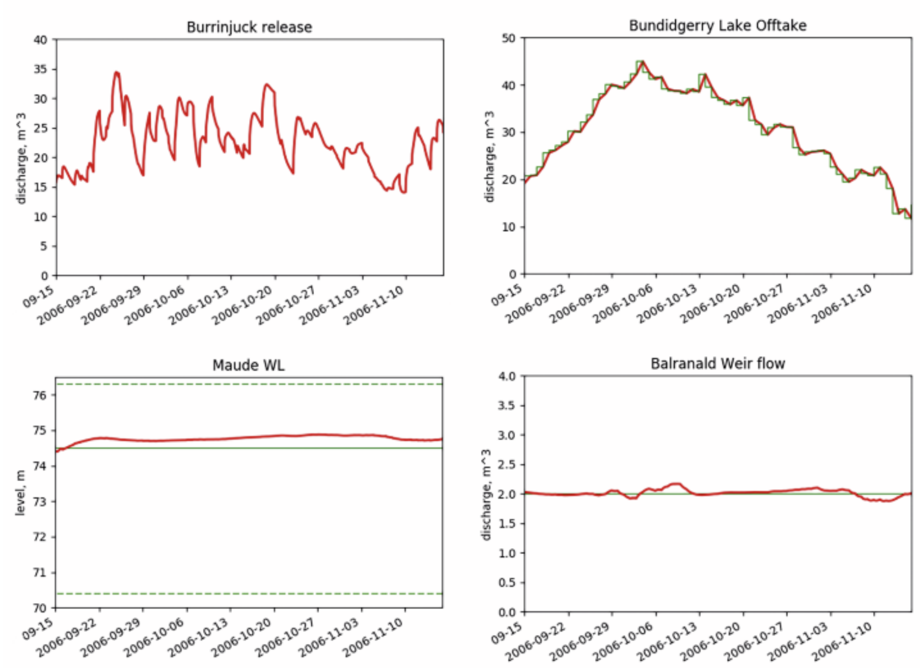

Figure 4. MPC test results: Release discharge [m3/s] at Burrinjuck Reservoir (upper left), Offtake discharge [m3/s] at Bundidgerry Lake (upper right), water level [m] at Maude (lower left), and end-of-system flow [m3/s] at Balranald (lower right). Red line: high-fidelity model results forced with MPC releases, green line: target levels/flows and irrigation water demands, green dashed line: upper and lower bounds

Optimising operations of the Murrumbidgee River system

We have applied the MPC framework for testing optimisation of the Murrumbidgee River system in New South Wales, Australia. The regulated part of the river is about 1,300 km from Burrinjuck Dam to Balranald (see illustration of the system in Figure 3). Along the river, a number of inline reservoirs regulate the flow and divert water to the major irrigation areas. Three major irrigation areas account for approximately 70% of the total irrigation demand, and the remaining part is extracted by about 700 individual users. The system is operated for provision of water for irrigation and environmental flow requirements. Water is supplied from two upstream reservoirs, Blowering and Burrinjuck, and from natural inflows downstream.

The MPC framework has been set up for part of the Murrumbidgee River system and tested at Level 2 in the test hierarchy. The schematisation of the surrogate model is shown in Figure 3. We use the hydrological-hydrodynamic model that was developed for the Computer Aided River Management (CARM) project (van Kalken et al., 2012) as high-fidelity model.

The operation objectives are: (1) supply ordered water to major irrigation areas and individual users, (2) minimise spills at end-of-system, and (3) keep the river in a lean state to minimise evapotranspiration losses and make storage available for natural inflows. In the MPC optimisation model, the lean state is defined as either a target water level or an operational zone (lower and upper water levels) in the inline reservoirs. At the end-of-system at Balranald a target flow corresponding to environmental flow requirements is defined.

The MPC optimises release hydrographs at Burrinjuck Reservoir, the six inline reservoirs, and Beavers gate (see positions of controllable gates in Figure 3). In the test, only releases from Burrinjuck Reservoir are optimised, whereas historical releases from Blowering Reservoir are used. The control horizon of the MPC is set to 14 days with a 3-hour temporal resolution for each release hydrograph, which gives in total about 1,100 control variables to be optimised.

The MPC controller has been tested for a two-month test period where the optimisation has been repeated every 24 hours (Madsen et al., 2017). Selected results from this test are shown in Figure 4. The figure shows the optimised release from Burrinjuck Reservoir (upper left). The MPC is able to meet irrigation water demands at the major offtakes, as shown for Bundidgerry Lake (Figure 4, upper right), as well as individual water demands along the river. At all inline reservoirs, water levels are kept close to the defined target levels and operational zones (see results for Maude in Figure 4, lower left). At the end-of-system at Balranald the flow is kept very close to the target flow of 2 m^3/s (Figure 4, lower right), essentially eliminating spills.

With respect to computational requirements, the MPC is very efficient. It takes about two minutes for one MPC optimisation on a standard laptop, and additionally 1.5 minutes to advance the high-fidelity model for initialising the next MPC optimisation. Computational efficiency is essential for real-time implementation of the MPC, and furthermore it allows a thorough tuning and evaluation using the proposed test hierarchy. ■

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***Anne Katrine Falk* is Senior Researcher in Applied Mathematics at DHI. She has more than 15 years of experience in research and implementation of state-of-the-art mathematical methods into DHI's software portfolio. Her main field of research include model-predictive control, optimisation, data assimilation, stochastic modelling and uncertainty analysis.**

ECOLOGICAL OPERATION OF CASCADE RESERVOIRS FOR SPAWNING OF REPRESENTATIVE FISH SPECIES IN THE LOWER REACHES OF THE JINSHA RIVER

BY JIN CHEN, JIJUN XU & ZHENG-JIE YIN

The impounding of cascade hydropower stations (Xiangjiaba and Xiluodu) in the lower Jinsha River results in substantial changes in spawning and breeding of rare and endemic fish species in the national nature reserve downstream of these reservoirs. In this study, we quantitatively evaluated changes in the hydrologic regime in the national nature reserve in response to the impounding of upstream reservoirs, as well as their effects on the spawning and breeding of representative fish species.

Attempts are also made to identify important hydrologic factors for the spawning and breeding of these fish species. The results show that it is imperative to ensure at least one high flow pulse for representative fish species in their spawning and breeding periods. Finally, the optimal operation model for cascade reservoirs is established, in which the demands of fish species are taken as the constraints.

Introduction

The two cascade hydropower dams in the lower Jinsha River, Xiangjiaba and Xiluodu, began to impound water in 2012 and 2013, respectively, resulting in substantial changes in the hydrologic regime in their downstream national nature reserve for rare and endemic fish species in the upper reaches of the Yangtze River (as shown in Figure 1), and consequently a reduction in spawning and breeding of fish in the national nature reserve, particularly those fish with pelagic eggs. According to monitoring data of early fish resources in recent years, the spawning scale of fish species with pelagic eggs decreased from 3.97 billion in 2012 before the impounding of the Xiangjiaba hydropower station to 1.4 billion in 2015 after the impounding. Thus, there is an urgent need to evaluate changes in the hydrologic regime in the national nature reserve in response to the impounding of the upstream reservoirs, as well as their effects on the spawning and breeding of fish species in the national nature reserve. Attempts should also be made to identify important hydrologic factors and their appropriate threshold ranges for the spawning and breeding of representative fish species in the national nature reserve, based on which the ecological flow required by those fish species in their spawning and breeding periods can be established. Finally, these requirements can be satisfied by the ecological operation of the cascade reservoirs upstream of the national nature reserve. Thus, this study may contribute to mitigating ecological impacts caused by changes in the hydrologic regime on the spawning and breeding of fish species and optimizing the operation of cascade reservoirs.

Changes in hydrologic regime and their effects

The historical hydrological data collected at two gauges (Pinshan and Zhutuo) for the period 1954-1997 under natural conditions were analyzed to determine changes in the hydrologic regime in the national nature reserve. The results show that the river flow was relatively stable before the impounding of reservoirs, with no obvious changes in both annual and monthly runoff volume. We then investigated the effects of the impounding of reservoirs and their normal

Figure 1. Geographic position of the national nature reserve for valuable and rare fish species in the upper reaches of the Yangtze River

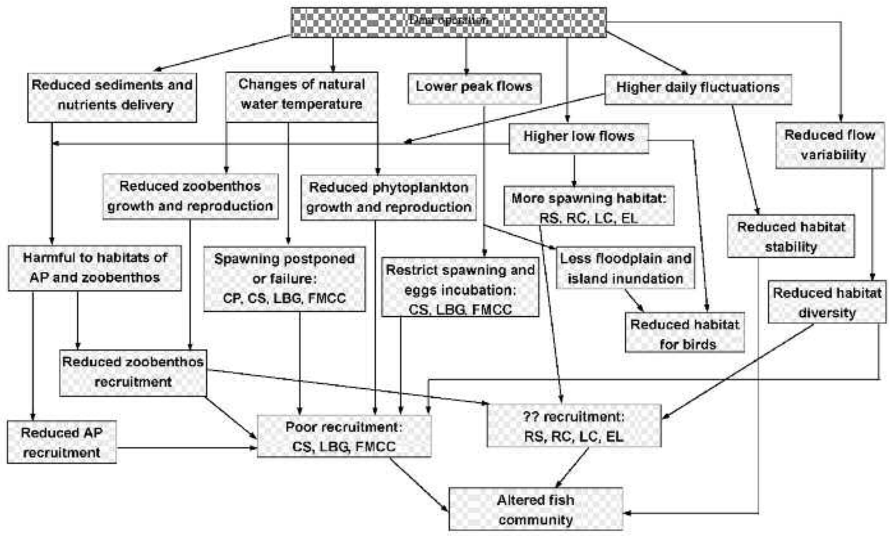
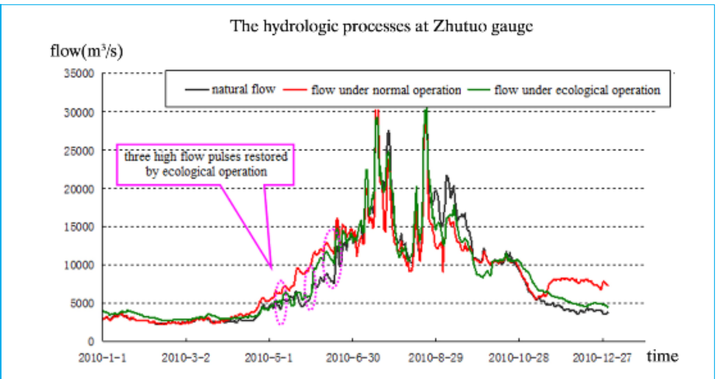


Figure 2. The effects of changes in hydrologic regime on the river ecosystems downstream the reservoir in the Lower Jinsha River. Aquatic plants (AP), Chinese paddlefish (CP), Chinese sucker (CS), Yangtze sturgeon (YS), largemouth bronze gudgeon (LBG), longnose catfish (LC), elongate loach (EL), Four major Chinese carps (FMCC).

Table 1. The eco-hydrological demands (high flow pulses) at the Zhutuo station

High flow pulses	First high flow pulse in May		Second high flow pulse from June 11 to July 11	
	Characteristics	Recommendation	Characteristics	Recommendation
Occurrence time	Begins 1-2 days after a small rise of water, depending on the incoming flow	May 1-May 30	Begins 1-2 days after a small rise of water, depending on the incoming flow	June 11-July 10
Initial flow rate m³/s	3500-5000	No less than 3900 (corresponding to the frequency of 25%)	4500-10500	No less than 6500 (corresponding to the frequency of 25%)
Initial rise m³/s	Relative increase is >15%; The increase rate is 660-2000	No less than 900 (corresponding to the frequency of 25%)	800-8700	No less than 1200 (corresponding to the frequency of 25%)
Average increase rate m³/s/d	300-1500 (corresponding to frequency of 25%)	No less than 700	220-6040	No less than 760 (corresponding to the the frequency of 25%)
Peak flow m³/s	5500-8000	No less than 6200 (corresponding to the frequency of 25%)	6700-50000	No less than 14000 (corresponding to the frequency of 25%)
Duration	3-8 d	No less than 4 d	3-52	No less than 5 d

Figure 3. The hydrologic processes in the national nature reserve under different operation models of cascade reservoirs



operation on the hydrologic regime in the national nature reserve. It was found that during the impounding from May to July in 2013 and from June to September in 2014, the river flow in the national nature reserve decreased dramatically; during normal operation in 2015-2016, the discharge during the pre-flood period from March to May and the impounding of water during the post-flood period from September to November could have had an effect on the hydrologic regime in the national nature reserve. The conceptual model for the assessment of the effects of changes in the hydrologic regime on the river ecosystem downstream of the reservoir is shown in Figure 2. The results of the application of this model showed that the spawning of representative fish species is closely related to the hydrologic processes in the river, especially the high flow pulses during the spawning period, indicating that the high flow pulses can be a critical eco-hydrological index for the spawning and breeding of representative fish species in the national nature reserve. The impounding of cascade hydropower stations can significantly impair the natural high flow pulse process in the national nature reserve. The high flow pulse process becomes fragmented and steeper with a relatively low peak flow and short duration, which is obviously detrimental to the spawning of fish species.

Eco-hydrological demands of representative fish species in their spawning and breeding periods

The high flow pulses at the Zhutuo gauge before the impounding from May to July were analyzed. The results show that in order to better satisfy the eco-hydrological demand of representative fish species in their spawning and breeding periods, it is imperative to ensure at least one high flow pulse in May (May 1-30) for Coreius heterodon and the four major Chinese carps and one high flow pules in the period from June 11 to July 1 for Leptobotia elongata, as shown in Table 1.

Ecological operation of cascade reservoirs

An optimal operation model for cascade reservoirs in the Jinsha River was established, in which the eco-hydrological demand of representative fish species during their spawning and breeding periods were taken as constraints for reservoir operation. The simulation of the ecological operation of cascade reservoirs in 2010 and 2014 shows that the discharge in the pre-flood period from May to July in each year can be regulated to produce high flow pulses required for the spawning and breeding of fish species in the national nature reserve. It shows that the simulated ecological operation can well satisfy the eco-hydrological demands of representative fish species in their spawning and breeding periods, as shown in Figure 3. In addition, the effect of ecological operations on hydropower generation of the two hydropower stations can be controlled within 1-2%, indicating the feasibility of the proposed ecological operation. ■

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RESERVOIR OPERATION RULES FOR CONTROLLING ALGAL BLOOMS IN A TRIBUTARY TO THE IMPOUNDMENT OF THREE GORGES DAM

BY JIJIAN LIAN, CHAO MA & YE YAO

Since the first impoundment of Three Gorges Dam in 2003, algal blooms occur frequently in the near-dam tributaries. An attempt is made in our study to develop reservoir operation rules that would reduce the level of algal blooms in the near-dam tributaries. The reservoir operations can further increase the water exchange between the mainstream of the Three Gorges Reservoir and the Xiangxi River tributary and thus move a larger amount of algae into the deep water where it would die. Analysis of the model results indicated that water discharge fluctuations consisting of a lower night-time valley-load flow and a larger flow component to satisfy daytime peak load during short-term operations (within a day), the rise in water level during the medium-term operation (e.g., over weeks), and the combination of these two during the long-term operation (e.g., over months) can provide feasible reservoir operation rules in the non-flood season for TGR.

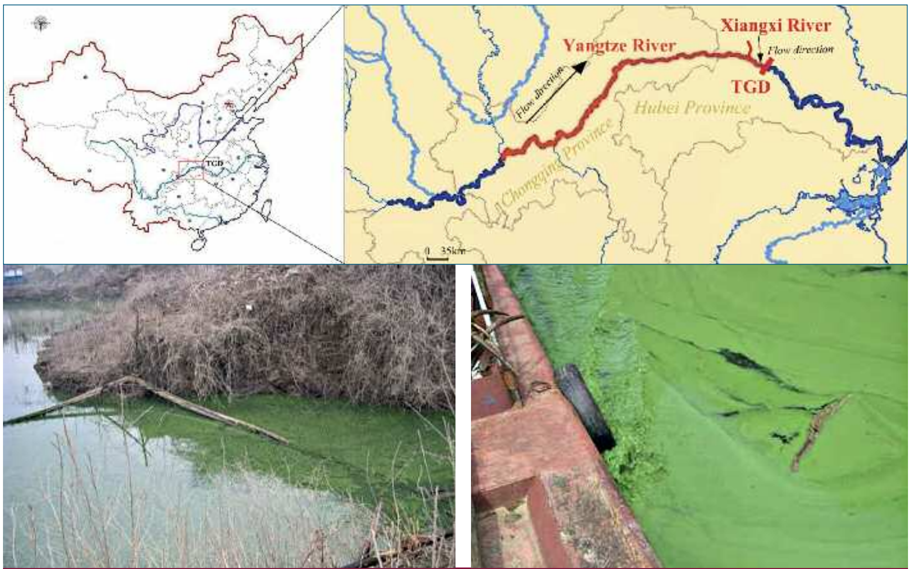

Figure 1. Algal blooms occur in near-dam tributaries of TGR

What is the problem?

After reservoir impoundment, the hydrodynamic conditions significantly changed from those occurring under the natural state of the river. Lower water velocity and longer residence time, resulted in degraded water quality and eutrophication problems [1,2]. The Three Gorges Reservoir (TGR) is the largest man-made reservoir system in the world according to the annual report of eco-environmental monitoring of TGR released by Executive Office of the State Council Three Gorges Project Construction Committee [3]. More than 30% of the monitoring sections in the major tributaries are in a state of high eutrophication, and algal blooms occur in over 20 tributaries from March to October every year, such as the Xiangxi River (XXR), the Tongzhuang River and the Daning River. Algal blooms occurring in XXR seriously affect the quality of life of local residents because of increased water turbidity and odor problems [4,5]. Harmful algal blooms with toxins are a prime agent of water quality degradation and result in loss of water for recreation and drinking. In order to alleviate the increasing algal bloom problems in TGR, more and more attention is being paid to seeking feasible solutions.

How did the reservoir operation rules come?

The occurrence of algal blooms in near-dam tributaries of TGR in the studied non-flood season is caused by slow water movement, which in combination with favorable meteorological conditions (e.g., warm air, low wind) and high nutrient loads, provides suitable environment for algae to grow. Xiangxi River (XXR), a near-dam tributary of TGR, is used as an example, in an attempt to develop reservoir operation rules that would reduce the level of algal blooms. For this purpose, a hydrodynamic and water quality model for the mainstream of TGR and the XXR arm (TGR-XXR model) was developed and calibrated using the CE-QUAL-W2 software to study the influence of reservoir operations on the algal blooms.

The formulation of reservoir operation rules is based on the current scheduling rules of the Three Gorges Hydropower Station as well as on scenario simulations. Water movement and algal bloom processes in XXR are simulated and analyzed under different scenarios of short-term daily water discharge fluctuations or medium-term water level variations using chlorophyll-a as the indicator for algal blooms.

The daily water discharge process is planned according to the daily inflow, the release requirements and load demand with peak-load regulation. The day is divided into four typical periods and four transition periods with a total of 48 time intervals (each being 0.5 hours), including the valley-load period (when the discharge is the lowest) (0:00–6:00), the morning peak-load period (8:00–11:00), the medium-load period (12:00–17:00), and the evening peak-load period (19:00–22:00). The water discharge does not change over each of the previously defined load periods but it changes linearly during each transition period. The flow difference is the difference between the water discharge in the evening peak-load period (peak-load flow) and the valley-load period (valley-load flow). Different scenarios include different combinations of valley-load flow and flow difference. For the medium-term operation, the water level variation over a period of time is set to rise or fall

How do the reservoir operation influence algal blooms?

During the season when algal blooms occur frequently, water from the mainstream TGR enters into the upper layers of the XXR arm of the reservoir and outflow from the XXR arm discharges from its lower layers into the main TGR as a result of the water temperature difference between the two river branches. Contour plots of Chl-a concentration on four different Julian days, from the beginning to the end day of the 40-day simulation period, are shown in Figure 2. The vertical distribution of velocity vectors at various locations along the longitudinal direction are also shown in the same figure. The velocity vectors illustrate the flow field described above and also help understand how algae move through the reservoir. (It is noted that the distance shown on the horizontal axis in Figure 2 is from the upstream to the downstream end of the reservoir.) Algae primarily grow in the upper layers and emerge at the water surface, so they are mainly influenced by the flows in a direction from downstream to upstream within XXR, which come from the mainstream TGR. The flow from the downstream to the upstream pushes the algae towards the upstream end of the XXR arm of the reservoir, and the concentration of algae at the confluence with the mainstream TGR is diluted since the Chl-a concentration in the mainstream of TGR is always lower than that in the XXR [2]. When the algae reach the upstream boundary of the backwater zone created by the impoundment of TGR, they are carried by the flow downwards into the deep water where the conditions of no light and lower temperatures are not suitable for their growth. There the algae die gradually. Thus, the transport process of algae in the XXR arm of the reservoir is characterized by a counterclockwise motion.

The reservoir operation is used to accelerate the transport process of algae by enhancing the water exchange between the two river branches, in order to reduce the algal bloom level. Flow fluctuations through the peak-load regulation provide an effective way of strengthening the water exchange between the mainstream reservoir and the tributary arm, because peak-load regulation makes both the flow entering from the mainstream into the XXR arm of the reservoir and the discharge flow from the XXR arm into the mainstream reservoir large. More intensive flow pushes the algae towards the upstream end of the XXR arm and moves them into deep water faster. In the meantime, the water level rise, similar to the peak-load regulation is also effective for reducing the algal bloom level by strengthening the flow into XXR to accelerate the upstream transport process of algae.

Reservoir Operation Rules for Controlling Algal Blooms

In conclusion, the reservoir operation can contribute to water quality improvement in the XXR as it can enhance the water exchange between the mainstream of TGR and the XXR tributary resulting in more water from the mainstream entering into the XXR leading to higher dilution, as well as in the acceleration of the transport of algae. Through the comparisons of algal bloom levels under different values of operation factors, operation rules aimed at water quality improvement are formulated. For short-term operation, daily peak-load regulation should be conducted. For the medium-term operation, regulation over a period of two weeks for water level rise can be conducted. For TGR, if inflows are sufficient, the water level can be raised to a certain extent in non-flood season without influencing the reservoir flood control capacity. Thus water level rise is beneficial for both algal blooms control and electricity generation. For long-term operation (e.g., over months) in the non-flood season for TGR, the short-term flow regulation and medium-term water level rise can be combined periodically. ■

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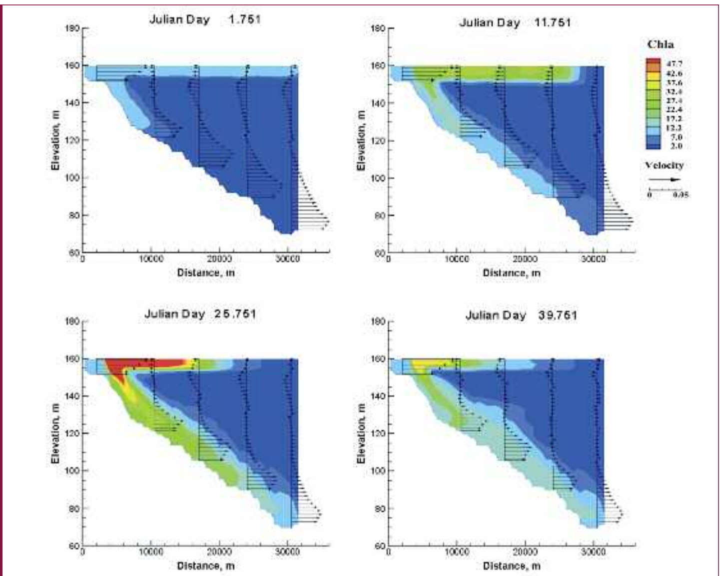

Figure 2. Transport process for algae in XXR under one scenario

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COMPREHENSIVE OPERATION OF THE ECO-HYDROLOGICAL PROCESSES IN SHALLOW MACROPHYTIC LAKES

BY ZHIFENG YANG, YUJUN YI, XUAN WANG & XINAN YIN

Changes in natural hydrologic regime due to intensive human activities and climatic changes are largely responsible for the ecological degradation of shallow macrophytic lakes, and thus ecological water should be supplemented in order to prevent the drying up of the lake. In this study, we investigated ecological water supplement in Baiyang Lake, a typical shallow macrophytic lake in northern China. It is recommended that water should be supplemented simultaneously through the northern and southern routes to increase the hydraulic disturbance in the central lake area and the water quality near the entrance.

Lakes play important hydrological, ecological and economic roles in regulating runoff, mitigating flood and drought impacts, and ensuring safe navigation, adequate water supply, and a high-quality habitat for a wide variety of aquatic species, as well biodiversity and sight-seeing. In China, most shallow (average water depth: < 10 m) macrophytic lakes are located in the plains in the middle and lower reaches of rivers (Fig. 1), which are known as the most populated and economically developed regions in China. Changes in their natural hydrologic regime due to intensive human activities and climatic changes have been shown to be responsible for the ecological degradation of these shallow macrophytic lakes. It is noteworthy that even a small change in water level can have a substantial effect on the area and hydrodynamics of shallow macrophytic lakes. In conclusion, the ecosystems of shallow macrophytic lakes are particularly susceptible to changes in their hydrologic regime. More importantly, intensive human activities over a short period of time can bring about dramatic changes in the water demand of lake ecosystems, as well as in their water surface area, water environment, habitat quality, population and distribution of biological species, and the structure and function of lake ecosystems.

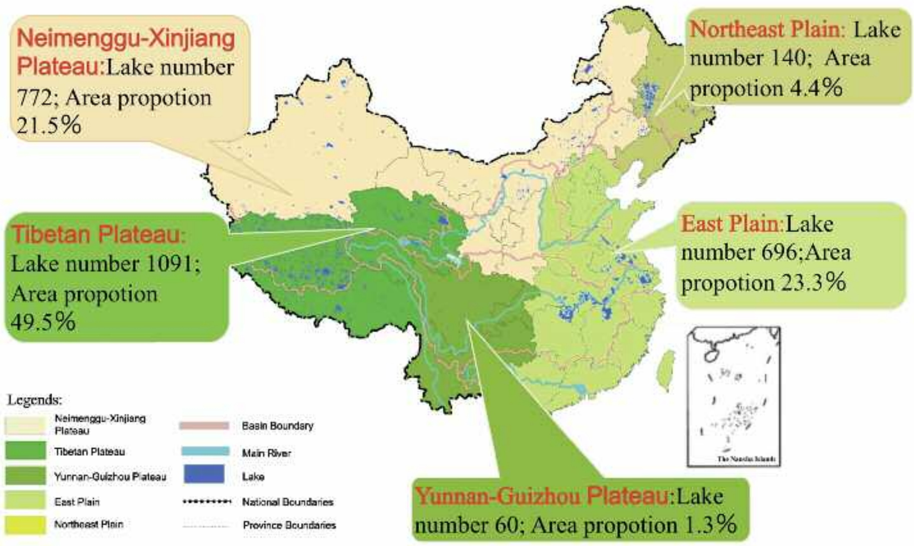

Figure 1. Geographical distribution of shallow macrophytic lakes in China

Three major problems faced by shallow macrophytic lakes

Three major problems may arise in shallow macrophytic lakes. First, shortage of ecological water can result in decrease of the lake area and, as a consequence, reduction in flood control and storage capacity and greater flood damage. For example, the inflow into the Baiyang Lake, the largest freshwater lake in northern China, has been reduced by approximately 55% in 2000 compared with that in the 1990s. The average annual inflow into the Baiyang Lake was about 240 million m^3 for the period 1980-2005, whereas that after 2000 was less than 50 million m^3 (Fig. 2). Thus, water has to be supplemented externally in order to prevent the drying up of the lake. Second, because of the effects of intensive human activities and global climatic changes, water resources management models for multi-purpose reservoir use, such as flood control, irrigation , power generation, industrial and domestic water supply, and emergency ecological water supplement, may fail to produce operational solutions that match the natural hydrologic regime characterized by low stable flow over a long period of time and a high flow pulse over a short period of time and the natural hydrologic process, thus resulting in the ecological degradation and reduced biodiversity in the shallow macrophytic lakes. Third, ecological restoration cannot be achieved merely by adjusting the structure of the lake ecosystems. Ecological water is often supplemented in emergency settings and it may conflict with industrial and domestic water demands. Thus, the effect of ecological water supplement can be greatly limited.

Ecological water supplement: A case study of Baiyang Lake in China

The evapotranspiration of plants, especially reed, is probably the most important cause of water consumption in Baiyang Lake. An optimization model was established for water resources management in Baiyang Lake, and

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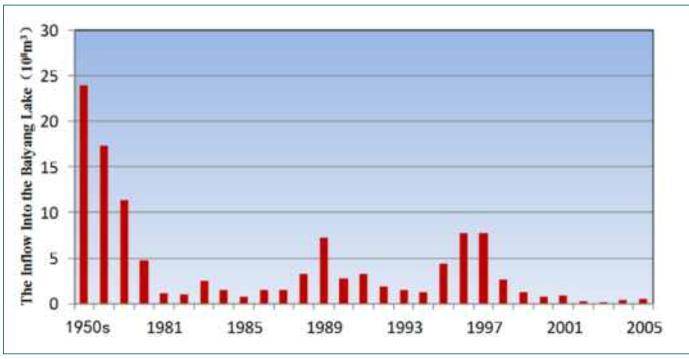


Figure 2. Changes in inflow into the Baiyang Lake

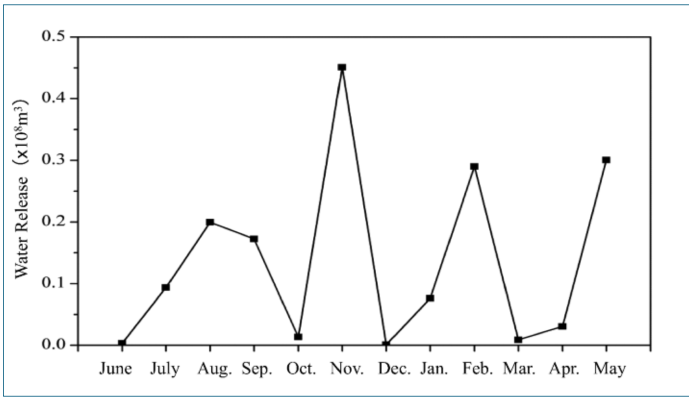


Figure 3. Ecological water supplement in Baiyang Lake

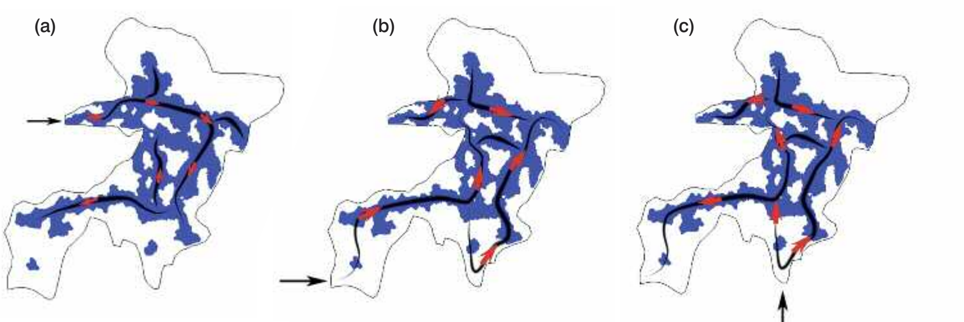


Figure 4. Flow routes of the environmental flow release in Baiyang Lake (a, b, and c stand for the flow routes of environmental flow released into the lake from Anxin, Hancun, and Dashuliuzhuang, respectively)

the results show that the optimal growth area for reed in Baiyang Lake is 91 km^2. The evapotranspiration of reed in its middle and later growth period far exceeds water surface evaporation, but the biomass remains largely unchanged during this period, indicating that only a small amount of nutrients are uptaken by reed. Thus, reed can be harvested some time ahead of its death, which can help to reduce unnecessary water consumption due to evapotranspiration. The water supplement to Baiyang Lake which takes into consideration the reed harvest is shown in Fig. 3.

It is clear that increasing the discharge of freshwater from upstream reservoirs contributes to the dilution of pollutants in the lake. However, the effects of different water supplement strategies on the water quality of Baiyang Lake remains to be elucidated. In order to better address this problem, a two-dimensional hydrodynamic water quality model was established. The simulation results showed that the area of Baiyang Lake affected by water supplement depends largely on the amount of water supplemented, the topography and the inflow rate. Water can be introduced into the lake through three routes, which can have different effects on local hydrodynamics and water environment. In order to more efficiently utilize the available water resources, water is preferably supplemented simultaneously through the northern and southern routes to increase the hydraulic disturbance in the central lake area and the water quality near the entrance (Fig. 4). ■

Our research group is looking for students and post-doctoral associates who are interested in the topic around environmental flow, eco-hydraulics, hydraulic modeling, and reservoir operation. Please contact us if you are interest in our work or join our group. Dr. Yujun Yi: yiyujun@bnu.edu.cn

THE SKY RIVER PROJECT

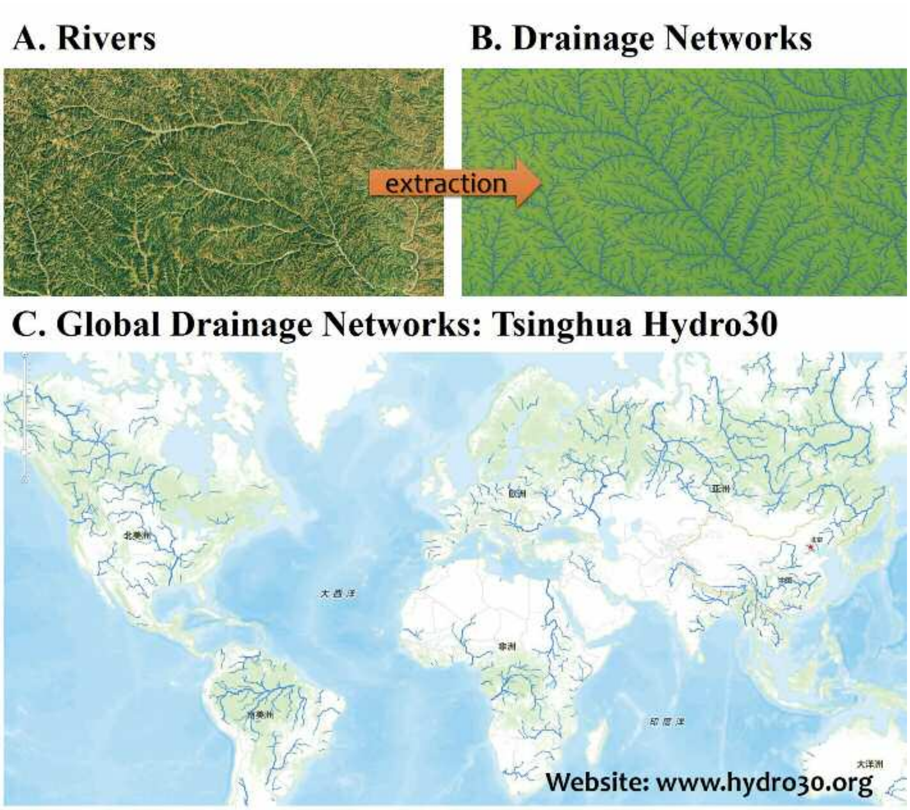
BY GUANGQIAN WANG, JIAHUA WEI, YUEFEI HUANG, XUDONG FU & DEYU ZHONG

The "Sky River Project" is a comprehensive research project initiated by Professor WANG Guangqian, member of Chinese Academy of Sciences (CAS). The project aims at solving the water shortage crisis in West China by exploiting cloud water resources. Sky River dynamics provides the theoretical basis for exploiting atmospheric water resources. Integrated utilization of water resources of both sky rivers and earth surface rivers is proposed. Combinations of traditional and modern artificial weather modification techniques have been tested. Effects of the different techniques are evaluated through the monitoring system. Temporal and spatial impacts of utilization of atmospheric water resources on the earth surface rivers will be investigated in various spatial regions.

Global Drainage Network Hydro30

The global digital drainage network Tsinghua Hydro30, produced by our team, describes important spatial information used in hydraulic research and public services. Besides the intrinsic characteristics of space and topology, the digital drainage network contains information useful for hydraulic engineering, environmental, ecological and other studies. Extraction, storage, and management of the high resolution digital drainage network, however, faces difficulties which limit its use. While current software for extracting the drainage network mainly works with Digital Elevation Model (DEM) data with the amount of data points (pixels) at the million level, our team has adapted a highly scalable and efficient algorithm which can deal with DEMs with the amount of pixels at the ten billion level, to make the extraction and coding of large-scale drainage networks possible. Combined with auto-detection of channel headwaters based on geomorphological features, the accuracy of the extraction is also improved significantly. By coding and storing the drainage networks, and developing a hierarchical retrieval algorithm for large-scale networks, the dataset for the main river basins in the world, which consists of features such as the vector drainage network, its characteristics, and precipitation data from remote sensing, is established. The results of this research can offer convenient data support for wide use of the digital drainage network in fields like fluvial geomorphology, water resource management, hydraulic engineering, environmental studies, and GIS.

Figure 1. Tsinghua Hydro30: A global digital drainage network



Digital River Basin Integrated Model

The Digital River basin Integrated Model (DiRIM) focuses on the simulation of runoff and sediment processes at the river basin scale. With the high-resolution structural digital drainage network obtained from Hydro30, integrating sub-models of different subprocesses of the yield and concentration of runoff, and the yield and transport of sediment in each hillslope-channel unit, it provides a complete system for hydrologic and sediment transport simulations in river basins. The DiRIM model efficiently solves several problems in the interaction between datasets and models at different scales, and it increases the efficiency of computation of large-scale river basins by using a binary-tree based coding algorithm for the drainage network and the technology of parallel computing in computer clusters. The DiRIM model has been applied in the Yellow River, especially in the coarse sediment source region on the loess plateau, and other river basins including the Yarlung Zangbo River, the drainage basin of the Tangjiashang Barrier Lake, and etc.

The Sky River Concept and the Project

Based on meteorological reanalysis data, we found that highly structured water vapor conveyance systems exist in the troposphere of the atmosphere. The water vapor conveyance systems have higher vertically integrated transport flux than their immediate environments, consisting of dominant channels for atmospheric water vapor transfer ranging from local scale to global scale.

The water vapor transfer systems in the troposphere providing high water (vapor) conveyance are similar to land surface rivers and thus can be referred to as “Rivers in the Sky”, or simply “Sky Rivers”. Studies on Sky Rivers will help us have a new appreciation of global atmospheric water vapor transfer and a better understanding of the global water cycle.

Figure 2. Digital River Basin Integrated Model and its methodology

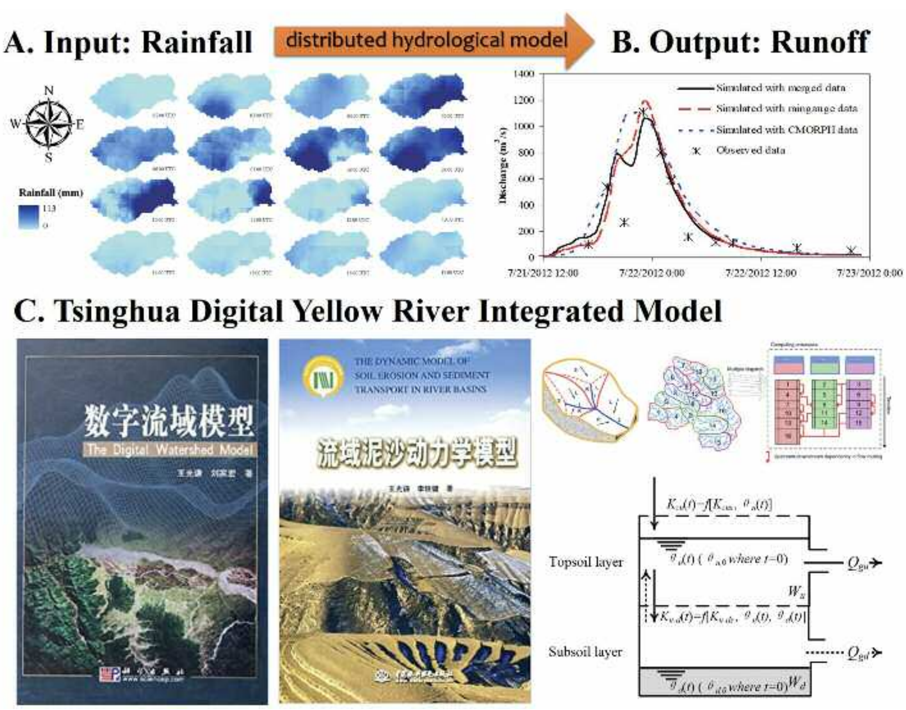
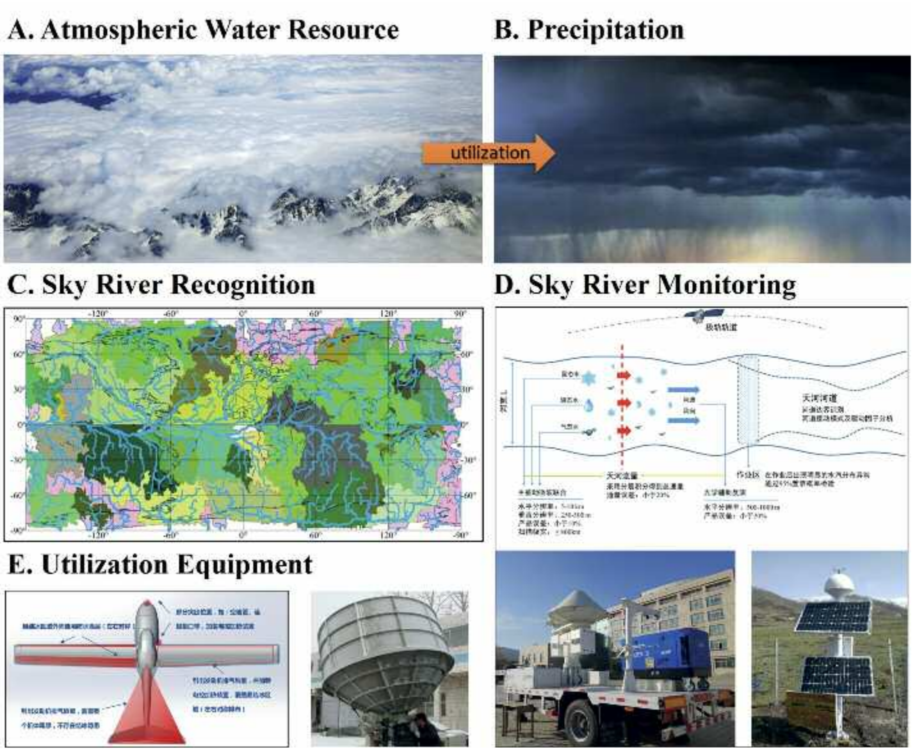


Figure 3. The sky river theory and the project



Guangqian Wang, **born in 1962 in Nanyang, Henan Province, China. Professor of Tsinghua University, President of Qinghai University, member of the Chinese Academy of Sciences, director of the National Natural Science Foundation Division of Materials Science and Engineering. He is Leader of the Sky River Project.**

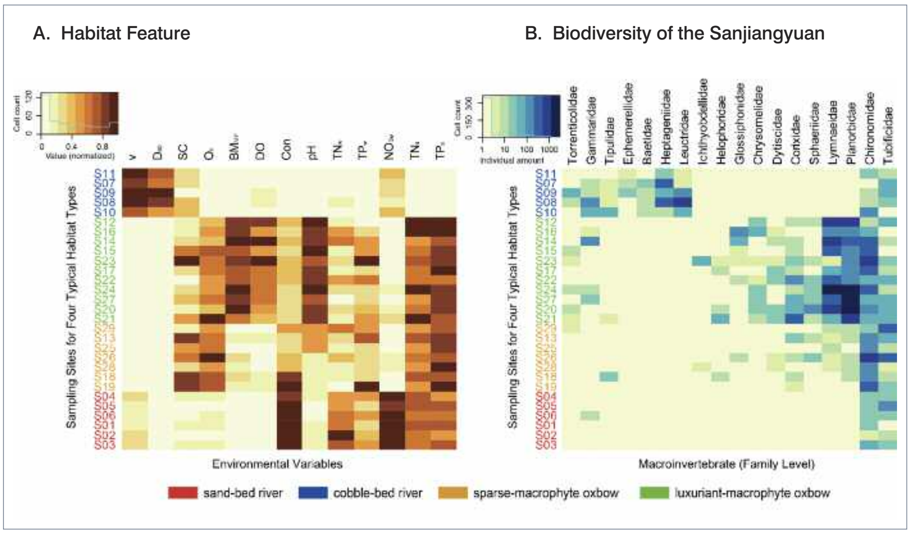
Jiahua Wei, **professor of Tsinghua University (2004~NOW), distinguished professor of the Changjiang Scholars of the Ministry of Education (2014), executive vice-president of the School of Hydraulic and Electric Power Engineering of Qinghai University, chief scientist of the State Key Laboratory of Plateau Ecology and Agriculture (Hydrology and Water Resources). He is Chief of Technology of Sky River Project.**

Yuefei Huang, **professor of Tsinghua University. His research interests include the multidisciplinary field of ecological response of the hydrology-energy-carbon cycling processes, predicting model for non-point pollution and substance transportation, the theory and methods of risk management in water resources and environment adaptability. He is Chief of Remote Sensing monitoring of Sky River Project.**

Xudong Fu, **professor and Vice Dean of School of Civil Engineering at Tsinghua University. He serves as a council member of Chinese Society of Soil and Water Conservation (CSSWC) and Vice Chair of CSSWC Landslide and Debris Flow Committee. His research focuses on fluvial processes and watershed sediment dynamics. He was awarded the NSFC Fund for Distinguished Young Scholars in 2015. He is Chief of Digital River Basin Modelling of the Sky River Project.**

Deyu Zhong, **professor of Tsinghua University, distinguished professor of the Changjiang Scholars of the Ministry of Education. His research interests include sediment mechanics, fluvial processes, flood control. He has improved the sediment dynamic theoretical system by applying two-phase flow theory to the river management, protection and exploitation. He is Chief of Theoretical Research of the Sky River Project.**

Based on this concept and on related research results in recent years, the Sky River research group further proposed the concept of the "Sky River Project". The aim of the "Sky River Project" is the joint and coupled utilization of atmospheric and surface water resources in different regions. Specific regions can be selected when the atmospheric water vapor distribution and transport patterns are fully understood. A new ground-based weather modification technology is being developed and tested for long-term operation at fixed sites. The vision of the project is to achieve its aim -- the coupled utilization of water resources in the sky and on the earth surface in the future, by combining the Sky River theory and techniques with the Tsinghua Hydro30 and the DiRIM as its supports.



Responses of high plateau wetland ecosystem to the artificial weather interventions

High plateau wetlands provide important natural habitats in the Sanjiangyuan area with adequate food resources, as well as comfortable refuge for wildlife species listed in the National Key Protected Wildlife Species in China, IUCN red data book and CITES Appendices. In the context of global climate change, alterations in regional hydrological conditions have directly and/or indirectly influenced the physical environmental conditions of these wetland ecosystems, which have changed the trophic basis of the food web, and affected every consumption unit within these systems.

Aimed at comprehensively understanding the current ecological status of the high plateau wetlands, team members from the Sky River Project have been conducting extensive and systematic field investigations on the physio-chemical environmental conditions and food availability (mainly macroinvertebrates) through continuous monitoring and sampling. On the basis of the collected data, we have distinguished four different sorts of patch-scale habitats in the Sanjiangyuan wetlands according to their environmental conditions, biotic assemblage structures, and trophic characteristics. With the help of ecological statistical methods, we have established an interconnected model of relationships among the regional hydrology, the physio-chemical environments, the biotic assemblages, and the trophic supply. This statistical model can provide reliable evaluations of the ecological health and food resources of the current high plateau wetland systems. It can also be used to predict patterns of ecological conditions and changes in this area under potential human weather interventions. This environment-biota model can be regarded as a specific expansion of the digital watershed model in which the ecological influences of the sky river project will be evaluated based on the responses from terrestrial and aquatic systems. ■

HYDROSENSOFT 2017
A NEW CONFERENCE AIMED TO BRIDGE THE GAP BETWEEN ACADEMIA AND INDUSTRY

BY RUI ALEIXO

Following the goal that every committee should have its own conference, the EMI-LT (2015-2017) accepted the challenge and partnered through IAHR with IFEMA, the largest exhibition centre in Madrid, Spain, to organize HydroSenSoft. Pursuing a different model for a conference, and aiming to bridge the gap between academia and private sector, HydroSenSoft was designed with two main components: a symposium and an exhibition, running in parallel, allowing the change of ideas between the participants coming from the different sectors of activities.

The first edition of HydroSenSoft – Symposium and Exhibition took place from 28th February to 3rd March 2017, in Madrid, Spain. The venue was at IFEMA (the largest exhibition centre in Madrid). IAHR, through its Madrid Office personnel, gave the logistic support to HydroSenSoft (e.g. handling registrations).

The first day of HydroSenSoft (February 28th) was dedicated to the exhibition opening and to an independently organized side event: a course on MoHiD, quite participated, in particular by the Spanish community. For the exhibition part, seven companies were there because of HydroSenSoft. Since HydroSenSoft was held at the same time as the SIGA exhibition (Trade Fair for Innovative Water Management Solutions, one of the largest exhibitions in the urban water cycle domain) more than 50 manufacturers and/or representatives on water related technologies were also present in the exhibition hall.

As to the symposium, it was a two-day international conference (March 1st – 2nd) and a one-day parallel Spanish-speaking session (March 2nd). Over 160 attendees participated in the symposium, with a clear majority of participants in the Spanish speaking session.

A total of 42 papers and 6 posters were accepted after the peer-reviewing process for the international symposium. The authors came from some 20 countries showing the international interest that this first edition reached. Most authors came from academia but many representatives of both private and public sectors were also present. Different manufacturers submitted papers to show the applications of their instruments.

This first edition had three main themes: Theme 1 – Instrumentation and data acquisition tools; Theme 2 – Software tools for data acquisition and numerical modelling; and Theme 3 – Application of sensors and software for hydro-environmental problems. Three high-quality keynotes contributed to a good conference level: Marian Muste (University of Iowa and IIHR), Michael Natschke (Kisters) and Enrique Álvarez-Fanjul (Spanish State Ports). The keynote speakers represented the three main sectors: academia, private sector and public sector. Without any previous arrangement it was a good coincidence that there was a thread line between the different keynotes, in particular the ones from Michael Natschke and Enrique Álvarez-Fanjul, who used the Copernicus Emergency Management Service for different goals: flood emergency system (Natschke) and maritime/off-shore problems (Fanjul).

Rui Aleixo **has a PhD in Engineering Sciences from Université catholique de Louvain, Belgium. He is currently working in the University of Bologna on Acoustic Doppler signal processing. He is the IAHR Experimental Methods and Instrumentation committee (EMI) chair for the period 2015-2017. As EMI chair, he co-organized the W.A.T.E.R. Summer School and HydroSenSoft 2017 conference.**

The degree of participation of the delegates from the different sectors was high, with many debates and discussions in each session continuing into the coffee-breaks; a clear sign of the high interest this area has for academia, industry and private sector.

In the last day of the symposium, an open meeting was held with some of the delegates to debate HydroSenSoft, how to improve it for the next edition and to present the EMI committee and the work developed in these last two years.

HydroSenSoft ended with the technical visits. Three visits were planned: to the Tagus River Basin Management System and to the CEDEX installations in Madrid including Centro de Estudios Hidrográficos (CEH) and Centro de Estudios de Puertos y Costas (CEPYC). In this last visit, a technical demonstration was organized by one of the manufacturers present at HydroSenSoft.

For the success of HydroSenSoft much contributed the logistic support provided by the IAHR Madrid's Office personnel (Maria Galanty, Elsa Incio, Estibaliz Serrano, Carmen Sanchez and Manuela Suanno), responding in time to every question and need of the delegates. ■

Figure 1. Opening ceremony, from left to right: Rui Aleixo (EMI chair 2015-2017), Chris George (IAHR Executive Director), Ramón Gutiérrez Serret (IAHR Secretary General), Carlos González García de la Barga (IFEMA). Copyright IFEMA

The second edition of HydroSenSoft will take place in 2019 Feb 26th – March 1st, again in Madrid. www.hydrosensoft.com

EXPERIMENTAL HYDRAULICS AND THE SUSTAINABLE DEVELOPMENT GOALS

BY ALESSIO RADICE, RUI ALEIXO & RUI FERREIRA

Attaining the Sustainable Development Goals (SDGs) requires actions and measures that mostly depend on the political leadership at both the local and the national level. However, individuals and technical organizations can contribute to these goals by providing their expertise and facilitating the implementation of specific measures.

In this context, IHAR, through the Experimental Methods and Instrumentation (EMI) Committee, can contribute to wider use of new technology in the water sector, and can actively work on knowledge transfer and access to water-related data.

The mission of the IAHR Technical Committee on EMI is to foster international activities in the area of instruments, experimental methods, and data analysis software for both laboratory and field applications. The EMI committee is interdisciplinary and branches in all fields of experimental hydraulics. The EMI committee's mission is not limited to any specific process or product.

Experimental methods have been a key component of the scientific method, since theories and models are validated by means of carefully designed and executed experiments. Nowadays, hydraulic instrumentation and experimentation play a key role for understanding fundamental processes that affect the health of aquatic ecosystems and the safe use of water supply sources They are used in tests supporting the design of water infrastructure and more and more for real time monitoring.

A major recent initiative of the EMI Committee was the organization of HydroSenSoft 2017, International Symposium and Exhibition on Hydro-Environment Sensors and Software, in Madrid in March 2017 under the chairmanship of R. Aleixo, Á. L. Aldana and J. F. Sánchez. The aim of this event was to bring together users, researchers and developers interested in and working on software and sensors/instrumentation for acquiring, analyzing and using data for better understanding of the hydro-environment. (See also the article on HydroSensoft 2017 by Rui Aleixo included in this issue).

A random selection of papers from the proceedings of this symposium shows the vitality of research in this field and its relevance for different UN-SDGs, and illustrates the broad range of topics covered by EMI.

Several papers were related to the Water, Sanitation and Hygiene (WASH) objectives (SDG 6). For example, Climent et al. presented work on wastewater treatment applications using bioreactors [1]. A novel fluorescence-based method for continuous water quality analysis was proposed by Bridgeman & Zakharova [2], who described several potential uses of this technique, such as detecting organic and microbial matter in a range of water qualities (from sewage to drinking water), improving process efficiency in water treatment plants, and identifying potential contamination in service reservoirs and distribution systems. García-Rupérez et al. described a nanophotonics-based sensing technology capable of measuring the lowest concentrations of contaminants, with the possibility of deploying analysis platforms suitable for real-time on-site testing/monitoring [3]. A portable instrument for water quality analysis was presented by Ormaechea et al., who showed results from the measurement of several parameters such as pH, temperature, conductivity, and turbidity [4]. Sediment plays a significant role in aquatic environments, as fine suspended sediments degrade water quality; on the other hand, real-time measurement of suspended sediment is often complicated by adverse field conditions that may prevent physical sampling. Measurements of suspended sediment transport were presented by Guerrero et al. and Hoffman et al., discussing calibration of indirect methods and strategies for long-term sampling [5-6].

Innovative monitoring devices for observations in coastal waters and studies of nearshore hydrodynamics were presented by Cateura et al., who described the conceptual design and performance of a prototype buoy as a platform for efficient multi-variable observations, meeting requirements for robust observations with adequate coverage imposed by increasing pressure on coastal seas[7]. Brand et al.[8] studied the effect of offshore suspended sediment discharge on beach morphology in relation to simultaneous measurements of hydrodynamic conditions on a time meso-scale.

Alessio Radice **holds a Ph.D. in hydraulic engineering and is associate professor of Hydraulics at the Politecnico di Milano, Italy. He is scientific responsible of the Mountain Hydraulics Laboratory at the PoliMi. He joined the EMI in 2015 as vice-chair and is presently chair of the Committee for the term 2017-2019.**

Rui Aleixo **obtained is PhD in University Catholique de Louvain, Belgium. He currently works as a researcher in University of Bologna, Italy. He was the EMI chair from 2015-2017, contributing to the organization of the first edition of HydroSenSoft and of the W.A.T.E.R. Summer School.**

Rui Ferreira **is associate professor of Instituto Superior Técnico, Universidade de Lisboa, Portugal. Frequent user and developer of solutions for Particle Image Velocimetry, Laser Doppler anemometry, digital image processing and quantification of sediment transport. Long-time member of IHAR, is primarily affiliated to EMI and to Fluvial Hydraulics Committees. He is presently vice-chair of EMI.**

Making it possible to get a fish's perspective on ecologically-relevant flows was the goal of new pressure-based devices proposed by Schletterer et al.[9] and Tuthan et al.[10], simulating the highly evolved sensing system of fishes (work supporting SDG 14).

Climate change is changing precipitation patterns, Increasing the need for improved early-warning and monitoring systems. Several problems in dealing with meteorological data were addressed at HydroSensoft 2017, including large scale monitoring (keynote paper by Natschke et al. [11]), the treatment of disdrometer data for drop size distribution during storm events [12] and monitoring-forecasting-warning [13] (supporting SDG 13).

The work of Braunschweig et al. dealt with the optimization of large irrigation systems, to effectively manage the exploitation of water resources in the Alqueva system, Portugal [14]. The topic is relevant to *achieving a sustainable use of water resources* (SDG 12), as well as for the agricultural sector and food production (SDG 2).

These are just some contributions without mentioning the important sector of discharge measurements, that are vital for water course monitoring. In this respect, efforts are currently being devoted to guarantee continuous measurements, low cost of operations using common devices, portability (as in the work presented by Yu et al. [15]) and integration between different types of sensors.

Standard or advanced hydraulic measurements are also related to the general objectives of *increase the share of renewable energy* by prototype investigation (SDG 7) or the *resource-use efficiency with clean and environmentally sound technologies* (SDG 9).

In conclusion, hydraulic experimentation positively contributes to the several SDGs, as shown in the examples of ongoing research. The EMI committee, through its leadership team, is an active contributor to the effort to achieve the SDGs. For this purpose, is planning to organize special sessions/activities related to the SDGs within the different events organized by EMI, such as HydroSenSoft. The success of the Committee depends on the momentum that it will generate to engage a large number of participants to its planned activities. Therefore, we deeply thank all our contributors and wish to keep on this track in the future. ■

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[2] Bridgeman, J., Zakharova, Y.: Novel fluorescence-based instrumentation for continuous water quality analysis

[3] García-Rupérez, J., Ponce-Alcántara, S., Ortiz De Zárate, D., Caroselli, R., Prats, F., Ruiz-Tórtola, Á., Martín-Sánchez, D., Martínez-Pérez, P.: Nanophotonic sensing technology for high sensitivity analysis of water resources

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[5] Guerrero, M., Conevski, S., Baranya, S., Ruther, N.: Combining backscatter and attenuation measurements for suspended sediment concentration assessment

[6] Hoffmann, T., Hillebrand, G., Schmegg, J., Vollmer, S.: Monitoring long-term suspended sediment yields in Germany: quality controls on changing sediment sampling strategies

[7] Cateura, J., Sospedra, J., Gonzalez-Marco, D., Sánchez-Arcilla, A.: Multi-purpose platforms for efficient observations in coastal waters

[8] Brand, E., Chen, M., Montreuil, A. L., Dan, S., Intertidal beach recovery in relation to nearshore hydrodynamics, Mariakerke, Belgium

[9] Schletterer, M., Götsch, H., Tuhtan, J. A., Fuentes-Perez, J. F., Kruusmaa, M.: More than depth: developing pressure sensing systems for aquatic environments

[10] Tuhtan, J. A., Fuentes-Perez, J. F., Schletterer, M., Kruusmaa, M., Pressure Laplacian measurement with a bioinspired fish-shaped lateral line probe

[11] Natschke, M., Salamon, P., Schweim, C., Schwanenberg, D.: Quality-assured meteorological data for the copernicus emergency management service

[12] Arciniega-Esparza, S., Pedrozo-Acuña, A., Breña-Naranjo, J. A., Chaac: A GUI for processing and visualizing optical laser disdrometer data

[13] Batanero, P., Martinez, E.: Early-warning and monitoring real-time systems in rural and urban catchments

[14] Braunschweig, F., Costa, S., Pinheiro, A. N., Carvalho, A.: Modelling and optimization of large irrigation systems

[15] Yu, K., Lee, N., Kang, T.: Surface Image velocimeter using an android smartphone

IAHR EVENTS CALENDAR

IAHR Specialist Events

IAHR Gerhard Jirka Summer School-Environmental Fluid Mechanics
8 - 16 January 2018 Campo Grande, Brazil
http://gjss-2018.weebly.com/

7th International Symposium on Hydraulic Structures
15 - 18 May 2018 Aachen, Germany
www.ishs2018.de

7th International Conference on the Application of Physical Modelling in Coastal and Port Engineering and Science (Coastlab18)
22 - 26 May 2018 Santander, Spain
http://coastlab2018.com/

2nd International Symposium on Hydraulic Modeling and Measuring Technology
30 May 2018 - 01 June 2018 Nanjing, China
http://ishmmt2018.iahr.org.cn/16?lang=en

24th IAHR International Symposium on Ice
04 - 09 June 2018 Vladivostok, Russia
https://iahr-ice2018.ru/

8th International Symposium on Environmental Hydraulics (ISEH 2018)
04 - 07 June 2018 University of Notre Dame, Indiana, USA
https://ceees.nd.edu/iseh2018

13th International Conference on Hydroscience & Engineering (ICHE)
18 - 22 June 2018 Chongqing, China
http://iche2018.iahr.org.cn/2?lang=en

13th International Conference on Hydroinformatics (HIC 2018)
01 - 06 July 2018 Palermo, Italy
https://www.hic2018.org/

12th International Symposium on Ecohydraulics
19 - 24 August 2018 Tokyo, Japan
www.ise2018.com

6th International Conference on Estuaries and Coasts (ICEC 2018)
20 - 23 August 2018 Caen, France
http://lusac.unicaen.fr/evenements/icec-2018/

9th International Conference on Fluvial Hydraulics (River Flow 2018)
03 - 07 September 2018 Lyon, France
https://riverflow2018.irstea.fr/

29th IAHR Symposium on Hydraulic Machinery and Systems
17 - 21 September 2018 Japan, Kyoto
http://www.iahrkyoto2018.org/

11th International Conference on Urban Drainage Modelling (UDM 2018)
23 - 26 September 2018 Palermo, Italy
https://www.udm2018.org/

8th International Conference on Fluid Mechanics (ICFM8)
25 - 28 September 2018 Sendai, Japan
https://icfm8.joomla.com/

8th IAHR International Groundwater Symposium: Water Security and Sustainability
17 - 20 October 2018 (to be confirmed). Nanjing, China

1st International Symposium on Cascade Reservoirs and Water System Operations (ISCRWSO 2018)
19 - 23 October 2018 Beijing, China
http://iswso2018.medmeeting.org/38?lang=en

4th Arabian Coast Congress
March 2019 (to be confirmed). Kuwait
Contact: Dr. Mohamed Al-Rashed, Kuwait Institute for Scientific Research (KISR)

2nd International Symposium and Exhibition on Hydro-environment Sensors and Software (HydroSenSoft 2019)
26 February 2019 - 01 March 2019 IFEMA Feria de Madrid, Spain
Contact: email by www.hydrosensoft.com

8th International Conference on Flood Management (ICFM)
23 June 2020 Iowa, USA
Contact: Marian Muste (marian-muste@uiowa.edu)

IAHR World Congress

38th IAHR World Congress "Water: Connecting the World"
01 - 06 September 2019 Panama City, Panama
http://www.iahrworldcongress.org/

IAHR Regional Division Congresses

5th IAHR Europe Congress
12 - 14 June 2018 Trento, Italy
http://events.unitn.it/en/iahr2018

21st Congress of the Asian Pacific Division of IAHR
02 - 05 September 2018 Yogyakarta, Indonesia
https://iahrapd2018.ugm.ac.id/

XXVIII Congreso Latinoamericano de Hidráulica
18 - 21 September 2018 Buenos Aires, Argentina
https://www.ina.gob.ar/congreso_hidraulica/

THE ROLE OF YOUTH IN ACHIEVING UNITED NATION'S SUSTAINABLE DEVELOPMENT GOALS (SDGS):

LESSONS LEARNT FROM THE 37TH IAHR WORLD CONGRESS

BY CHEE HUI LAI, CHUN KIAT CHANG, HUI WENG GOH, & NOR AZAZI

According to a report by the United Nations Population Fund (UNPF), there are about 1.8 billion young people between the ages of 10 and 24 globally. This is the largest youth population ever, with a large part of this population living in developing countries.

As Goal 17 of the United Nation's (UN) Sustainable Development Goals (SDGs), "Partner for the Goals", emphasizes the importance of partnership with multi-stakeholders, youth must be engaged in achieving the SDGs. For SDG 6- "Water and Sanitation", youth plays a vital role in achieving water sustainability. For instance, Goal 6.1 and 6.2 emphasize the accessibility to safe drinking water and sanitation services. According to UNPF's statistic, in the world's 48 least developed countries, children or adolescents make up a majority of the population, many of whom can not satisfy their water and sanitation needs. For Goal 6.B which emphasizes the participation of local communities in improving water and sanitation management, youth have been claimed to be important voices influencing decision makers in planning water policy in cities. Hence, if by 2030, children or adolescents are expected to have access to better water and sanitation services, the water policies and strategies that will be implemented by 2030 should take into account the ideas of youth and engage youth to be part of the solution.

IAHR efforts in youth engagement

IAHR has been very keen to engage young professionals in various IAHR activities. Referring to an article by Professor Silke Wieprecht published in Hydrolink number 2/2017, according to the database provided by IAHR head office (status 8/2016), out of 4108 IAHR members, 34 % of the members were aged under 35. Through IAHR the Young Professionals Networks (YPN), groups of young professionals and students, gather to share experiences, work on special projects and are given the chance to take part in IAHR activities such as the biennial World Congress, and are thereby able to learn from other IAHR members and create a useful network for their future careers.

Youth's contributions to the 37th IAHR world congress

The 37th IAHR World Congress was held on 14th to 18th August 2017 in Kuala Lumpur, Malaysia. This was the first time ever that the IAHR World Congress was held in South East Asia. The congress attracted more than 1,000 participants from 60 different countries to share the ideas and best practices in managing water for sustainable development.

During this congress, the IAHR Malaysian National Chapter organized various activities to foster communications and networking between students and young water professionals as well as to discuss solutions and ideas related to hydro-engineering research. The activities included a half-day technical tour to learn about Malaysian practices and experience in wetland management and conservation (Figure 1). In addition, a talk was given by the Editor of Journal of Hydraulic Research IAHR, which provided valuable information and tips for young researchers on how to write a journal paper (Figure 2). The room where this talk was given was packed by many young researchers

Figure 1. YPN Technical Tour

Figure 2. YPN Talk on "How to Write a Journal Paper"

Figure 4. A briefing conducted by 37th IAHR World Congress PCO representative on YPN volunteer's duties during the congress

who were looking forward to improving their publication skills.

As for the youth's contribution to the congress, among the 768 papers that were accepted for publication in the congress proceedings, 210 papers were submitted by students (Figure 3). Besides, during the Congress two students received the John F. Kennedy Student Paper Competition Award, an award given to students who contribute the most outstanding papers to the IAHR World Congress. Apart from contributing papers, through the IAHR (YPN), students were the major force in assisting the Local Organizing Committee in various Congress events. In the 37th IAHR World Congress, 47 students from different Malaysian universities were chosen to be YPN volunteers. YPN volunteers were everywhere in the congress, ranging from being a receptionist at the registration counter to being a youth rapporteur in producing the daily congress newsletter. These valuable young volunteers instilled a new energy to the congress (Figure 4 & 5).

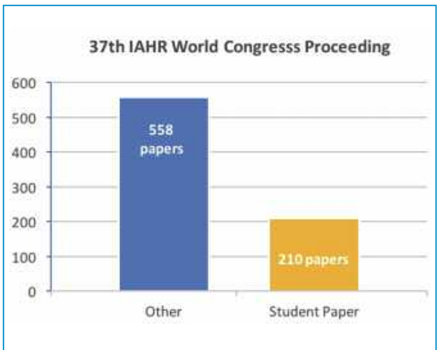

Figure 3. Comparison of congress proceedings submitted by student author and others (non-student author)

Lessons learnt and the way forward

Youth will certainly be a key to achieve the 2030 Agenda for Sustainable Development, but only if their voices are heard and counted as part of the solution to the issues that the world is facing today. Today, young people are eager to take more responsibility in making the world better. In this congress, it was proven that youth can play a vital role in major academic events, not only via presenting articles, but also by providing creative ideas to make the congress events more innovative and attractive. Based on the observations, and discussions with the young researchers and volunteers during the congress, there are more activities that can be organised in future IAHR World Congresses to better engage youth in being part of the solution to hydro-environmental-related issues. One suggestion is to organise a forum for young people that would bring diverse young voices and ideas to discuss solutions for the water and hydro-environental challenges we are facing today. During the forum, many of the youth-concerned topics such as the challenges and opportunities of young researchers in hydro-environmental research, the role of young people in achieving water sustainability, and the contributions of IAHR YPN in SDGs can be discussed. With the networking and resources of IAHR such a forum can contribute to achieving the UN SDGs. ■

Figure 5. YPN volunteers working with the congress PCO in the 37th IAHR World Congress

Chee Hui Lai **is presently a Research Officer in the River Engineering and Urban Drainage Research Centre (REDAC). He was involved in the 37th IAHR World Congress through the Congress PCO Secretariat. He was one of two Malaysian Youth Delegates to the 4th Asia Pacific Youth Parliament for Water, an event organized during the 7th World Water Forum for young people to discuss solutions for water in Asia Pacific Region. His research focuses in water policy and stakeholder engagement in water management.**

Chun Kiat Chang **started working at the River Engineering and Urban Drainage Research Centre (REDAC) in 2002. He has wide experience in various research and consultancy projects related to Sustainable Urban Drainage Systems (SUDS) and Bio-Ecological Drainage System (BIOECODS). He is a Certified Professional in Erosion and Sediment Control (CPESC), corporate member of Institute of Engineer Malaysia (IEM), and the Assistant Secretary for the IAHR Malaysia Chapter.**

Hui Weng Goh **is currently a lecturer at the River Engineering and Urban Drainage Research Centre (REDAC) as well as the Congress Manager for the 37th IAHR World Congress. She received her Bachelor of Engineering (Civil Engineering) from Universiti Teknologi Malaysia (UTM), Master of Environmental Engineer from National University of Singapore (NUS), and PhD in the field of Stormwater and River Management from Universiti Sains Malaysia.**

Nor Azazi Zakaria **has served in Universiti Sains Malaysia since 1994. He established the River Engineering and Urban Drainage Research Centre (REDAC) in 2001 and has since remained as the Director. His main research interests are Sustainable Urban Drainage Systems and River Management. Prof. Azazi is the leading researcher in the innovation of Bio-ecological Drainage System, and is now an established figure in the field of stormwater management at national and international levels. He sits in the Executive Committee for Malaysian National Committee on Irrigation and Drainage (MANCID) and Malaysia Stormwater Organization (MSO), as well as IAHR APD. He is a council member of IAHR.**

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