Sustainable and integrated water resources management for the coastal areas of Shandong Province, China

Water Science & Technology **Vol 54 No 11–12 pp 57–64** © IWA Publishing 2006

R. Kutzner*, B. Zhang, S. Kaden*** and W. F. Geiger***

*Urban Water Management, Department of Civil Engineering, University of Duisburg-Essen, Universitaetsstrasse 15, 45141 Essen, Germany (E-mail: *ralf.kutzner@uni-essen.de*; *wolfgang.geiger@uni-essen.de*)

**Water Conservancy Research Institute of Shandong Province, Lishan Road 125, Jinan 250013, China (E-mail: *boris_white2002@yahoo.com.cn*)

***WASY Institute for Water Resources Planning and Systems Research Ltd., Waltersdorfer Strasse 105, 12526 Berlin, Germany (E-mail: *SO.Kaden@wasy.de*)

Abstract Water scarcity and water pollution are severe problems in the Northern part of China, strongly affecting socio-economic development and standards of living and environment. The Shandong province is specifically plagued by water scarcity. In the coastal catchments of the Shandong province the water scarcity is even increased due to saltwater intrusion, reducing the usability of water resources available. The pressing water problems in the costal catchments in the Shandong province and resulting socio-economic troubles forced the Chinese authorities to implement a variety of measures to relieve water scarcity and abate saltwater intrusion. But not much has been achieved so far as the measures are not coordinated in their effects and cost-benefit relations have not been considered sufficiently. Such a situation calls for good, which means integrated, sustainable water management. The assessment of this situation in the project "Flood Control and Groundwater Recharge in Coastal Catchments" financed by the German Ministry of Research and Education is presented. Further objectives and first ideas for an IWRM-concept are explained. These ideas are based on concepts developed in Germany in the context of the fulfilment of the European Water Framework Directive.

Keywords Integrated water management; saltwater intrusion; sustainability; water scarcity

Introduction

Shandong Province is located in the east of China at the lower course of the Yellow River. The province has a coastline of more than 3000 km to Bohai Bay and the Yellow Sea. The total area of Shandong province is about 157 thousand km^2 with a total population of 90 million inhabitants by the end of 2000. The available water resource per capita is about 340 m^3/(capita.a). Compared to international standards for minimum needs of about 1000 m^3/(capita.a), there is a tremendous water scarcity in Shandong province. According to the present water supply ability, the annual water shortage is about 3.4 billion m^3/a. It is estimated that the water shortage will be about 6 billion m^3/a in 2010.

The Huangshui River basin is located in the coastal region of Shandong province and was the subject of the project "Flood Control and Groundwater Recharge in Coastal Catchments" financed by the German Ministry of Research and Education (Geiger *et al.*, 2005). Within this region the water scarcity is even increased due to saltwater intrusion and in consequence the economic development and socio-economic conditions are less favourable than in other regions of the province. Project work started with a deep investigation into the conditions in the fields of hydrology, water resources, water pollution and the consequences of water scarcity. Based on this analysis a concept for an Integrated

doi: 10.2166/wst.2006.842

Water Resource Management (IRWM) was elaborated and first ideas for its realization developed.

Analysis of water management condition of the study area

The Huangshui River basin covers an area of 1034 km^2. The river length is about 55.43 km. The catchment is located along Laizhou Bay. The catchment is shown in Figure 1. A main portion of the catchment is part of Longkou City (44%). The urban area is located at the lower end of the catchment above 36° northern latitude and 119° eastern longitude.

Climatic and hydrological conditions

The Bohai Bay coastal area, where Longkou City is situated, belongs to the half moist monsoon type continental climate. This temperate zone makes a clear distinction among the four seasons. The average rainfall amounts to 586 mm in Longkou city. The rainfall is unevenly distributed during the year: 72.9% of it falls from June to September. In June and July only, it accounts for 49.8 percent of the year's rainfall. The maximum rainfall in Longkou city was 1046.2 mm in 1964 and the minimum was 329.4 mm in 1989. The average temperature during the whole year is 11.6 °C. The potential annual average evaporation is between 1238.2 mm and 1350.2 mm. The relative humidity is about 70%.

Water resources and water demand

The Huangshui River with a catchment of 1034 km^2 has an annual mean runoff of 178 million m^3. A share of about 72% is from the monsoon season between July and Sept. At that time the runoff amounts to about 16.5 m^3/s on average. In the remaining season the Huangshui River and its tributaries fall more or less dry. In order to store water over the season, upstream of the Huangshui River a reservoir with a total capacity of 121 million m^3 has been constructed. In addition, along the river there are 6 weirs to store water

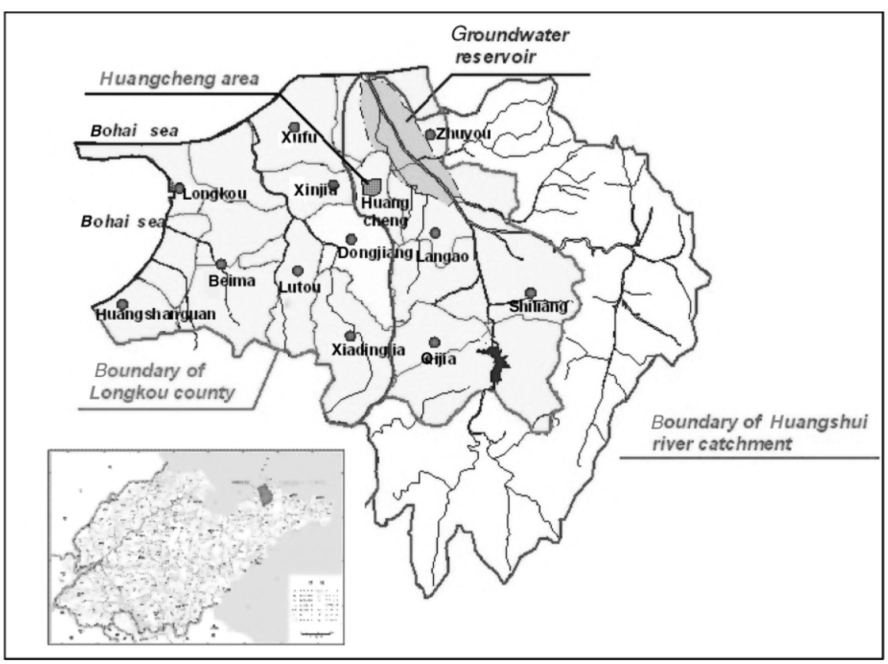

Figure 1 Map of Huangshui River basin and Longkou City

(about 5 million m^3) in order to increase bank infiltration for groundwater recharge. The groundwater reservoir capacity is about 53 million m^3. There is an underground dam to avoid salt water intrusion and store the groundwater downstream before the sea.

The total water consumption amounts on average to about 162 million m^3/a. It is composed of approximately: agriculture (irrigation) 69%, rural domestic 6%, urban domestic 3%, industry 21% and environment 1%. Although water saving techniques in irrigation after many years of research and international cooperation are introduced, agricultural water demand still increases. With a usable runoff of about 120 million m^3, the water demand of 162 million m^3/a exceeds the water resources on average by about 25%. This problem is even more severe considering the monthly and annual distribution of water resources and water demand. A sketch of the main water flows in the water balance is given in Figure 2.

Water pollution

There are various sources for the pollution of surface water and groundwater. Three main types can be distinguished.

(1) Domestic wastewater: There are about 620,000 inhabitants in Huangshui River basin, 25% of whom live in the city of Longkou. Only the urban area of Longkou city has a wastewater collection system connected to a wastewater treatment plant. The domestic wastewater is discharged untreated to the river. The storm water is collected in a parallel sewer system and discharged to the river.

(2) Industrial wastewater: In the Huangshui River basin, aluminium industry, paper industry, chemical industry, cement industry, coal mining and coal-fired power stations exist. Mostly the water is used only once and discharged without any special purification or treatment.

(3) Agricultural drainage and infiltration: In the considered area, there is intensive land-use for agriculture. The usage of manure and fertilizers is practiced, so that the discharge of harmful substances and nutrients into the soil and the groundwater is obvious.

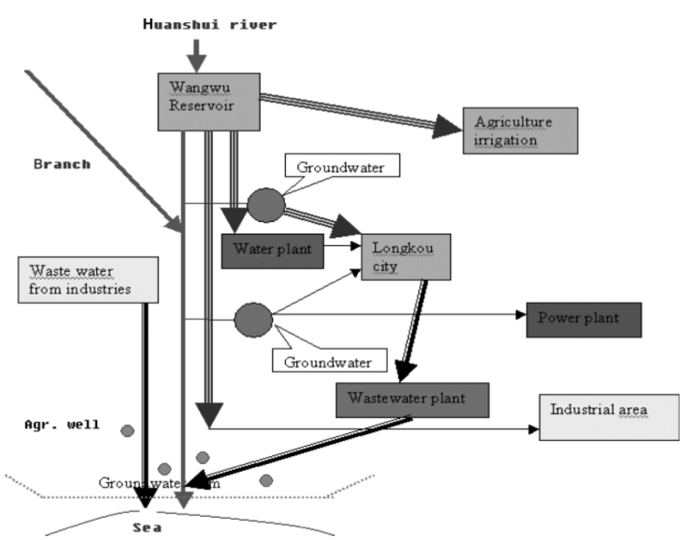

Figure 2 Systems sketch of water management in the Huangshui river basin

Saltwater intrusion

The increasing groundwater use results in groundwater depletion and due to that in the coastal regions, increasing saltwater intrusion from the sea. In the region of Longkou city, especially the Huangshui river basin, the area of salt water intrusion reached 81 km^2. The transition zone along the coast has a distance of about 3 km. The potential endangered area with groundwater table below sea water level amounts to additional 80 km^2. It has already caused a drinking water crisis for about 60,000 people, 200 wells were abandoned, and 2000 ha farmland lack of irrigation water capacity; and food production decreased causing socio-economic conflicts.

Consequences of present water management

The analysis of the existing water management can be summarized as follows.

(1) Overexploitation of groundwater results in saltwater intrusion which decreases additionally the availability of water resources.
(2) Social status and income of farmers in the Shandong province is significantly below a level that would allow them to keep up with the technology development in irrigation and farming. As a result they use more water than necessary and pollute groundwater and soils.
(3) Wastewater and stormwater is mostly discharged untreated. Wastewater reuse is not applied. Untreated discharge degrades surface waters as a source for water supply.
(4) Measures taken so far, e.g. the groundwater dam against saltwater intrusion, take effect against symptoms but not against the basic problem of the overexploitation and destruction of resources.

Such a situation calls for good, which means integrated, sustainable water management (Gumbo and van der Zaag, 2001).

General IWRM concept and methodology

The problems and conflicts in the coastal regions of Shandong Province and in the Huangshui river basin are tightly merged. Individual measures have no effect, as the past has shown, especially, because social-economic consequences result from a variety of influences. This becomes obvious when looking at the problem of saltwater intrusion. This could be stopped, if no further groundwater could be extracted for irrigation. This would lead to tremendous social problems. But the problem of saltwater intrusion can not be solved with technical measures alone. A solution can be only achieved with an integrated water resource management (IWRM).

The basic demand for a solution strategy is sustainability. For example, a groundwater dam may prevent the intrusion of saltwater into the groundwater, but the further extraction of groundwater results in a declining groundwater level. This leads to an increasing difference between ground and seawater level, and eventually saltwater will intrude into deeper layers of groundwater. The following simple equation has to be considered:

$$\sum_{j=1,i=1-12}(\mathrm{WR}(j,i)-\mathrm{WU}(j,i))\geq 0$$

with WR: available water resourses per month. WU: water consumption per month.

The balance should be positive at least over several years.

$$\sum_{j=1,J}\sum_{i=1-12}(\mathrm{WR}(j,i)-\mathrm{WU}(j,i))\geq 0$$

Following the principle of an IWRM, water is an essential element of the ecosystem. It is a natural resource and a social and economic commodity. According to this complexity, a variety of aspects have to be considered, in order to take account of the interaction between water and society. In addition, a variety of stakeholders has to be involved. The coordination of interests between these groups might be very complicated. Decision Support Systems (DSS) support this complicated planning and decision process.

In general, the possibilities for a sustainable IWRM are versatile. The applicability depends on local and regional conditions, as well as socioeconomic states and requirements. It is almost impossible to analyze all of the effects of a possible measure in detail. Therefore, the concept of a two-stage DSS is recommended, after a detailed analysis of the catchment area.

Within the first step of the first stage DSS (DSS-1) all available measures especially in the fields of water saving, ground water recharge, water recycling, structural measures against salt water intrusion and institutional measures are considered. As a basis it is planned to setup measure catalogues that include all potential measures. These catalogues should include a description, the boundary conditions for the application, dimensioning rules, effectiveness and costs (investment and operational expenses, economic lifetime), as well as manufacturers of hardware (examples), environmental and resource effects and information about the social acceptance.

In the next step of DSS-1, the measures have to be identified which are suitable for the specific project considering political and social aspects, costs and environmental conditions. Within the third step of DSS-1 a small number of the best scenarios are selected upon environmental and resource costs. For the final planning (DSS-2) and the implementation only a small selection of bundles of measures can be analyzed in detail. On the basis of technical, economic and social criteria and in close cooperation with the regional decision makers, a final strategy can be selected. For this purpose the use of multi-criteria analyses is intended.

In this phase a detailed analysis of the linkage of individual measures, if relevant, is carried out to find an optimal combination of measures. At this point the relevant processes are modelled in the natural system and the efficiency of the individual measures is calculated while considering the social economic aspects.

Figure 3 illustrates the way applicable measure bundles (scenarios) are developed on the basis of general measure catalogues and the further step to the most sustainable solution.

Within DSS-2 a detailed analysis of the selected scenarios has to be performed in order to find the "optimal" solution. This level should combine both modelling of the relevant processes, impacts and measures under study and their socio-economic evaluation. Figure 4 illustrates the major step of the DSS-2.

In a GIS-based system the database for the modelling and the integrated water resource management is stored. The basis is a system developed in Germany (Loucks and Kaden, 1999) for the implementation of the EU-water framework directive named ArcWFD/WISYS. This system is also the platform for the integration of the interactive components of the DSS.

As mentioned before, the participation of so called stakeholders in the planning and decision process is of great importance. It is intended to develop and apply a participating approach that is adapted for the Chinese conditions. For the evaluation step of DSS-2 (Figure 4) Multi Attribute Decision Making (MADM) techniques (Mahmoud and Garcia, 2000) will be used to identify so called pareto-optimal solutions. These solutions will be provided to stakeholders and decision makers by the Reasonable Goal Method (RGM) based on computer based Interactive Decision Maps (Lotov *et al.*, 1997). At last the "optimal" solution has to be elaborated in an interactive process between decision makers and stakeholders.

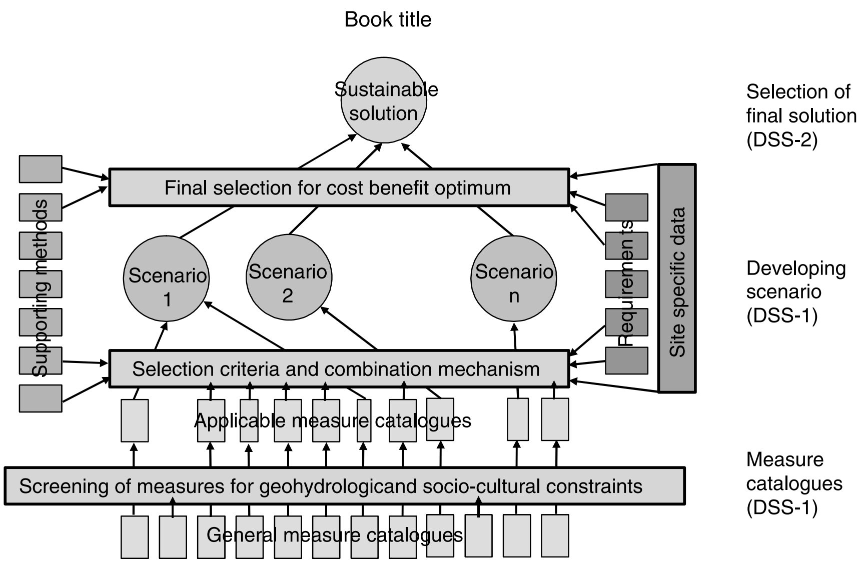

Figure 3 Structure of the two stage Decision Support System

Impact analysis (see Figure 4) will be done by applying appropriate models. For the application in Huangshuihe River basin it is planned to use the following models:

(1) Mike 11: surface run off model (DHI)
(2) WBalMo: Model for the planning of water resources including economic ratings (WASY GmbH)
(3) FEFLOW: 3D groundwater flow- and quality transport model (taking the density into account)

The integration of the individual models is shown in Figure 5.

Potentially applicable measures within an IRWM

There are different domains of measures which could be applicable for the intended IRWM application. These are as follows:

(1) water saving in households
(2) water saving and water recycling within industrial applications
(3) reduction of water losses in the water distribution system

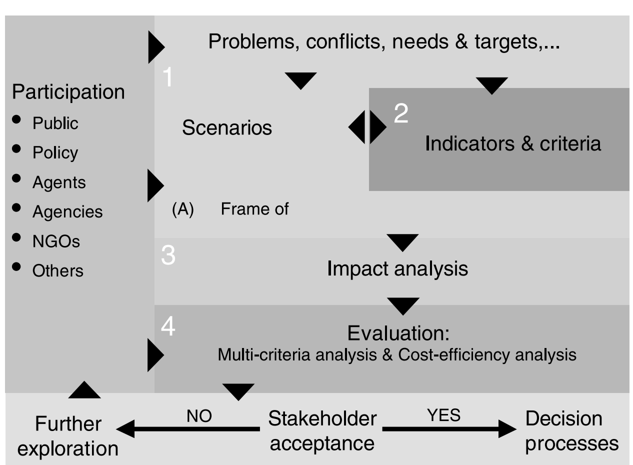

Figure 4 The participative approach of second stage of Decision Support System (www.glowa-elbe.de)

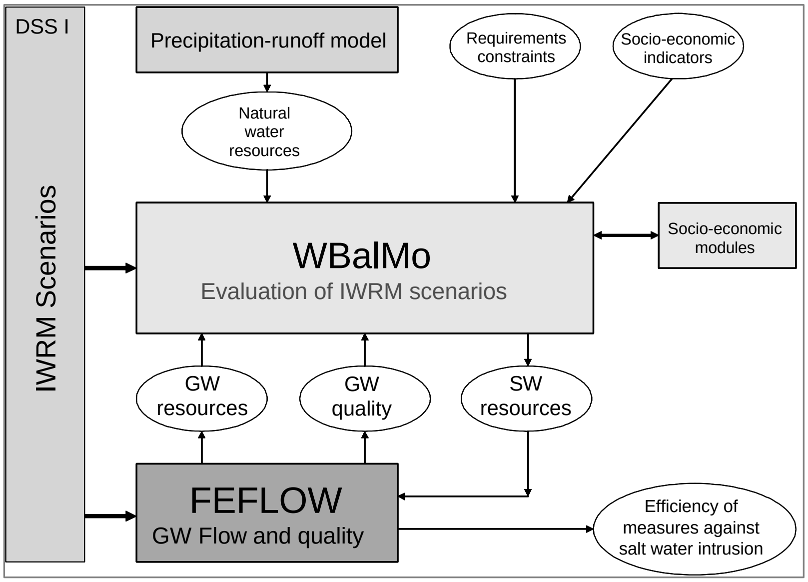

Figure 5 Models used within second stage of the Decision Support System

Water saving: the characteristic of water use will be analyzed exemplarily. That is why data on water usage of selected industrial companies has to be collected (e.g. paper industry). Afterwards, measures for water saving will be introduced, e.g. reduction of volumes, sealing of leaking pipes and circuitry. For example in Germany the average water consumption was reduced over 400% based on the current conditions in the last 30 years by these kinds of measures.

(4) water saving in agriculture

(5) grey water and black water recycling

(6) rainwater use in agriculture, industry and houses

The possibility of rainwater harvesting and storing surface waters should be analyzed, also as an alternative water source for industry. Especially the fact, that most of the precipitation accumulates in summer (72.9%) from June to September, makes the storage of rainwater an important measure for irrigation in agriculture.

(7) new technologies for ground water recharge

(8) institutional measures like water pricing, implementation of standards and obligations

(9) consulting for stakeholders like farming associations to ease implementation of measures

A second group of alternatives relates to the monitoring and reduction of water pollution. The basis should be the establishment of a master plan for the Huangshui River basin: a consistent and complete plan that adequately considers pollution sources (sewer overflows, insufficient wastewater treatment, sewage treatment, industrial waste, soil erosion and diffuse sources from agriculture) and possible alternatives (source control of rainwater drainage, storage volume in sewers and treatment of polluted drainage, recycling of industrial waters, enforcing the compliance of regulations etc.) does not exist today.

Conclusions

Sustainable and integrated water resources management not only consists of technical measures and modelling techniques. It is fundamental to prevent social conflicts caused by planning decision by the integration of stakeholders into the planning process.

The presented two stages Decision Support System is able to integrate technical, social and political issues into water management decisions. It is important to mention that this kind of approach can only be successful by being integrated into Chinese law and administrative regulations.

References

Gumbo, B. and van der Zaag, P. (2001). Principles of integrated water resources management (IWRM). *Proceedings of Southern Africa Youth Forum*, 24–25 September 2001, Harare, Zimbabwe.

Geiger *et al.* (2005). Cost-effective measures for flood control and groundwater recharge in coastal catchments. Research project founded by BMBF, Förderkennzeichen: CHN 04/015, Bonn, Germany (in German).

Loucks, D.P. and Kaden, S. (1999). Sustainability of water management systems. *Wasserwirtschaft Wassertechnik (wwt)* 1/99, pp 46–48 (part 1), 2/99, pp 49–50 (part 2); 3/99, pp 10–16 (part 3) (in German).

Lotov, A., Bushenkov, V. and Chernykh, O. (1997). Multi-criteria DSS for river water quality planning. *Microcomputers in Civil Engineering*, **12**(1), 57–67.

Mahmoud, M.R. and Garcia, L.A. (2000). Comparison of different multicriteria evaluation methods for the Red Bluff diversion dam. *Environmental Modelling & Software*, **15**, 471–478.