Overall-effective measures for sustainable water resources management in the coastal area of Shandong Province, Huangshui River Basin

山东省滨海地区水资源可持续管理的有效措施：以黄水河流域为例

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Abstract

Water scarcity and water pollution are severe problems in the Northern part of China, seriously affecting socio-economic development and standards of living and environment. In the coastal catchments of the Shandong province the situation is even more stressed due to salt water intrusion. The positive results of previous projects on rainwater harvesting in a salt water intrusion area at Jiangsu coast in 1995 and on flood control and groundwater recharge in Beijing from 2000 to 2005 encouraged to apply a holistic IWRM approach to the complex water and socio-economic problems in Shandong, in particular for the Huangshui River Basin and the Longkou district. With good water management there is a realistic opportunity to relieve the water scarcity situation, to abate salt water intrusion and with this to stop the already ongoing socio-economic depression. The project is funded by BMBF on the German and MOST on the Chinese side, started in June 2008 and will last until Mai 2011. On the German side, totally seven partners are involved in the project; all of them are experienced in solving water related problems. The overall project contains two phases – a planning phase and an implementation phase. On the one hand Integrated Water Resources Management indicates that all single relevant physical processes should be treated as a part of a complete and interactive system. In the project it will be focused on the interaction of groundwater recharge, surface and groundwater, both from the quality and the quantity point of view. In practice, this means that a detailed integrated hydrological model for the Huangshui River Basin will be developed using the specific experiences and

software provided by the different partners. On the other hand, IWRM means that decisions should be made, taking into account the different stakeholders in the project area as well as future social and economical developments. For this reason, a GIS supported DSS system will be developed. In the first stage of the project a detailed simulation-model independent analyses of all possible measures to reduce the water stress in the region will be made. From this, a so-called measures catalogue will be generated that will consider ecological, political as well as social aspects and will provide a cost benefit analysis for each of these. This catalogue will be the main input for the DSS, which will use the hydrological model to analyze the different selected measures packages in detail. On the basis of technical, economic and social criteria and in close cooperation with the regional decision makers, a final strategy can then be selected. For this purpose the use of multi-criteria analyses is intended, which allows multiple attributes, both tangibles and intangibles, imprecise and uncertain probabilities, dependency and feedback and is interactive and learning based. Finally a short overview on the implementation phase focusing on water saving, greywater recycling and waste water reuse will be given.

摘 要

在中国华北地区，水资源短缺与水污染正严重制约着当地社会经济发展、人民生活水平提高和环境质量的改善。在山东省滨海地区，由于存在海(咸)水入侵问题使得这一现象更加突出。1995 年在江苏省滨海海水入侵区采用了雨水收集利用措施，2002-2005 年在北京进行了防洪与地下水回灌技术研究。在以上两个项目成功经验的基础上，本项目决定利用水资源综合管理(IWRM)技术来解决山东省特别是黄水河流域及龙口市存在的日益严峻水资源与社会经济问题。利用该项管理技术可以有效的缓解水资源短缺及海水入侵问题，减缓由于缺水引起的日益严重的社会经济问题。该项目由德国教研部(BMBF)和中国科技部(MOST)共同资助，实施期限为 2008 年 6 月至 2011 年 5 月。德方共有 7 个单位参加，每个参加单位在解决水问题方面都有着丰富的经验。该项目包含两个阶段—规划阶段和执行阶段，本文主要针对第一阶段。一方面，IWRM 意味着所有单一的物理过程都将是整个交互式系统的一部分，本项目中重点从水质水量两个方面来关注地下水补给、地表水与地下水之间的相互作用，实际操作过程中，在黄水河流域将利用不同参加单位提供的经验和软件来完成一个整合的水文模型；另一方面，IWRM 意味着必须在考虑项目区不同用水户利益及未来社会经济发展指标的基础上做出正确的决策，为此，必须开发基于 GIS 的决策支持系统(DSS)。在项目实施第一阶段，在对该地区可以缓解水资源紧张状况的各种可能措施分析的基础上将开发出详尽的模拟模型，因此形成的措施方案集将考虑生态、管理及社会等方面，同时可以为不同方案提供成本效益分析。这一方案集将作为 DSS 的主要输入部分，并利用其中的水文模型对所选择的不同的措施方案集进行详细分析。基于技术、经济和社会的准则，再加上当地政府决策部门的密切合作，即可找出解决问题的最终策略。为此需要进行多准则分析，它允许多种属性，包括具体和抽象的，不精确和不确定性的，依赖和反馈的以及互动和学习为基础的。最后，对于项目实施第二阶段中的节水、中水循环与废水再利用等方面进行了简要说明。

1 Project outline

The Shandong Province, especially the Huangshui River Basin (Longkou county), is an out-standing example for water conflicts arising from piece meal action as well as fast growing population, industry and agriculture.

In the coastal catchments of the Shandong province the water scarcity is even increased due to salt water intrusion, reducing the usability of available water resources. Furthermore, 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. The socio-economic problems can only be tackled by truly integrated water management approaches. In the following table the salt water intrusion development in Longkou City is shown. In the 90's already many measures against the saltwater intrusion have been implemented. In 1995 for example an underground dam was finished in the downstream part of the Huangshui River, 1.2 km from the seaside, with a total length of approximately 6 km (LIU, 2003). The average depth of the dam is 26.7 m. On the one hand, the dam prevents the ground water from flowing into the sea. On the other hand, it can stop the sea water intrusion. The table shows that even after this project was finished, the area affected by salt water intrusion continued to increase. It is part of the project to investigate the influence of this dam and to analyze whether its effectiveness can be increased.

Table 1: History of Sea Water Intrusion in Longkou City (Guo, 2004)

Year	Annual Intrusion Rate (km^2/year)	Cumulative Area of Sea Water Intrusion (km^2)	Highest Intrusion Distance over Land (km)
1984	5.1	45.8	3.1
1988	4.6	64.3	4.6
1989	19.4	83.7	---
1990	-5.0	78.7	---
1991	10.3	89.0	---
1992	1.8	90.8	---
1993	5.6	96.4	5.3
1998	1.7	105.0	5.9

The general objective of the project however is to bring together German expertise in water management and newer developments in context with the European Water Framework Directive with the research efforts in the coastal area of Shandong province to relieve the desperate water scarcity situation. The total water consumption within the project area amounts in average to about 162 million m^3/a. It is composed by 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 clearly exceeds the water resources, in average by about 25%. This problem is even more severe considering the monthly and annual distribution of water resources and water demand (Kutzner, 2006). After further assessment of the present situation and the many abatement measures tried with, especially to stop salt water intrusion, it was found that there is a tremendous potential to improve the situation by appropriate integrated water management. If a solution for this extremely complicated problem can be developed and implemented the methods and technologies used may be generalized and applied to the whole Shandong province or even to other parts of China. The project area is shown in the following figure.

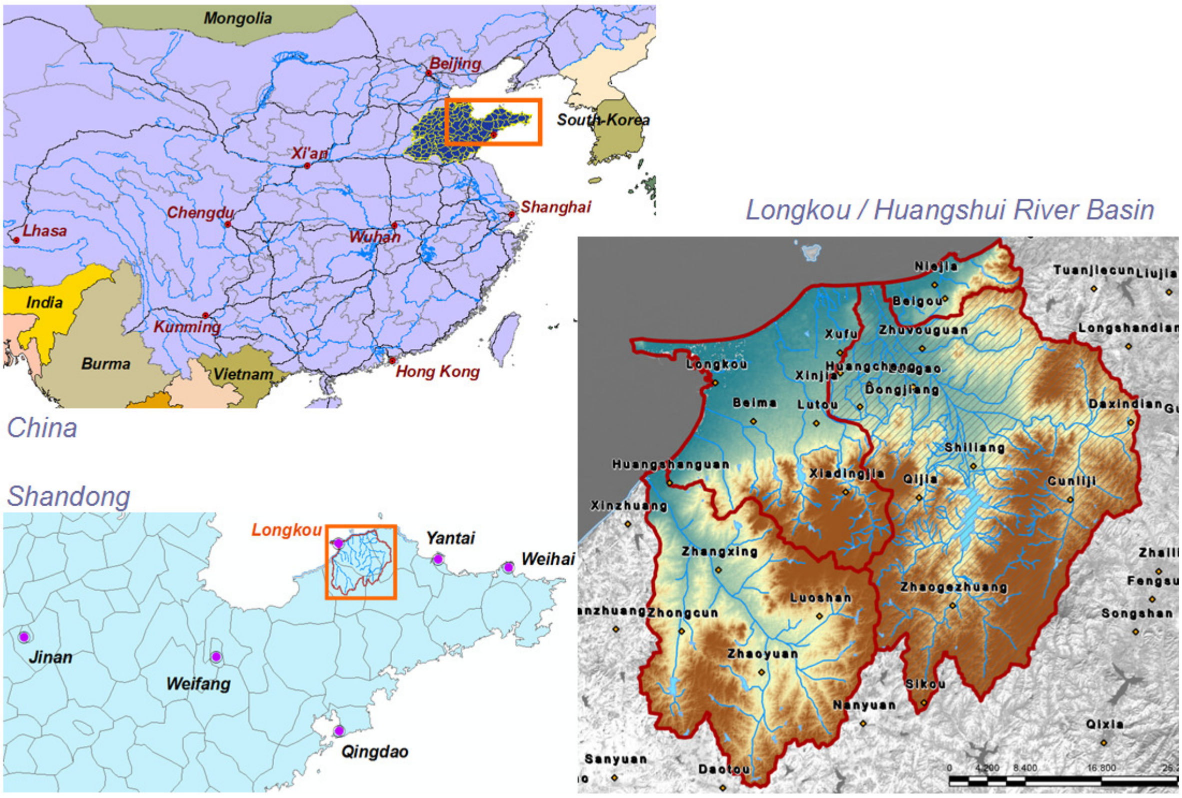

Figure 1: Study area Huangshui River Basin / Longkou

The figure below gives an overview of the structure of the ongoing Chinese-German project. It is divided into a planning and an implementation phase. The project is funded by the German Ministry of Education and Science BMBF and the Chinese Ministry of Science and Technology MOST.

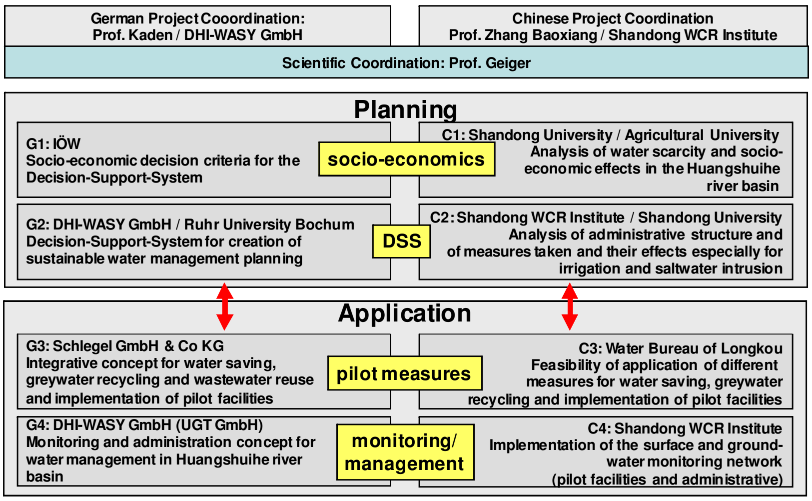

Figure 2: Project structure

2 Planned results

In the following the basic methodology and planned major project results and solutions are shortly explained. In the course of the project this list might be modified and extended.

2.1 Methodology for IWRM

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 salt water intrusion. This could be stopped, if no further ground water would be extracted for irrigation. This would lead to tremendous social problems. But the problem of salt water intrusion can't be solved with technical measures alone. A solution can be only achieved with an integrated water resource management (IWRM).

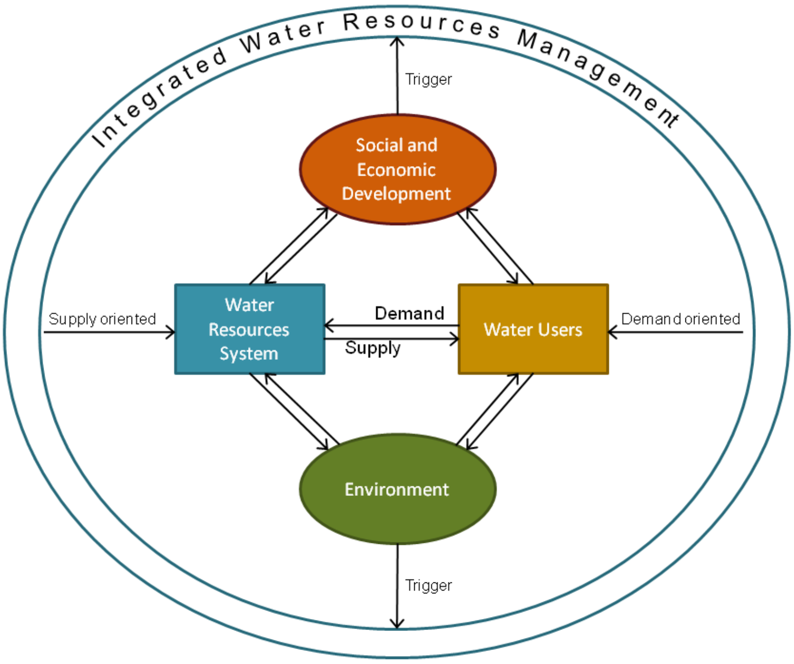

Figure 3: IWRM after Koudstaal et al., 1992

Figure 3 clearly displays pathways that have led to the current water resources problem in Shandong. A predominantly demand oriented water management, with a main focus on the water users displaying an ever increasing demand, has led to an over-taxation of the water resources system, causing serious limitations to the social and economic development of the region triggering a call for an integrated water management. Additionally, a disruption in ecosystem functioning impacts water quality and water users' health and threatens to further decrease available fresh water resources.

Following the principle of an integrated water resource management, water is an essential element of the ecosystem. It is a natural resource and a social and economic commodity. Water demand should be calibrated to be in equilibrium with water supply, thus safeguarding the ecological and socio-economical services this resource supports. According to this complexity, a variety of aspects have to be considered, in order to take into account the multitude of water related interactions in the 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 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 socio economic 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. The methodological approach is characterized by the phases; problem identification, pre-selection of cost effective measures (Stage 1) and verification and selection of a final strategy (Stage 2). This approach guarantees that on the one hand, no possible measure is left out, and on the other hand the effort for the planning procedure is reduced to the necessary.

In Stage 1 all available measures especially in the field of water saving, ground water recharge, water recycling, structural measures against salt water intrusion and institutional measures are considered. In the first step of the decision process, all applicable measures for the project area and the considered water-related issues are collected, sorted and combined in a logical and functional measures catalogue. Every measure will be appraised according to a number of criteria, relevant for determining a sustainable integrated solution. Sustainability is considered in their economic, social and environmental aspects. Important criteria considered here are construction and operation costs, durability, effectiveness in reducing water consumption or increasing water availability, water quality aspects, risk assessment and such social and political criteria as political acceptance, impacts on employment rates in several branches, redistribution of incomes and fairness. All relevant items in the measures catalogue will be typecast according to these hierarchically structured criteria.

In the next step in this stage, scenarios for socio-economic developments are defined which are used to evaluate the measures of this catalogue by resulting political and social and economic aspects. This sort of sensitivity analysis ensures that unknown future conditions are considered. Finally a small amount of the best scenarios are selected upon environmental- and recourse costs. At this point it should be certain, how this measure can be put into practice. Guidelines for the dimensioning need to be available.

In the following final planning (Stage 2) 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 will 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.

2.2 Socio-economic Analysis and Catalogue of Measures

Chinas water resources are relatively small and uneven distributed. In average, Chinas water resources per capita are only one quarter of the world average (Yang, 2001). Especially the North of the country, where Shandong is located, is affected by water scarcity (Varis, 2001). The amount of the available annual water resources in Shandong is only about 340 m³ per capita, which is classified as absolute water scarcity (Falkenmark, 1992). Currently, water management practice is not sustainable in Shandong. Groundwater is used at an amount, which leads to dropping groundwater level (Varis, 2006). Overexploitation and water pollution results in considerable environmental, social and economical costs. Due to population and industrial growth as well as ongoing urbanisation, water demand will even increase in the future. Therefore, measures are to be taken for achieving a more efficient and sustainable water use.

Ecological targets such as sustainable water use can usually be achieved in various ways at heavily differing financial costs and ecological side effects. Water saving can be achieved by applying a variety of alternative measures. To identify the best alternative, it is necessary to incorporate not only the financial impacts but also the ecological and social side effects. Therefore, these impacts have to be quantified and in a second step weighted against each other as well as against the financial costs and benefits. Potential measures and management alternatives are evaluated from the perspective of economic efficiency. For sustainability, the social acceptability and the distributional effects of a decision (i.e. unequal costs and benefits for different stakeholders) are taken equally into account. However, weighting ecological and social effects' contribution to social welfare does typically create substantial difficulties for political decision makers. It is simply difficult for policy makers to estimate the importance of various effects on ecosystem goods at the same time. Environmental economic valuation offers a systematic and traceable procedure for translating impacts on ESS into economic terms and thereby making them far more accessible to the public and policy makers. In addition, a comprehensive qualitative assessment of the preferences, values and believes of the local stakeholders and of the distributional effects of alternative measures can explain existing oppositions and implementation problems. Acceptance and chances of implementing innovative land use options depend on the (positive and negative) consequences for the relevant stakeholders and on their perceptions regarding their participation in the decision making process.

After identifying desirable measures for achieving sustainable water use, policies for implantation are to be developed. Additionally to the direct and opportunity cost calculations, the institutional conditions for the implementation of the developed management alternatives; administrative structures, legal, political and socio-cultural conditions are of great importance. Institutional analysis facilitates the development of feasible and consensual management plans. Proposals for cooperation structures and financing instruments (including fresh- and wastewater pricing options) take the availability of public budgets and the social acceptance into account, which is closely connected with the share of household income that could be affected by alternative water management options.

Planned results:

- Detailed socio-economic assessment of the alternative management options as an input for the decision support system
- Methodology for an applied socio-economic assessment that is transferable to other planning regions and water management problems
- Catalogue of potential measures for IWRM, characterized according to the following major topics:
  - General function of the measures
  - Advantages and disadvantages
  - Boundary conditions for usage
  - Cost for realizing and maintaining the measure
  - Social effects of the measure.

2.3 Decision Support System for IWRM

The overall objective of the project is to establish an integrated water resources management plan for the river basin management which adequately incorporates water management and socio-economic objectives, constraints and consequences. In general, the alternatives for sustainable water management are manifold and possible solutions are most likely a combination of technical strategies (water saving, water recycling, groundwater increase, waste water treatment, water supply) and institutional policies (Water Rights, river basin commissions with participatory approaches, water councils, etc.). It is impossible to analyze the effects of all alternatives in the measures catalogue in detail and, as shown above, the study and implementation of isolated, non integrated measures also proved to be insufficiently effective. This holistic approach can be achieved by analysing the multitude of technical and institutional measures and their combinations in a very general decision support system, aimed at determining the most effective measures and combinations for the study area in question (Stage 1). This preliminary selection of measures can then be analysed in detail using hydrologic, hydraulic, groundwater and socio-economic modelling. The modelling results can then be analysed in a more specific DSS (Stage 2), aimed at fine tuning the interactions between different technical measures and between technical and institutional measures in order to define the most effective integrated water management solution. In Stage 1, to analyse the effectiveness and interactions of all items of the measures catalogue, the predicted effectiveness and impact of all measures have to be estimated according to every relevant criterion. For instance, for a very specific irrigation technique criteria like construction and operation costs, durability, potential water saving ability, required space, potential risks, employment opportunities, necessary training, effects on water quality and groundwater enrichment, etc… will be estimated by a team of German and Chinese experts. This results in a fuzzy estimate of performance of this measure for each criterion.

Using algorithms based on the *Fuzzy - Analytic Hierarchy Process (F-AHP)* and *Dynamic Programming*, a finite amount of optimal combinations of measures will be generated based on the aforementioned fuzzy expert opinions. F-AHP (Vahidnia, 2008) uses matrices and linear algebra for the formalization of a decision process. It allows structuring of the complex decision problem of an IWRM in a hierarchical order, thus exhibiting the relationship between the decision alternatives, objectives and evaluation criteria. F-AHP facilitates analysis by transforming a complex evaluation into a hierarchy of smaller more manageable sub-evaluations (Kaden, 2009). A complex dataset is thus decomposed into smaller constituent elements between which pair-wise comparison is elicited, enabling well-founded expert-assessments of performance for each measure according to each criterion. Not all measures are equally efficient for all criteria, F-AHP is a compensatory decision methodology as alternatives that are deficient with respect to certain criteria can compensate by their performance with respect to other criteria (MERZ ET BUCK, 1999). Additionally, some measures might show an overlapping for some criteria. Dynamic Programming is a method of solving problems that exhibit these properties of overlapping sub-problems by means of recursion.

Stage 2 comprises a more detailed analysis of the selected scenarios. This Stage combines modelling of the relevant processes, impacts and measures under study as well as their socio-economic evaluation. With the help of technical, economic and social criteria and in close interaction with the regional stakeholders the final strategy can be selected. In this Phase an additional multi-criteria optimization module will be developed, which uses the results of Stage 1 of decision support as well as the information provided by the GIS-based simulation system. For this purpose a multi-criteria visualization based decision and negotiation support technique, named the Reasonable Goal Method / Interactive Decision Map (RGM/IDM) technique, will be applied. This tool provides excellent options to explore new ways to balance competing interests. The trade-off between different criteria is based on a dialogue defining a “reasonable goal”, a target, located at a convex hull of the criterion points. The user explores Pareto frontiers which helps him to understand tradeoffs between criteria. After a selection of the preferential goal the method identifies different alternatives which are close to this goal. This selection of alternatives offers new ways to differentiate among planning results at an early stage under consideration of the uncertainties of planning. Efficient measures can be estimated without an explicit formulation of preferences of decision makers or stakeholders in an interactive and collaborative decision process within a dynamic decision environment. The RGM/IDM technique belongs to the group of multi-attribute decision making (MADM) methods, in which the scenarios can also have a spatial reference.

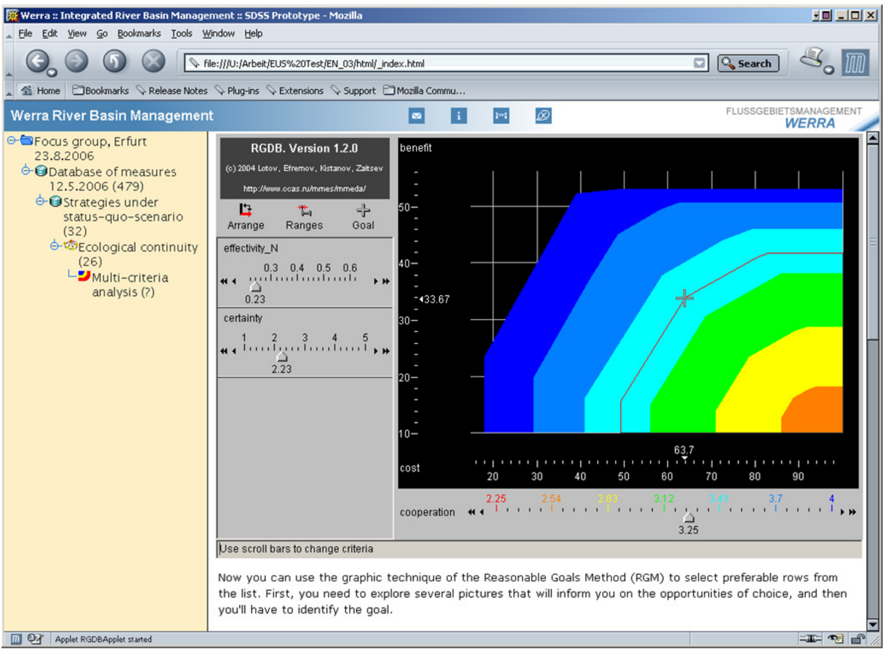

Figure 4: Example of the RGM/IDM technique used in an IWRM-project (Dietrich, 2004)

In a GIS-based system the data base for the modeling and the integrated water resource management is stored. The basis is a system developed in Germany for the implementation of the EU-water framework directive called WISYS. It offers a detailed object model, evaluation and process tools for water management related subjects. WISYS is based on ESRI's ArcGIS and covers both rural and urban topics. The evaluation and presentation tools WISYS offers can be used within the project. It is also intended (and already partly realized) that the software will be adapted to Chinese needs (i.e. water quality standards and language). Within the project, the object model will be adapted in order to be able to calculate the indicator values used by the MADM module efficiently for the scenarios to be evaluated. Further adaptations will be necessary in order to store and extract the information calculated by the simulation systems (ground and surface water levels and salinity values for example). It is also intended to extend the data model to provide the changes within the simulation models which have to be made according the scenario which has to be evaluated. Additional tools will then be needed to automatically adapt the simulation model parameters according to the selected scenario.

The models used describe most of the hydrological circle, including interception, infiltration, evapotranspiration, overland flow, unsaturated flow, groundwater recharge, groundwater flow and surface water flow. Each of the components offers also the possibility to describe mass transport processes. The groundwater component even takes into account the effects of density dependent flow processes. Especially for this project this is very important. The basic concept of the simulation part of Stage 2 of the DSS includes two different model approaches; a relatively coarse and a detailed model. The coarse model is used to verify the general feasibility of the water usage proposed in the selected scenario. For this, the groundwater flow processes are of secondary importance. This model consists of the simulation packages MIKESHE (for example in Sahoo, 2006) and WBalMo (for example in Kaltofen, 2008). MIKESHE dynamically couples all major hydrologic flow processes, including 2-D overland flow, 1-D channel flow, 3-D saturated zone flow, 1-D (Richard's based) unsaturated zone flow, snowmelt and evapotranspiration. The latter can be calculated by using the Kristensen and Jensen method (1975), by which the actual evapotranspiration and the actual soil moisture status in the root zone is calculated from the potential evaporation rate, along with maximum root depth and leaf area index for the plants. Overland flow is calculated by a diffusion wave approximation using a finite difference scheme. MIKESHE is also capable of simulating integrated advective-dispersive transport, sorption, biodegradation, geochemistry, and macropore flow and is generally applicable for most hydrologic, water resources and contaminant transport applications. In contrast to similar codes, MIKESHE utilizes rigorous physical flow equations for all major flow processes, but also permits more simplified descriptions (NIVA, 2007). The 3D finite difference groundwater component can be exchanged by a simplified cascade model for example. This option will be used for the coarse model.

WBalMo (Water Balance Model) is an interactive simulation system for river basin management. WaBalMo has been used to identify management guidelines for river basins, design reservoir systems and their operating policies, and perform environmental-impact studies for development projects. Using an ArcView (ESRI) user interface, a representation of the river basin is derived from an existing digital stream network. The natural processes of runoff and precipitation can be stochastically (Monte –Carlo) simulated and the respective time series are balanced with monthly water use requirements and reservoir storage changes. By recording of relevant system characteristics during the simulation, probability estimates can be provided for water deficits, maintaining minimum runoff or reservoir levels. Simulations can be performed both for stationary and transient (e.g. climate changes) conditions (Loucks, 2007). If the resulting deficits of a coupled WbalMo and MIKESHE simulation are within the limits set by the user, the suggested water usage from the evaluated scenario can be accepted and some of results can be automatically transferred to the detailed model (groundwater recharge, extraction rates, direct rainfall runoff in the streams by overland flow).

The detailed model also consists of two software packages; FEFLOW (Diersch & Kolditz, 2002, Zheng, 2007) and MIKE11 (for example in Szylkarski, 2002). The groundwater model FEFLOW is one of the most sophisticated groundwater modeling packages available. The program provides an advanced 2D and 3D graphically based modeling environment for performing complex groundwater flow, contaminant transport, and heat transport modeling. Both saturated and unsaturated flow regimes can be modeled, in either case steady or transient. New features even include the representation of multi-species reactive transport modeling. FEFLOW uses a Galerkin-based finite element numerical analysis approach with a selection of different numerical solvers and tools for controlling and optimizing the solution process. Both confined and unconfined problems can be simulated. Most important though for this project is the possibility to take into account density dependent flow processes.

MIKE11 is a powerful numerical surface water model developed by Danish Hydraulic Institute (DHI) to simulate 1D flow problems. The software offers to simulate unsteady flow in river networks as well as looped networks using an implicit finite difference scheme. Both sub- and supercritical flow conditions can be calculated by solving the full Saint-Venant (1871) equations. These equations are especially accurate for simulations in flat areas like the downstream part of the Huangshui River Basin. MIKE11 offers the possibility to represent several types of structures in the model, of which some can be automatically operated according the results of the running simulation. Furthermore, MIKE11 is able to simulate mass transport processes as well as sedimentation and erosion processes. MIKE11 and FEFLOW can be coupled using the module IfmMIKE11 (Monninkhoff, 2007). The module will be extended for this project in order to be able to take into account also mass exchange processes between the ground- and surface water bodies. This detailed model will give detailed information about the impact of the proposed measures on the groundwater levels, the salinity of the rivers and the groundwater, as well as the effectiveness of the artificial recharge along the rivers. Furthermore, the locations of the extraction wells can be optimized to minimize the salt water intrusion. Here, a second module is intended to be used. This module uses grid technology to speedup model design as well as operational tasks like model-based optimization (Arndt, 2008).

The results of the detailed model will be compared with the results of the coarse model; in particular the exchange rates between the surface and groundwater bodies. In case of large differences, the coarse model has to be adapted to verify the availability of the proposed extractions. The results of both models will be stored in the database, in order to compare different scenario packages using the DSS module mentioned above.

In Figure 5 the basic concept of GIS-based and model-supported DSS System, Stage 2 is displayed.

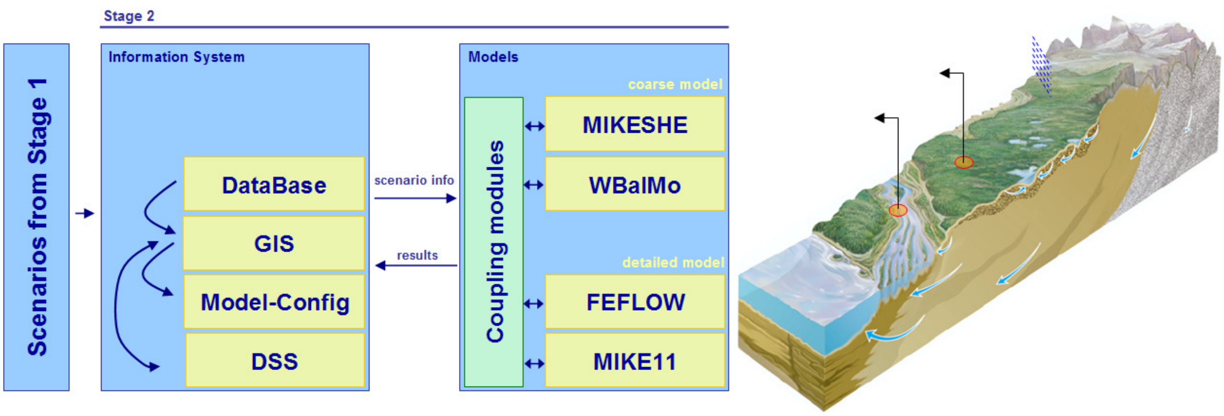

Figure 5: Concept of the proposed GIS-based and model supported DSS system (from Winter, 1998)

Planned results:

- Implementation of the developed tools and methods for sustainable water resources management for the Huangshui River Basin as an example for the Shandong Province

- Generalization of the results in the Huangshui River Basin in form of comprehensive scenarios to applied on the regional (province) level
- generalized methods and information and decision support system for application under different natural and socio-economic conditions

2.4 Concept for Water Saving and Pilot facilities

The simulation models integrated in the DSS system will mainly support to quantify the water availability distribution and the possibilities to improve or stabilize the quality of the water resources. Another important aspect of the project will be to suggest enhanced solutions to reduce the water demand in the region. For this the possibilities of the application of the following German techniques will be verified and, if applicable, tested in practice:

- Water saving measures in private households and industry
- Rainwater using for private and agricultural purposes
- Water reuse in private households
- Water circulation in industry
- Recycling of domestic and industrial wastewater for use in agricultural irrigation
- These measures are applied within an integrated concept which is shown in Figure 6. The development of this concept and the realization of fitting measures is the aim of this project.

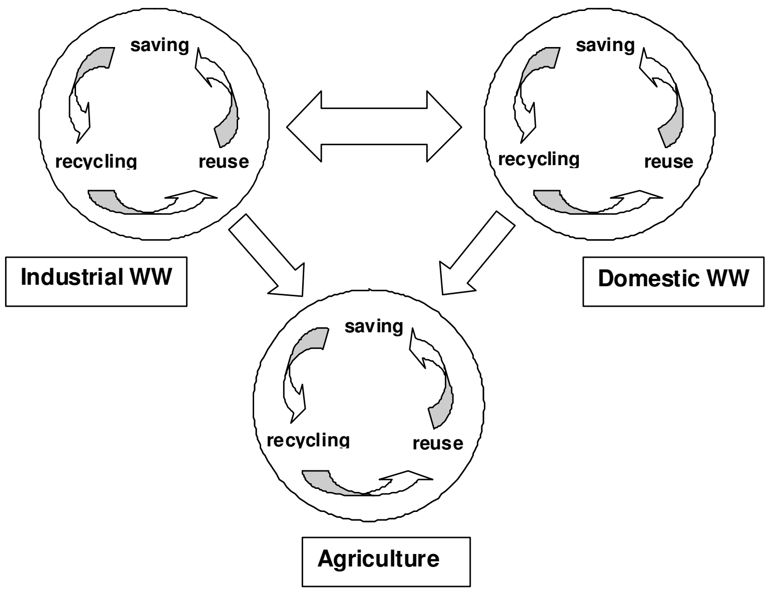

Figure 6: Integrated water saving and wastewater reuse concept

2.5 Monitoring Concept

In the pilot region Huangshui River Basin a monitoring system satisfying the needs for integrated management is missing. Although in some amount monitoring of groundwater is being done (including water quality monitoring and monitoring of salt water intrusion), the density of the network of gauges is too low to be able to set up a regional ground- and surface water modelling and DSS system. Furthermore, compared to the groundwater monitoring network, surface water quantity and quality observations are rare both in space and time. The objective of this sub-project is to develop a monitoring concept for the pilot region fitting to the requirements of IWRM including soft- and hardware.

A thorough survey and evaluation on the existing installations and standards concerning various monitoring purposes will be performed. Based on that, the monitoring concept will be developed in a step-wise approach. In the first stage of the project the concept will concentrate on the fast improvement of the existing system in order to support the data collection for the implementation of the presented IWRM approach. In the second stage the monitoring concept will be refined based on the tools and results of the project. The groundwater model will be used to optimize the monitoring system for salt water intrusion abatement. Groundwater monitoring equipment produced in Germany will be tested for use under the given local conditions.

This monitoring system will be designed above all for:

- Monitoring and evaluating the influence of salt water intrusion abatement measures
- Analyzing the characters of groundwater quantity and quality and its variations
- Investigating water quality variation of infiltrated water during the infiltration process in the soils
- Investigating the elimination efficiency of pollutants in the reclaimed water

Planned results:

- Monitoring concept for the pilot region according to the requirements of IWRM
- Test reports for monitoring equipment
- Prototypes of automatic monitoring techniques for observation of saltwater intrusion.
- Information system for storing and processing the monitoring data

2.6 Potential for application/duplication for environmental and WRM improvement in China

As the overview above indicates it is the intention of the project to generalize the methods, tools etc. developed within the project in order to apply those for other regions as well. According to the characteristics of the project area along the coastal zone, this generalization takes special consideration to similar coastal areas.

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