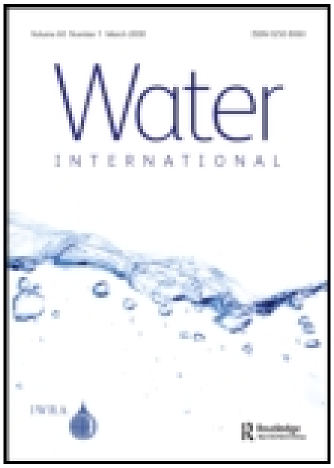

Water International

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/rwin20

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Published online: 19 Oct 2010.

To cite this article: Jun Xia , Guo H. Huang , Zhi Chen & Xiang Rong (2001) An Integrated Planning Framework for Managing Flood-endangered Regions in the Yangtze River Basin, Water International, 26:2, 153-161, DOI: 10.1080/02508060108686900

To link to this article: http://dx.doi.org/10.1080/02508060108686900

International Water Resources Association
Water International, Volume 26, Number 2, Pages 153–161, June 2001

An Integrated Planning Framework for Managing Flood-endangered Regions in the Yangtze River Basin

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Abstract: *This paper presents an integrated sustainable development decision support system (ISDDSS) for the management of flood-endangered regions in China. The ISDDSS is based on comprehensive analyses of the previous flooding events in China, especially the one that occurred in the Yangtze River Basin in 1998. A large number of conditions including the hydrological features and the economic losses resulting from flooding disasters are addressed. Due to the frequent floods in the Yangtze River Basin, the management of flood-endangered regions in the middle stream area has become one of the most important water-related issues in China. This is mainly because of such factors as the regions' high population density, flat alluvial plain, far-flung farmlands, and strong economic potentials. The flood-endangered regions are greatly vulnerable to flooding in rainy season due to the flat terrain and their direct connections with surface rivers and lakes. Moreover, they were often chosen to retain floodwater in order to protect major cities in the Yangtze River Basin. The ISDDSS is proposed to prevent flooding disasters, to minimize flood damages, and to promote sustainable development in such regions.*

Keywords*: Decision support, flood-endangered region, flood control, model, sustainability, water resources.*

Introduction

Along with its economic development and population growth, China is facing a series of challenges arising from water issues such as flooding disasters and drought (Qian, 1992; Chen, 1994, 1995, and 1996; Chen and Xia, 1999). In the past decade, a number of disastrous flooding events occurred in China, leading to approximately US$100 billion in economic losses (Zhang et al., 1997). In 1991, flooding along the Huaihe, Yangtze, and Songhuajiang rivers led to a total direct economic loss of US$10 billion. In 1994, flooding along the Zhujiang, Xiangjiang, and Liaohe rivers resulted in a direct loss of US$20 billion. In 1995, flooding along Dongting Lake, Boyang Lake, and the Second-Songhuajiang River resulted in a direct loss of US$21 billion. In 1998, the direct economic losses from several flooding disasters were over US$31 billion, accounting for 50 percent of the China's yearly GNP growth in that year. The shocking fact is that no extremely high runoff has occurred in the past decade according to statistical data. Although many factors were related to these unusual flooding disasters, human activities such as deforestation, land reclamation, and resources over-exploitation can lead to soil-erosion problems and reduced flood-retaining capacities. Flood control planning and management in the changing world is thus a main challenge in China.

Previously, flood-control related studies have been widely reported. For example, Jin (1999) proposed a method to monitor flooding in China using remote sensing tools. Power and Niemi (1998) evaluated a number of flood control alternatives in the Vermillion River Basin, South Dakota. Haeuber and Michener (1998) investigated methods to control flooding in a natural way. However, there has been lack of considerations on sustainable development of flood-endangered areas, which has been regarded as a crucial issue in China (Huang, 1999; Chen and Xia, 1999). The studies proposed by Hersh (1998) and Churchill and Baetz (1999), pertaining to the development of decision support tools for sustainable development, may have advantages in providing meaningful extension of the current flood control and management efforts.

This paper focuses on the major flooding disaster, which occurred in the Yangtze River Basin of China in 1998. The barriers to the sustainable management of flood-endangered regions are also discussed. Because of the complex nature of the interrelations among different components of the flood-control planning process, a decision support system (DSS) called integrated sustainable development decision support system (ISDDSS) is proposed as a framework for the development of effective management plans. This interactive computer-aided system can be developed to create, run, save, and analyze the related modeling results under projected scenarios for regional development (Simonovic, 1996). The DSS helps users to assess geological conditions and natural hazards, and provides extensive technical bases and supports for decisions related to sustainable management of flood-threatened or affected areas. The study contributes to new methodologies for flood management, with an emphasis on: (1) uncovering the complexities of and reasons for a variety of contradictions and conflicts existing in the flood-endangered regions, including factitious and natural factors; (2) systematically integrating the proposed approaches within a general framework in order to provide a comprehensive decision-support tool for directly conducting scenario analyses; this should lead to desired alternatives for resolving various contradictions and conflicts in flood-endangered regions; and (3) providing re-education and training for decision makers and the public on the importance of the sustainability in the flood-endangered regions.

A number of models, tools, and approaches are considered under a general framework, which can be used to: (1) develop a supporting system for long-term regional socio-economic development and flood-prevention planning; (2) provide effective management on population mobilization and disaster reduction during the flooding period; and (3) conduct optimal planning on the rehabilitation of flooded areas. The DSS will be applied to the flood-endangered regions in the Yangtze River Basin.

Major Flooding Disasters in the Yangtze River Basin

The Yangtze River (also called the Changjiang River) originates from Mountain Tanggula in the Qinghai-Tibet Plateau and meanders over a distance of 6,300 km. It is the largest river in China (Figure 1). The Yangtze River flows across China's mainland from the west to the east, and discharges its water into the Pacific Ocean with a yearly flow of 10,000 billion m^3. The river basin has 3,600 tributaries with a total drainage area of 1.8 million km^2. The Yangtze River Basin is a densely populated and economically prosperous area of China, with many large cities such as Chongqing, Wuhan, Nanjing, and Shanghai. However, as a freely flowing river, it may naturally bring floods. Historically, several great flooding disasters along the Yangtze caused tremendous damages to human lives and properties. During the past 2,100 years, from the beginning of the Han Dynasty (202 B.C. to A.D. 220) to the end of the Qing Dynasty (1644 to 1911), there were a total of 214 flooding events, with an average frequency of once every ten years. In the early 20th century, five severe floods occurred in the Yangtze. The great flood in 1931 drowned 145,000 people and inundated 1.8 million houses. The biggest flood struck in 1954. It claimed 20,000 lives, inundated 3.2 million hectares of cultivated land, and made more than 18 million people homeless. A major flooding disaster occurred again in the Yangtze River Basin from June to September in 1998. This flood has broken many historical records. It was characterized by extended periods of heavy rainstorms, high flooding stages, and enormous flood damages, as described in detail below.

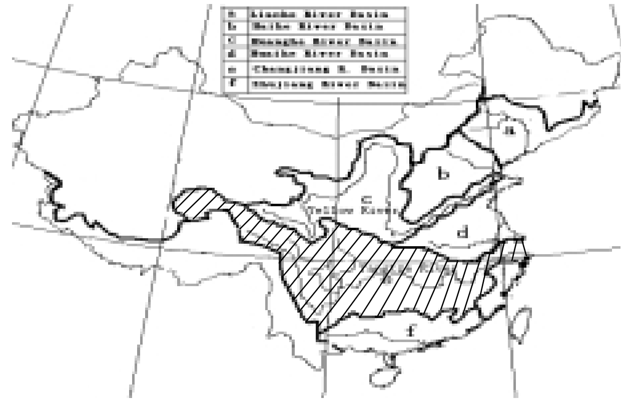

Figure 1. The Yangtze River basin in China.

The Heavy Rainstorms Covering a Large Area Within a Long Period

Since entering the monsoon season on June 11, 1998, heavy rainstorms were frequent in the Yangtze River Basin. If the daily rainfall in a rainstorm-covered region is over 50 mm, then this day is named a rainstorm day (RD). Table 1 shows a total of 74 RDs during a span of 82 days from June to August 1998. The number of days with daily rainfall in excess of 100 mm totaled 64, and that in excess of 200 mm was 18 days. Thus, only eight days out of the 82 days from June 11 to August 31 were without rainstorm events.

The heavy rainfalls during the flooding period covered a vast area. In regions around the Boyang Lake and the Dongting Lake, for instance, the total rainstorm area with daily rainfalls over 50 mm reached 150,000 km^2 on June 23, 1998. On June 13, the area of heavy rainstorm over 100 mm was about 51,000 km^2. Moreover, the intensity of the rains during the flooding period was very high. For example, the precipitation over Wuhan City within 48 hours on July 20 and 21, 1998, reached 457 mm, with a maximum intensity of 95 mm/hr. In the Yuanshui Watershed of the Dongting Lake region, accumulated rainfall in three days from July 20 to 22 was over 655 mm, with all three days having daily rainfalls over 100 mm.

Table 1. Rainstorm Days Occurred in the Yangtze River from June 11 to August 31 of 1998

Date During	*June*	*July*	*August*	*Total*
P > 50 mm	19 d	30 d	25 d	74 d
P > 100 mm	17 d	26 d	24 d	64 d
P > 200 mm	6 d	8 d	4 d	18 d

P - Daily rainfall amount in a rainstorm region in the Yangtze.

The High Flooding Stages

The flood in 1998 ranks the second largest in the Yangtze River basin's history, next to the one in 1954. Statistics in the highest flooding stages, the maximal discharge and the number of days with water levels exceeding the warning line for the 1954 and 1998 floods are given in Table 2, demonstrating the remarkable magnitude of the 1998 flood.

Enormous Flood Damages

Flood has tremendously hindered the sustainable development of the Yangtze River Basin. In 1998, flooding along the Yangtze River caused losses of at least US$ 2.6 billion. The disaster claimed between 2,000 and 4,000 lives and affected more than 223 million people, one-fifth of the country's population. Over 14 million people were evacuated, 17 million homes destroyed, and 21.3 million acres of farmland flooded (Figure 2) [Huang, 1999]. Table 3 lists the major indicators for socio-economic losses as a result of the 1998 flood. It indicates that great floods are the most significant disaster to China's national economy in the long run. When battling the disastrous flood, it was discovered that the most difficult decisions were associated with the flood-endangered regions. These regions are located in the middle reaches of the Yangtze River where the heaviest damages occurred. Accordingly, they are the most critical areas for battling the flooding disaster with all sorts of problems, difficulties, and complexities. Therefore, flood control and management decisions in those regions are extremely challenging and must be addressed by a systematic and quantitative approach.

Barriers to the Management of Flood-endangered Regions

The flood-endangered regions in the Yangtze River Basin are characterized by extensive locations in flooded alluvial plains, vast farmlands with fertile soils, active economic and industrial activities, and effective transportation networks. Because of their flat topography and their direct connections with rivers and lakes, the flood-endangered regions are very vulnerable to flooding in rainy season. Moreover, they often must carry the burden of retaining floodwater in order to protect some major cities.

Figure 2. A flooded area of middle stream of the Yangtze river in 1998.

For example, the Dongting flood-endangered region with a population of 1.48 million and an area of 436.7 km^2 (with 231.3 km^2 of farmland) was burdened by about 163.8 billion m^3 of floodwater in order to ensure the safety of Wuhan City in 1998 (Huang, 1999). As the flooding could happen every few years and the flood-endangered regions need systematic management, it has become an important issue to protect these regions from flooding disaster and to ensure regional sustainable development. Therefore, the following crucial questions need to be answered:

- How can we resolve conflicts and identify tradeoffs between regional planning for sustainable development and the special function for preventing or reducing flood damage?
- How can we provide technical bases or tools for decision-makers to plan for the region's development?
- How can we minimize the damage of properties and the loss of lives during the flooding period?
- What is the desired economic development model suitable for such regions?

Table 2. Comparison of the 1998 Floods with the 1954 Floods on the Highest Flood Level (H_{max}) and the Maximum Discharge (Q_{max}) in the Yangtze River Basin

Station Names	*1998 Floods*		*1954 Floods*		*Duration over the Warning Water Stage (days)*		
	H_{max} (m)	Q_{max} (m^3/s)	H_{max} (m)	Q_{max} (m^3/s)	$H_{warning}$ (m)	1998 Floods	1954 Floods
Yichang	54.50	63,300	55.73	66,800	52.0	44	38
Zhichen	50.62	68,800	50.61	71,900	49.0	31	19
Shashi	45.22	53,700	44.67	50,000	43.0	57	34
Jianli	38.31	46,300	36.57	36,500	34.5	82	64
Luoshan	34.95	67,800	33.17	78,800	31.5	81	72
Wuhan	29.43	71,100	29.73	76,100	26.3	84	100
Jiujiang	23.03	73,100	22.08	73,000	19.5	94	116
Datong	16.32	82,300	16.64	92,600	14.5	83	107

Table 3. Social-economic Loss Due to 1998 Major Flooding Disaster in Hubei, China

Items	*Loss*
Stricken counties/cities	66
Affected persons	36.88 million
Fatalities	345
Wounded/disease persons	8.9 million
Stricken farmland areas (hectare)	381 million
Lost grain production (kg)	4.9 billion
Direct economic loss (US$)	5.9 billion

These problems have been carefully considered in this study, with the details specified as follows:

- Human activities including industrial and agricultural activities have affected the flood-endangered regions significantly. The sediment deposited heavily at the bottom of the Yangtze River is in part due to soil losses. The capacity for retaining floodwater in those regions is also decreasing. These have led to ever-increasing losses and damages during the flooding season. The public may be under the threat of a serious disaster even the river flow is not very high.
- There are a few drawbacks in the current flood-control planning strategy. It is not adaptable to changes of the environment due to lack of consideration of ecological and socio-economic effects. In addition, there has been no systematic consideration of safety issues in the development of flood-endangered regions, as reflected by the following:

  (1) The local engineering infrastructure cannot satisfy the demand of retaining the floodwater.
  (2) There is no scientific support for the current process of decision making.
  (3) There is no well-established policy for flooding loss compensation, which brings difficulties in the evacuation activities and may result in more damages.

- Currently, the mid- and long-term planning for regional economic development and integrated consideration of environmental impacts, flood control, and their interactions need to be improved. The management system also lacks sound technical support because no efficient tools have been developed for providing a technical basis.

With these problems taken into account, the sustainable development of the flood-endangered regions is a tailor-made case for systematic study of economic development and flood control in flood-endangered regions. A detailed outline of such a study to be conducted in China is described in the following sections.

Approaches for Sustainable Flood Prevention and Control

The proposed study of the flood-endangered region in the Yangtze River Basin will integrate flood prevention, disaster reduction, ecological protection, and economic development within a general framework. The formulation of the long-term planning of economic development, the management of flooding impacts, and the reconstruction/rehabilitation of flooded areas will be examined based on the following four aspects: sustainable development, ecological quality, macroscopic impacts, and changing natural and social systems.

A number of modeling tools covering hydrology, ecology, sociology, economics, and interdisciplinary subjects will be employed or developed. In particular, the proposed models will be integrated under a general framework for systematic management. The detailed components of the framework are presented in Figure 3.

Modeling of Interactions Among Environmental and Socio-economic Sub-systems in Flood-endangered Regions

This will include modeling of the effects associated with natural dynamics and human activities as well as their interactions.

In terms of natural dynamics, the following need to be quantified:

- The natural changes of landform and terrain in river basins
- Impacts of climate change on the flooding phenomena and the related disaster factors
- Transport of sediments in the Yangtze River Basin and the resulting effects on riverbeds
- Flooding impacts on ecosystems
- Relationships between epidemic diseases and flooding disasters

In terms of human activities, the model is intended to quantify:

- Impacts of agricultural activities on river and lake basins
- Impacts of land use variations
- Relationships between the construction of flood prevention systems and its effects on disaster reduction
- Impacts of population and economic policies
- Impacts of human cultural activities and local administrative structures
- Effects of disaster compensation mechanisms

The integrated modeling efforts would include the following studies:

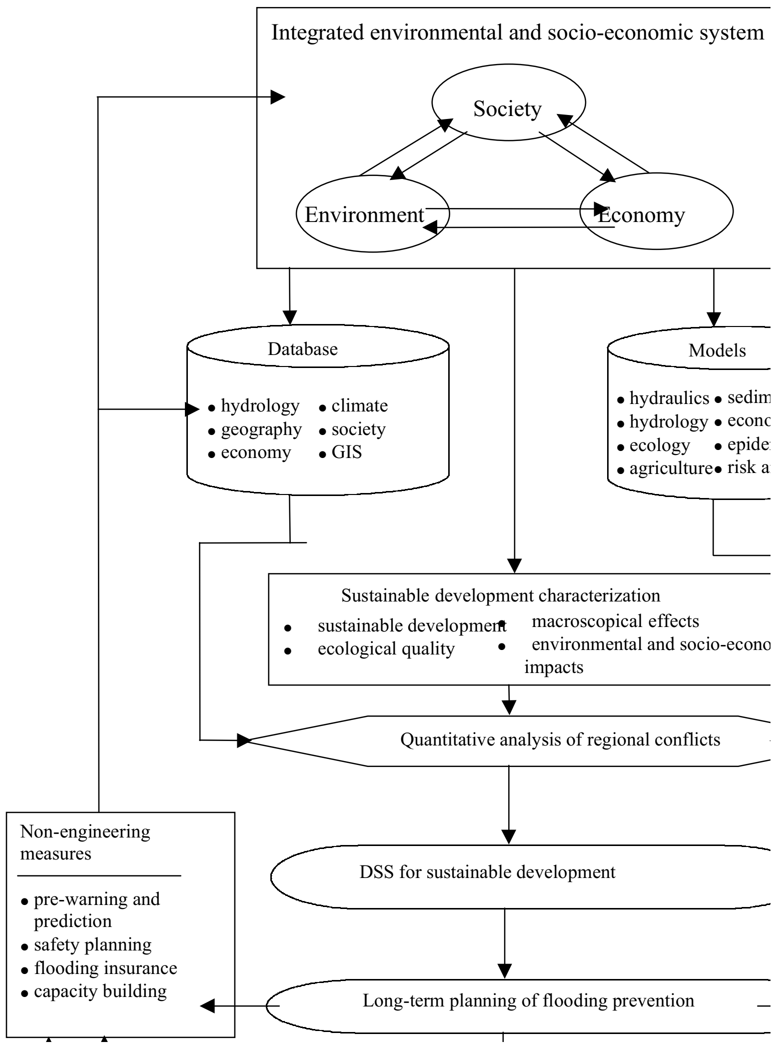

Figure 3. Conceptual framework of DSS for the sustainable development of flooding-endangered regions.

- Socio-economic, ecological and environmental consequences (positive and/or negative) of different prevention and control activities
- Overall sustainability of the development in flood-endangered regions

A number of innovative studies need to be undertaken, including simulation models for forecasting various flood-related activities, assessment models for quantifying risks of flooding disasters, optimization models for providing basis for decisions of short-term flood control and long-term flood prevention, and a series of computer-aided tools for information acquisition, management, and presentation. The details are specified as follows:

- From a hydrological point of view, this study will develop a numerical hydrological model for distributed river basin systems based on region-specific characteristics. This model will be integrated with GIS and remote sensing (RS) tools to quantitatively and graphically address the affluxion relationships among variations in land use, impacts of climate change, and dynamics of regional hydrological conditions. Another important issue is the impact (negative or positive) from major hydraulic engineering projects such as the Three Gorges Dam.

- From a sediment transport point of view, a two-dimensional dynamic sediment transport model will be developed. It consists of a river sediment transport module, a lake sediment transport module, and a distributed river sediment transport module. By coupling them together, the dynamic flow-sediment relationship for the river-lake distributed systems in the middle reaches of the Yangtze River can be elucidated. The evolution of riverbed, the mechanism of sediment flushing, and the impacts of human activities will be modeled.
- From an ecosystem point of view, a distributed ecological model will be developed for the flooding basins. This model will be able to quantify: (1) the impacts of natural changes in ecological structure, sediment deposition, and epidemic diseases; and (2) the impacts of human activities, such as urbanization, agricultural works, and artificial infrastructure.
- From an integrated modeling point of view, an integrated model will be developed to quantify macroeconomic effects and system sustainability. This model will be capable of reflecting interactions among environmental and socio-economic sub-systems and the resulting effects. Therefore, the positive and negative effects of population and economic policies on the society, economy, and environment in different periods will be quantified. The model will support decisions for sustainable development of flood-endangered regions.
- From a decision support point of view, not only simulation models but also risk analysis methods will be developed for supporting decisions under uncertainty. Methods of stochastic risk assessment, fuzzy system analysis, and scenario analysis will be developed. They will be selected to deal with real-world problems under different conditions with various uncertainties being quantified. The proposed models and tools will be applied to flood risk analysis, engineering risk analysis, disaster analysis, economic analysis, and real-time floodwater diversion analysis.
- From a training point of view, a variety of methods including workshops, national and international conferences, and environmental education at various levels will be used to get decision makers, stakeholders and the public involved. Issues regarding importance of regional sustainability, effects of climate change, and impacts of human activities will be highlighted. In addition to the potential socio-economic benefits to the public, a large number of professionals and innovative leaders will emerge through the education programs.

Development of Decision Support Tools

Development of the aforementioned management tools is intended to resolve the conflicts and contradictions between the development of flood-endangered regions and the potentially frequent flooding disasters, so as to provide decision support for the planning of these regions under complex and difficult conditions. Therefore, the key issue is to ensure the sustainability of the flood-endangered regions. An integrated optimization model under a multi-objective framework will be developed by incorporating a variety of proposed tools with a core target of sustainability and safety in the flood-endangered regions.

Decision Support Tools for Long-term Planning of Economic Development and Flood Prevention

Economic Model

The development of the economic model will maximize the overall production of agriculture, industry, fishery, and other economic activities with minimized economic losses in flooding seasons. The key issue is the identification of suitable economic models that reflect the local issues such as fertile farmland, active fishery, and convenient transportation system. The planning results will lead to desired plans for land uses and flood-prevention activities.

Ecological Model

The development of the ecological model is intended to protect local ecosystems and to conduct remediation after a flooding disaster. Concepts of ecological model and optimization model will be combined to support planning for reducing sediment deposition, returning over-used farmlands, and maintaining a desired land-coverage ratio of forest/crop during non-flooding seasons. Also, the model contains functions related to the recovery of flooded ecosystems and damaged river and lake beds.

Sociological Model

The development of the sociological model will provide a basis for identifying the requirements associated with such important issues as population control, economic development, land use planning, and emergency-response mechanisms. Given limited resources and complicated flood-related issues, many conflicts may exist in the study system. The sociological model will provide support for clarifying these complexities.

Development of Effective Emergency-response Systems

The systems planning and emergency-response models will be useful in supporting efficient and quick responses during flooding periods. This will help avoid serious losses of human lives and properties. In detail, an emergency-response model will consist of the following components:

- Emergency personnel mobilization system (including the pre-warning and prediction of flooding, the safety consideration of allocated sanctuaries, and the related providence for required equipment and set up of necessary agencies).
- Sanitary, anti-epidemic, and safety system in flooding period (including the engineering construction of temporary sanctuaries, the emergency medical system, the

temporary organizations for medical or rescue needs, and the prevention and treatment of epidemic diseases).

- Safety education and training system (including mobilization under emergency, provision of first-aid help to injured people, prevention of epidemic diseases, and self-protection).

Decision Support for Mitigating Socio-economic Damages

Decision support for the reconstruction of flood-damaged areas will be provided. They include: (1) evaluation of economic losses and damages; (2) assessment of environmental and economic impacts; (3) cost accounting; (4) public involvement; and (5) planning of recovery and reconstruction activities.

Decision Support for Sustainable Development in Flood-endangered Regions

A computer-aided decision support system (DSS) will be developed. It contains databases, a graphics library, and a model library. It can process various kinds of information related to regional development and flood prevention, using a variety of embedded models and objective-oriented management tools. This leads to human-machine interactive DSS, as shown in Figure 4. The system mainly includes: (1) distributed databases (hydrological, climate, sediment, and socio-economic); (2) simulators (hydrological, sediment, economic, ecological, planning, decision analysis, and risk); and (3) user interfaces (graphics, tables, and questions).

GIS- and RS-supported Interfaces

In order to effectively manage spatial information and to present modeling inputs and outputs graphically, GIS and remote sensing (RS) techniques would be integrated within the general DSS framework. Moreover, internet technologies would be employed to develop distributed database systems, advanced graphic user interfaces (GUI), and user-friendly interactive systems in order to satisfy the requirements of different users at different levels.

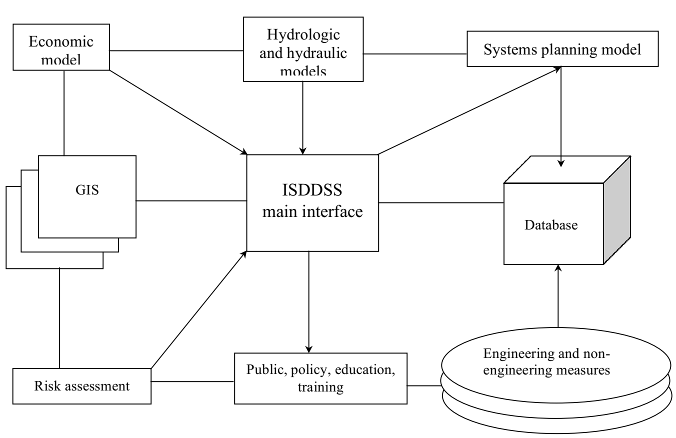

Figure 4. Operational diagram of the decision support system.

Concluding Remarks

Flooding is the most significant natural disaster that injures China's economic development. This is perhaps one of the important reasons why both water ecosystem protection and infrastructure development (e.g., the Three Gorges Dam Project) have to be given so much attention in the country. The special geographic location of the Yangtze River Basin with a high frequency of heavy rainfall events could easily result in a flooding disaster. On the other hand, human activities are another set of important causes that lead to increased flooding risks. For instance, the flood-retaining capacity of the Dongting Lake, which is connected with the Yangtze River, has decreased significantly during the past 40 years due to a number of land reclamation projects. Moreover, soil erosion and sediment accumulation in the river are other causes that contribute significantly to the intensified flooding events. They are attributed to ecological deterioration in the middle and upper reaches of the Yangtze River.

China's annual flooding losses are considerable and it appears that they will continue to rise in the 21st century. Given the challenges of flood prevention and management, the most important technical issue is to improve the knowledge of the system's hydrological processes. They include modeling land phase of hydrological cycles at both catchment and regional scales, initiation of applicable hydrological information systems, development of hydrological modeling methodologies, and establishment of viable flood control and hazard mitigation mechanisms. Based on the above considerations, the following questions can be answered: "Why does the flooding disasters occur so frequently?" "Why have flood damages become increasingly serious?" "What are the potential solutions?" Four main reasons for the frequent occurrence of flooding disasters in China are highlighted as follows:

- Unfavorable geophysical-geographical conditions are responsible for the frequent occurrence of flooding disasters.
- The shriveling up of rivers and lakes led to greatly decreased floodwater retaining capacity and thus a raised flood stage.
- For most of the watershed in the basin, the flood control standards are too low despite considerable upgrades over the last decades. They can only be used for handling normal floods but not risky ones.
- The intensive human activities and great variations in the natural water environment have been significantly affected and, therefore, changed the normal patterns of the floods.

An integrated sustainable development decision support system (ISDDSS) has been proposed for effective management of the flood-endangered regions. The ISDDSS is a sophisticated tool with GIS- and RS-supported user-friendly interfaces through which users or decision makers could effectively predict flooding events, manage flood-endangered regions, undertake recovery/reconstruction plans, and identify desired schemes for regional development. Specifically, the ISDDSS would provide: (1) supporting information for decision makers to gain in sight of system dynamics, real-time status, flooding damages, and risk levels; (2) technical analyses of historical records of floods and their distributions, as well as economic losses under different management scenarios; and (3) case studies that focus on urgent and/or risky events, where socio-economic and environmental consequences under different decision alternatives would be evaluated.

Acknowledgement

This research has been supported by the Canadian International Development Agency, the Hundred Talents Program of CAS, the Natural Science Foundation of China (49971017), and the Natural Sciences and Engineering Research Council of Canada.

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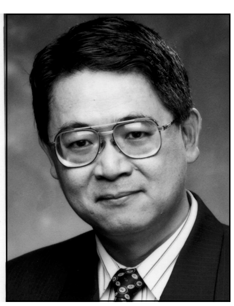

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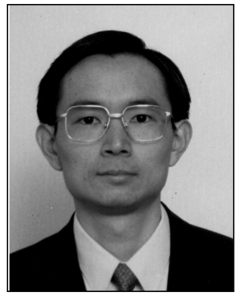

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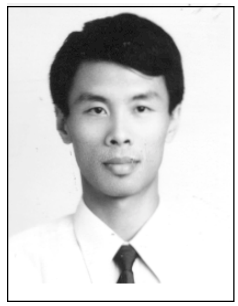

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Discussions open until December 1, 2001.

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