Multi Criteria Analysis
East Route Water Allocation
South-North Water Diversion Project
China

南水北调东线工程水资源配置方案的多准则分析

水

Adriaan Ruijmschoot s0005592
Iwen Legro s0011967
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Executive summary

In November 2002 the Chinese government approved the decision to start construction of the South - North Water Diversion Project which will facilitate the transport of water from the Yangtze River to the arid North China Plain. When all three planned routes (West, Middle, and East) have been finished, the project will have a capacity of 59 billion m^3 of water per year. Together with several partners, the China Institute of Water Resources and Hydropower Research (IWHR) is currently involved in the Sustainable Water Integrated Management of the East Route in the South – North Water Diversion Project (SWIMER). This project aims at determining the optimal water allocation strategy for the East Route Project (ERP).

The goal of this study is to produce an independent report containing a rapid assessment in which water-allocation alternatives within the SWIMER-project are compared by means of designing and applying a robust multi-criteria analysis (MCA). This allocation is specifically an allocation among sectors, e.g. industry, agriculture, drinking water, etc. The study area is the ERP area, and more specifically the 21 southern most municipalities of this area which are currently certain to be receiving water in the near future. Due to time constraints and the limited availability of data, the alternatives presented in this study will only divide water within municipalities between the agricultural and industrial sector and will leave the total amount of water per municipality and in other sectors of society constant.

The goal of the MCA in this study is to identify a water allocation alternative which ensures a stable continuation of economic growth while paying attention to social issues (e.g. rural-urban migration) as well as environmental issues, which is assumed to be a reasonable representation of the Chinese government's preference. The MCA technique selected to serve this purpose is the Simple Multi Attribute Rating Technique (SMART), which was chosen for its relative simplicity and transparency as well as its ease of application. The main criteria on which the alternatives are rated are economic, social and environmental.

A large amount of data on GDP (subdivided into agricultural and industrial GDP's) and agricultural production (economy), income and rural-urban migration (social) and groundwater level and untreated wastewater discharge (environmental) was collected. Next, a model which could forecast the future states of all these factors for different water allocation alternatives was created. With this model the impact of the different alternatives on these factors was determined. The outcomes of this model were used as input for the MCA. Three alternatives were created; two putting emphasis on either economic or agricultural growth, and one with equal growth for all sectors. Furthermore, two extreme alternatives were added in which all water would go to either agriculture or industry. Partially serving as a validation check, the optimal water allocation from the SWIMER project was used as a sixth alternative. In order to compare these alternatives, weights had to be assigned to each parameter by the decision-maker. As he was inaccessible in this case, the authors took the role of decision-maker. The weights given to the different criteria are based on the decision-makers preference and the relative impact of each criterion, i.e. a criterion that changes a lot will naturally have a higher weight.

Apart from the determination of the weights, the utility of the different criteria had to be determined. This is due to the fact that, to the decision maker an increase from 0 to 1 will not have the same value as an increase from 100 to 101. Therefore, so called value functions were created which compensate for this fact. By multiplying the normalized value function scores for each criterion and aggregating these results, a single score per alternative was obtained. Alternative 2, being the alternative which puts emphasis on agricultural growth came out as the best alternative, but the differences with the optimal SWIMER alternative and the equal growth alternative in particular were so small that no conclusions could be drawn before a sensitivity analysis was carried out.

An in-depth sensitivity analysis is of utmost importance in order to gain a better understanding of the model's behaviour. What will happen with the outcome if the decision-maker assigns slightly different weights, or when different boundary conditions are assumed? By fluctuating a certain input parameter, the influence on, and thus the sensitivity of the MCA outcome can be determined. The sensitivity of the outcomes of the MCA was researched on several different factors of importance. This was done for the value functions, the boundary condition that the water per municipality was fixed and for the weights. Due to the structure of the data generation model, the sensitivity to a change in source data could unfortunately not be assessed.

The MCA did not appear to be very sensitive to changes in value functions and boundary conditions. In both cases the maximum influence was not only relatively small, but the relative scores between the alternatives remained very much the same. As was expected, the model's sensitivity to changes in weights was rather large, especially for the economic weight. The sensitivity analysis yielded as much as five different optimal alternatives for different weights on economy. A striking conclusion is that the alternatives that had the highest scores in the MCA are also the least sensitive to weight changes, i.e. regardless of what the weight given to a certain criterion is, these alternatives' MCA scores will never differ much and thus satisfy the interests of different groups of stakeholders in the same way. This especially goes for the water allocation alternative that was derived from the SWIMER project.

Concluding, one can state that the researched alternatives in this study perform worse nor better than the one that was identified as the optimal alternative in the SWIMER report.
However, since the amount of available data was not only rather limited but also processed in a strongly simplified way, many improvements are needed to ameliorate the scientific credibility of this study. Moreover, the future state of the criteria has a linear relationship with the amount of diversion water, which is a strong simplification of reality. Furthermore, a lot of data on criteria that ideally should have been taken into consideration was not available. Before these issues have been resolved, no binding conclusions can be drawn from this study.

A final recommendation is to conduct a survey in which a statistically representative group of experts, preferably representing all relevant groups of stakeholders, is asked to determine the weights of the MCA. This will greatly improve the credibility of the assumption that the weights used in the MCA truly represent reality.

Preface

In the spring of 2006 we made plans to do an internship together in China, a plan we had cherished for a long time. As two master students at the University of Twente, our plan was to look for a joint internship in which we could combine our respective majors: Water Management and Industrial Engineering and Management. Prof. Dr. Ir. Hoekstra of the department of Water Engineering and Management at the faculty of Engineering Technology facilitated the initial steps. He advised us to contact the China Institute of Water Resources and Hydropower Research (IWHR) in Beijing to discuss the possibilities. Because of the unconventional combination of study fields an assignment was put together while still in the Netherlands, in association with the two mentors from the University of Twente: Prof. Dr. Ir. Hoekstra and Prof. Dr. Van der Veen. This assignment was discussed with the host organisation and carried out in the summer of 2006.

It has been a very valuable and enriching experience for us to come to China. First of all, it was an important academic experience to carry out a reasonably independent research within a professional environment. The traineeship has provided an interesting possibility for the exchange of ideas between people from different cultural backgrounds, in both directions. Furthermore, the chance for us to come to China was a great opportunity to learn some Chinese, which has proven to be very useful in daily life and possibly in the future. Finally we have been able to see quite a bit of China in our travels before and after the traineeship. Altogether it has been an unforgettable experience.

The completion of the internship and the resulting report would not have been possible without the help of a lot of people who we would like to thank. First of all we would like to thank the Water Resources Department of the IWHR, and especially deputy director Dr. Gan and Prof. Dr. Jia for granting us the opportunity to undertake an internship in their department. Our thanks also goes out to the people at IWHR who were always helpful and made us feel very welcome during our stay. Ms. Li and Ms. Han have been especially helpful in aiding us to overcome language difficulties and other general problems.

Furthermore, we would like to thank our mentors, Prof. Dr. Ir. Hoeksta and Prof. Dr. Van der Veen for their comments and remarks which helped to improve our results.

Our special thanks goes out to Dr. Ma Jing of IWHR. We greatly appreciate her efforts to make our stay as rewarding as possible, both within the institute and within our daily life. Whenever problems came up, she always made time for us to discuss these issues and look for a solution. Without her support, suggestions and dedication we would never have been able to carry out the research.

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Iwen Legro | Adriaan Ruijmschoot

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List of Abbreviations

AHP:	Analytical Hierarchy Process
CASS:	Chinese Academy of Social Sciences
DM:	Decision Maker
ERP:	East Route Project
GDP:	Gross Domestic Produc
IWHR:	China Institute of Water Resources and Hydropower Research
MCA:	Multi Criteria Analysis
MRP:	Middle Route Project
ResSim:	Reservoir System Simulation
ROWAS:	Rule-based Objected-oriented Water Resources System Simulation Model
SMART:	Simple Multi Attribute Rating Technique
SWIMER:	Sustainable Water Integrated Management of the East Route in the South– North Transfer Project
2010E:	The best water allocation in 2010 *without* any South – North diversion water, according to the SWIMER report
2010F:	The best water allocation in 2010 with South – North diversion water, according to the SWIMER report

Introduction

In November 2002 the Chinese government approved the decision to start construction of the colossal South - North Water Diversion Project. This project aims at solving the acute water shortages expected to influence 450 million people in the North China Plain in the coming decades. Currently already one of the world's most water-scarce areas per capita, the exceptionally high economic growth rates further spur the need for this drastic measure.

The ultimate goal is the transfer of 59 billion m^3 of water annually from various reaches of the Yangtze River to the North China Plain. Many studies have been performed to assess the impact of this project and to discuss possible alternative measures. Scientists both in China and overseas disagree greatly on the environmental, social and economical damage or gain resulting from this project. However, it is not within the scope of this report to assess the necessity of the diversion project.

The diversion project will be realised through construction of three routes: West, Middle and East. Although building has already started on the last two of these, many issues are still being studied and optimised. One of these issues is the optimal allocation of the diversion water with respect to season, municipality and sector of society. The meaning of this is best reflected with an example: how much diversion water will go to the industry in the municipality of Jinan in the month of June? Because of the large amount of influencing factors, this question is not easily answered.

Together with many national and international partners, the China Institute of Water Resources and Hydropower Research (IWHR) is currently performing extensive research to determine the optimal water allocation in the area of the first phase of the East Route of the diversion project. This project is called Sustainable Water Integrated Management of the East Route in the South – North Transfer Project (SWIMER). The core of SWIMER is the development of an integrated management model which will allow the evaluation of the impact of various water diversion schemes in different sectors of society and will facilitate the identification of the optimal alternative. One of the modules within SWIMER is the performance of a Multi Criteria Analysis to determine how the diversion water should be divided among different sectors of society. This module provides the scope of this report.

<u>Goal</u>
The goal of this project is to produce an independent report containing a rapid assessment in which water-allocation alternatives within the SWIMER-project are compared by means of designing and applying a robust multi-criteria analysis (MCA). This allocation is specifically an allocation among sectors, e.g. industry, agriculture, drinking water, etc.

The MCA used in this study is different from the MCA applied in the SWIMER project. In this report the SMART (simple multi-attribute rating technique) is used, a fairly straightforward method. Given the extremely large amount of influencing factors in the diversion project, a determining factor in the choice of an MCA is simplicity. However even with a simple method there is a large data deficit, as the SWIMER project provides ample information on allocation per municipality, but none on allocation per sector. This creates the need for an additional goal. A second additional goal is added in order to enable a solid and robust MCA as described above and to stress the importance of the sensitivity analysis in this study. These goals are the following:

1. *Generation of measurable properties (social, economic, environmental) "in a scientifically founded way" for a situation in which the ERP has been fully implemented*

2. *Performance of a sensitivity analysis on the choice of system boundaries and assumptions (which can differ depending on the designer of the MCA), because of the influence these choices have on the outcome of the MCA*

In order to be able to measure the different effects of the alternatives on social, economical and environmental parameters, data is required that links these parameters to the amount of diversion water received per sector. With this data, a simple model can be constructed showing the expected results of every allocation. As is often the case in scientific research, the readily available data is insufficient to carry out the MCA. Therefore a large amount of effort has to be put into the generation of sufficiently sound measurable properties.

In the MCA design, decision makers perform an influential role, as they determine what characteristics of alternatives are important. As complete objectivity does not exist, the decision maker's opinion and interpretation of reality may cause the results of an MCA to change. Other external effects may influence the MCA's outcome in similar ways. The second goal, a sensitivity analysis, is therefore indispensable to clarify the influence of both the choices made in the MCA and the input data used in the model. The sensitivity analysis thus provides a measure to weigh the reliability of the results.

Report structure

Chapter one provides extensive insights into the background of the South – North Diversion Project, the project area and the SWIMER project. Chapter two explains the basic methodology used to achieve the goals stated above. A lot of effort in this project has been put into the collection of the basic data needed for the research. The process of this data collection and its reliability is described in chapter three. The application of the MCA methodology on the specific problem stated in this report forms the content of chapter four, including the results. The value of these results is thoroughly reviewed in chapter five: sensitivity analysis. Finally, in chapter six the relevant conclusions are presented, along with recommendations for further research.

Chapter 1 The South - North Water Diversion Project

1.1 Background[1]

Economists and leaders around the world largely agree that the 21st century will belong to China. The last 25 years have shown a seemingly unstoppable rise of this world power in military, economic and political aspects. Already the second world economy in 2005 in terms of GDP (PPP)[2], the country continues to achieve annual GDP growths of around 10%[3]. Logically, this has enormous implications for a country the size of China, both positive and negative.

One of the most pressing issues to be solved is the hydrological situation of the North China Plain. Also known as the 3-H plain (as its three major rivers are the Hai, Huang (or Yellow) and Huai), water usage here has seen drastic changes in the past decades due to population growth and fast economic development. The 3-H plain is the lowland area north of the Yangtze River, recognizable by the light shade in Figure 1. About 450 million people (7.25% of the world total) populate this area, with renewable water per capita at less than 500 m^3/year. This is less than in many other arid world regions and almost four times as low as the national average[4]. Surprisingly, the region is an important agricultural producer, providing 27 % of China's grain[5]. Intensive irrigation from the rivers and groundwater extraction have enabled farmers to obtain sufficient supply of water in most years until now. The same goes for the developing industry, producing 31% of China's gross industrial output value[6]. These numbers are surprising considering that the 3-H plain only has 10% of China's water resources. But if no measures are taken, the future is not looking very promising.

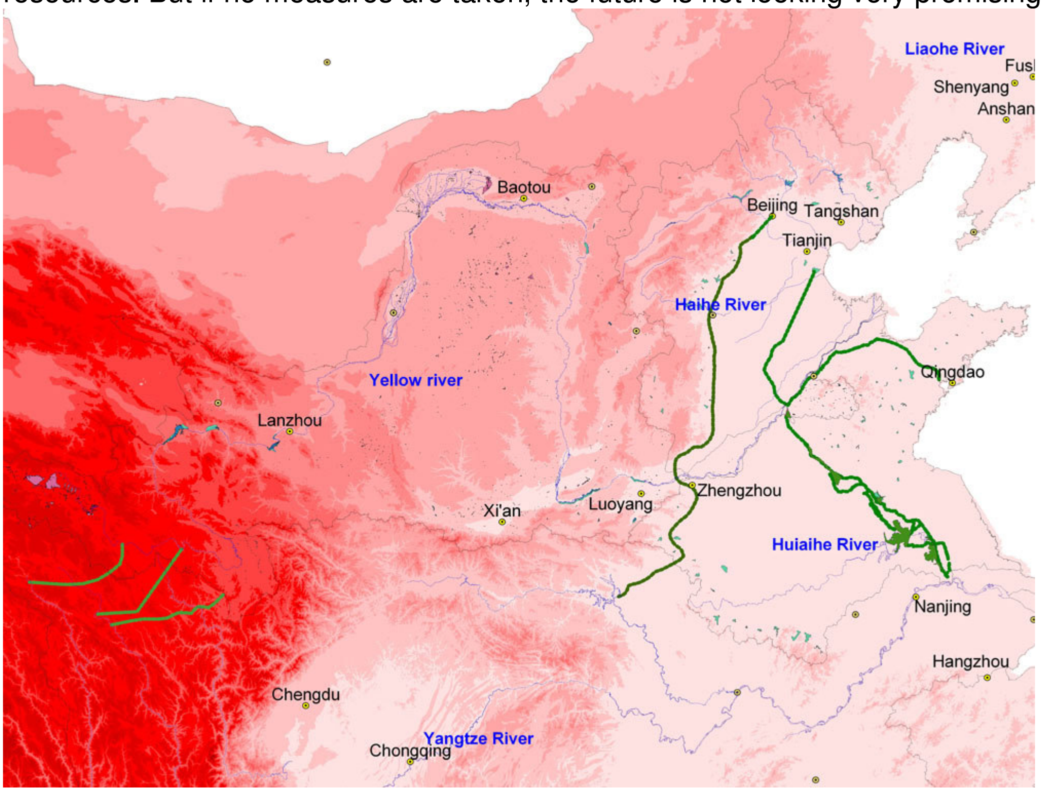


Figure 1: North China elevation map, showing the three proposed water diversion routes: West, Middle and East

Backing Chinese government reports, a 1997 US-embassy report stated that water shortages were a major constraint on the Chinese economy: each year water shortages affect 230 billion Yuan (+/- € 23 billion) of industrial production and reduce crop production by

20 - 30 billion kilograms[7]. The environment –already in a deplorable state- cannot defend its minimally necessary share of water and is further deteriorating. Many rivers in Northern China run dry outside of the rainy season and the rivers that do flow are dangerously contaminated. Groundwater tables are dropping at staggering rates[8].

When water becomes scarce, conflicts arise between water users. To protect the availability of water for the poorer share of water users (mainly subsistence farmers), the government has to intervene. The subsistence farmers do not have the financial resources to access deeper layers of groundwater, nor the political power to assure their share of the remaining storage water. If nothing changes, water-scarcity will soon become a very determining factor in the increase of an already very high rural-urban migration rate. The Chinese government has set the limitation of this migration as an important goal, next to existing goals like the continuous growth of the economy, rehabilitating the environment and ensuring a self-sufficient food supply for the entire population. In times of water scarcity, all these goals are directly dependent on the availability of water.

On one hand, this availability depends on how much water can be supplied, both physically and financially. On the other hand, it depends on the total quantity of water used. With no additional supplies of water at hand, additional available supply can only be raised by cutting down on the demand. In the current situation, water efficiency can be much improved. Some ways of lowering water demand are raising the water-price, stimulating water savings programs in industry and agriculture and educating people about the value of water. But although many studies have been done to assess the actual shortage of water in the current situation and on the long term, no conclusive evidence has been found proving that only water use reduction will solve the problem[6,9]. If demand can not be sufficiently reduced, supply needs to be increased.

In the 1950's Chairman Mao mentioned the idea to transfer water from the water-rich South to the arid North. After about five decades of study and more than 1000 proposed routes, the three most promising routes (East, Middle and West Routes) have been selected (Figure 1). While the technically challenging Western Route is still in a research phase, the government decided in 2002 to go ahead with the construction of the Middle- and East Routes. If the project is implemented completely, it will enable the transfer of 59 billion m^3 water per year from the South to the North.

The Eastern Route Project (ERP) will enable the transfer of 10 – 15 billion m^3 water per year from the Yangtze River mouth to ultimately reach Qingdao and Tianjin in the north. Much of the infrastructure of this route is already there in the form of the Grand Canal, but many pumping stations will have to be added to tackle the negative gradient of the first part of the route. The Middle Route Project (MRP) is different. The positive gradient over the whole route enables water transfer by gravity. The starting point is the Dangjiangkou reservoir on the Han River, a major tributary in the middle reaches of the Yangtze River. This route will have a maximum capacity of 12 – 14 billion m^3 of water per year with the final goal of reaching Beijing. The bulk of the water of both routes will be used to supply the agriculture in municipalities along the route.

The project is of a magnitude seldom or never seen before in water engineering around the world. Obviously the implications are enormous and the project finds much opposition both within China and around the world. While also costing a lot of money, many people argue that the effects of this project will be devastating and irreparable. According to them, downstream sections of water-intake points will experience large declines in flow, dangerously affecting current morphological and ecological balances. Hundreds of thousands of people have to be relocated because their houses will be inundated. Most importantly, they argue, dependability on a constant supply of cheap water will be created in times of possibly decreasing precipitation due to climate change. They claim that currently so much water is wasted by inefficiency, that this project is completely unnecessary. This tendency to waste will only be encouraged by the additional supply of large quantities of subsidized diversion water[7].

It is not however within the scope of this report to assess the necessity of the S-N Diversion Project. The starting point of this report is the government decision to construct the South – North Diversion Project in November 2002. The study further limits itself to the water allocation alternatives of the ERP.

1.2 Characteristics of East Route Project[10]

The ERP is characterised by its usage of existing infrastructure, its many pumping stations and its complexity. It will start in the lower reaches of the Yangtze River, supplying water from there to the provinces of Jiangsu, Anhui, Shandong and Hebei and Tianjin municipality. The trunk of the canal will be 1156 km long, ending in the Beidagang Reservoir just south of Tianjin city. An additional 740 km of subsidiary routes will be made ready, mainly for water supply into the Jiaodong peninsula on the eastern end of Shandong province. Existing channels and lakes will be used for 90% of the ERP, although most of these will require auxiliary constructions and an increase of capacity.

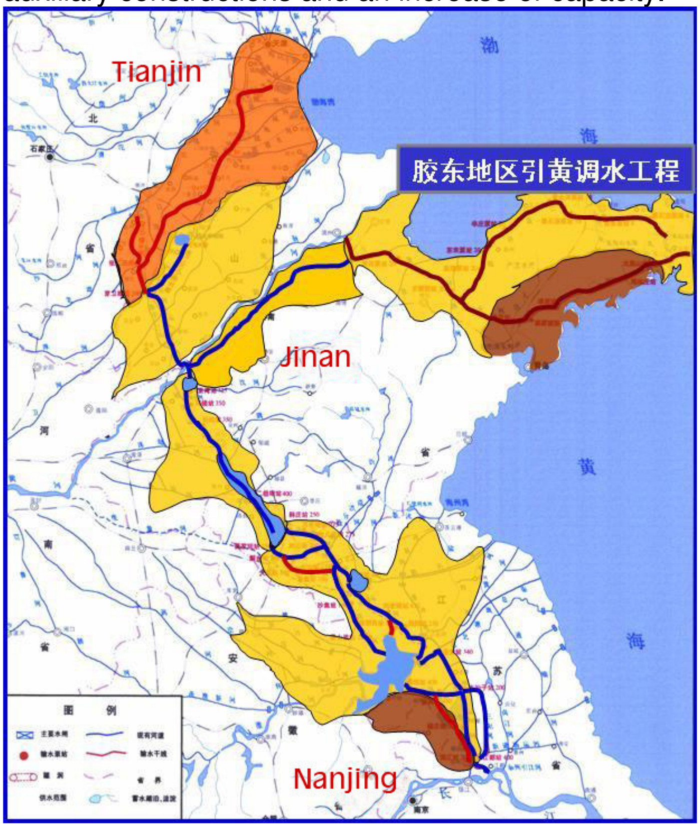


Figure 2: Layout of the ERP
Yellow = Phase 1, Orange = Phase 2, Brown = Phase 3

The project has been planned to be executed in 3 phases. The first phase, to be completed by the Olympic Year 2008, will transport 8.9 billion m^3 of water per year as far north as the town of Hezhou on the Shandong-Hebei border and just south of the Yellow River mouth in eastern direction, where it will be connected with an existing water diversion canal running south-east (Figure 2). Subsequent phases, increasing the maximum capacity to respectively 10.6 billion m^3 and 14.8 billion m^3 per year will provide water to the city of Tianjin and further into the Shandong peninsula. Actually, a part of the project had already been completed by 1961, when the 400 m^3/s Jingdu pumping station was inaugurated in order to provide

Jiangsu farmers with a constant supply of irrigation water. This was later included into the current plans. Table 1 gives an overview of how much water will be provided to various destinations in the subsequent stages, according to the current plans.

Destinations	First stage (m^3/s)	Second stage (m^3/s)	Third stage (m^3/s)
Intake from Yangtze river	500	600	800
Through Yellow River tunnel	50	100	200
Shandong Peninsula	50	50	90
Tianjin	0	50	100

Table 1: The three stages of the ERP

One of the biggest challenges of this project is pumping the water up the negative gradient between the water intake and the Yellow River. The water will be lifted 65m by large scale pumping stations in twelve stages, as shown in Figure 3[9]. After crossing the Yellow River the water can flow further north by gravity. The Yellow River will be crossed using two 9.3 m diameter tunnels 70 m below the riverbed. Construction on many parts of the project, including both the tunnels and the pumping stations, has already begun.

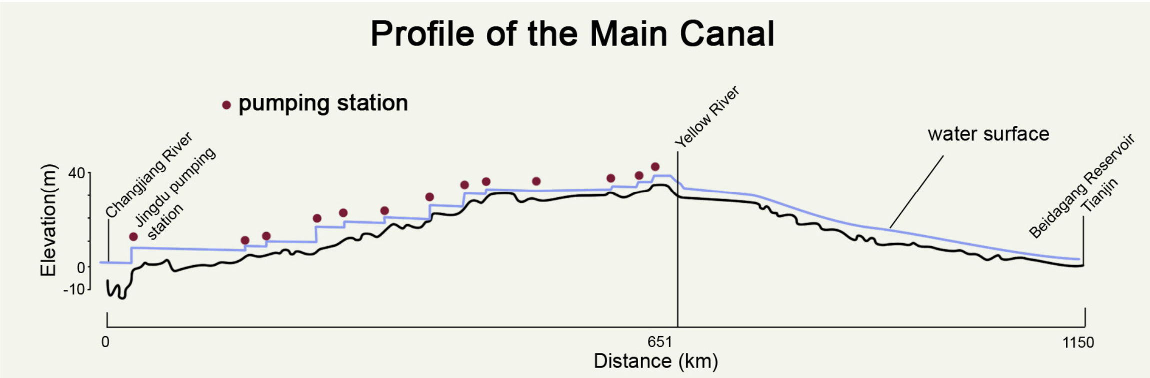


Figure 3: Profile of the ERP

The current water infrastructure along the route causes many complications. Especially in Jiangsu province, the land is intensely drained and irrigated, connecting most rivers and lakes with each other. Unfortunately most of this water has an unacceptably low quality due to pollution from agriculture and industry. This pollution should not infiltrate the relatively clean diversion water. Consequently, the ERP is directly linked with the construction of many water treatment facilities. These works are so extensive that their costs may eventually exceed the construction costs of the ERP. These works will not be included in this study.

The project has a large number of beneficiaries including urban users (e.g. drinking water), industry and agriculture (and nature, but allocating water to nature is currently hard to defend). Logically, a clear division of the transferred water along the route will have to be defined by official decree to avoid potential conflicts, especially during droughts. Even though the ERP will provide large additional quantities of water, estimates indicate that shortages will continue to exist during parts of the year. Currently, studies are being performed on the best water allocation alternatives. These alternatives will be split into three levels:

1. The water division per season (summer, autumn, etc.)
2. The water division per municipality
3. The water division per sector (industry/municipality/agriculture)

This is no easy task to perform, because it requires a method to determine the value of water for every recipient. It is easy to decide to provide drinking water to a thirsty city rather than irrigational water to a few farmers, but the considerations to be made are not quite that simple. Which municipality has the biggest need for that extra 1% of the total water? And should it be divided equally among the subsistence farmers to improve income distribution, or should the economy receive an extra boost by making the water available to industry?

Together with many national and international partners, the IWHR is involved in a number of projects researching this issue. One of those projects is SWIMER (Sustainable Water Integrated Management of the East Route in the South – North Transfer Project). The next chapter will describe the background and basic conclusions of this project.

1.3 SWIMER

1.3.1 Introduction

The Sustainable Water Integrated Management of the East Route in the South – North Transfer Project (SWIMER) is a joint project of the Italian Ministry for the Environment and Territory (IMET) and the Institute of Industrial Economics, Chinese Academy of Social Sciences (CASS) and the China Institute of Water Resources and Hydropower Research. The SWIMER project aims to develop an integrated river basin strategy that will optimise water resources management along the East Route of the South – North Diversion Project in China, between the 3-H and Yangtze Rivers. The ultimate goal of SWIMER is to identify how much water must be supplied to the regions along the East Route before reaching the northern region in order to pursue an equitable socio-economic development and environmental sustainability of the whole region.

The core of the SWIMER Project is the development of an integrated management model which will allow the evaluation of the impact of different water diversion schemes in different sectors of society. The integrated model's goal is to understand the SWIMER project's socioeconomic and hydraulic impacts while taking climate changes into account, in order to optimally satisfy every municipality's water needs and socio-economic policies. This model will provide decision makers with an instrument that will allow the evaluation of different water allocation alternatives and facilitates the identification of the optimal alternative.

As stated before, the East Route project consists of three stages which will consecutively increase the water supply and extent of the project, encompassing 77 municipalities in total. The first stage of the project will supply water to the Anhui, Jiangsu and Shandong provinces, totalling 21 affected municipalities (see Figure 4). At the time the SWIMER report was written, the subsequent stages were still in the planning phase. Therefore, the SWIMER project's analysis is only concerned with the 21 municipalities which are certain to receive diversion water.

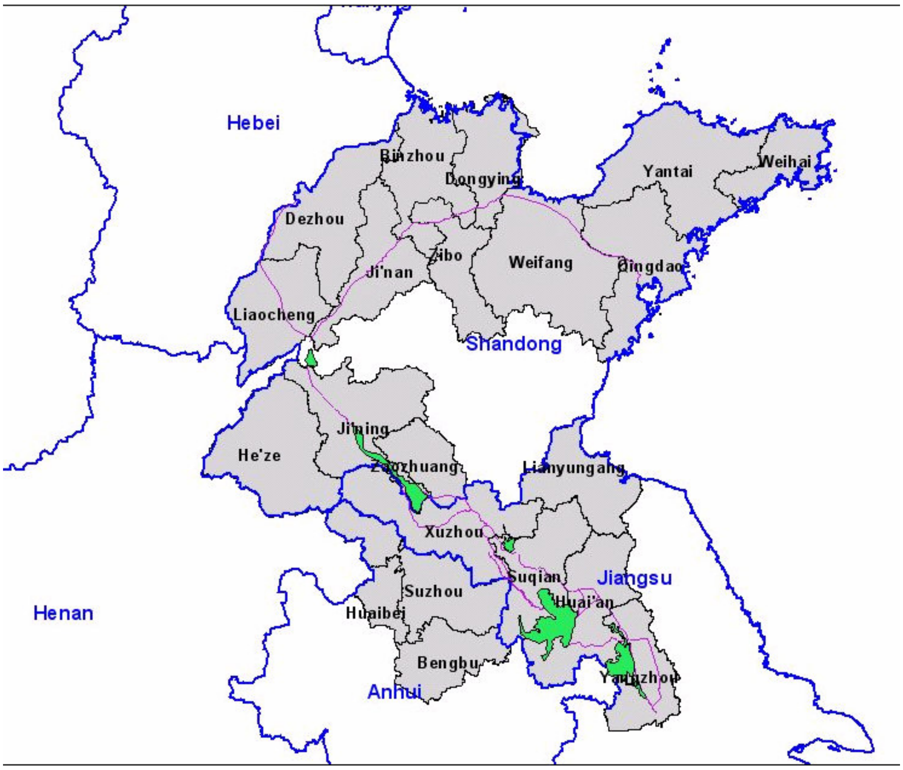


Figure 4: The 21 municipalities involved in phase 1 (purple line = diversion canal, green = lakes and reservoirs)

Because of the project's magnitude and complexity, a two step approach has been taken. First a complete integrated working model was implemented and tested on the pilot area Xuzhou (one of the 21 municipalities). After this, the tested methodology was replicated for all the other municipalities influenced by the 1st stage of the East Route. With the gathered information, the integrated model could be constructed, calibrated and applied to the entire project area. The different components of the integrated model will be discussed next.

1.3.2 Methodology of SWIMER

As was said before, the SWIMER project aims to determine the socioeconomic and hydraulic impacts on the project area while taking climate changes into account, in order to determine the optimal water allocation alternative. In order to achieve this, three separate models have been developed and linked to each other, as shown in the following diagram.

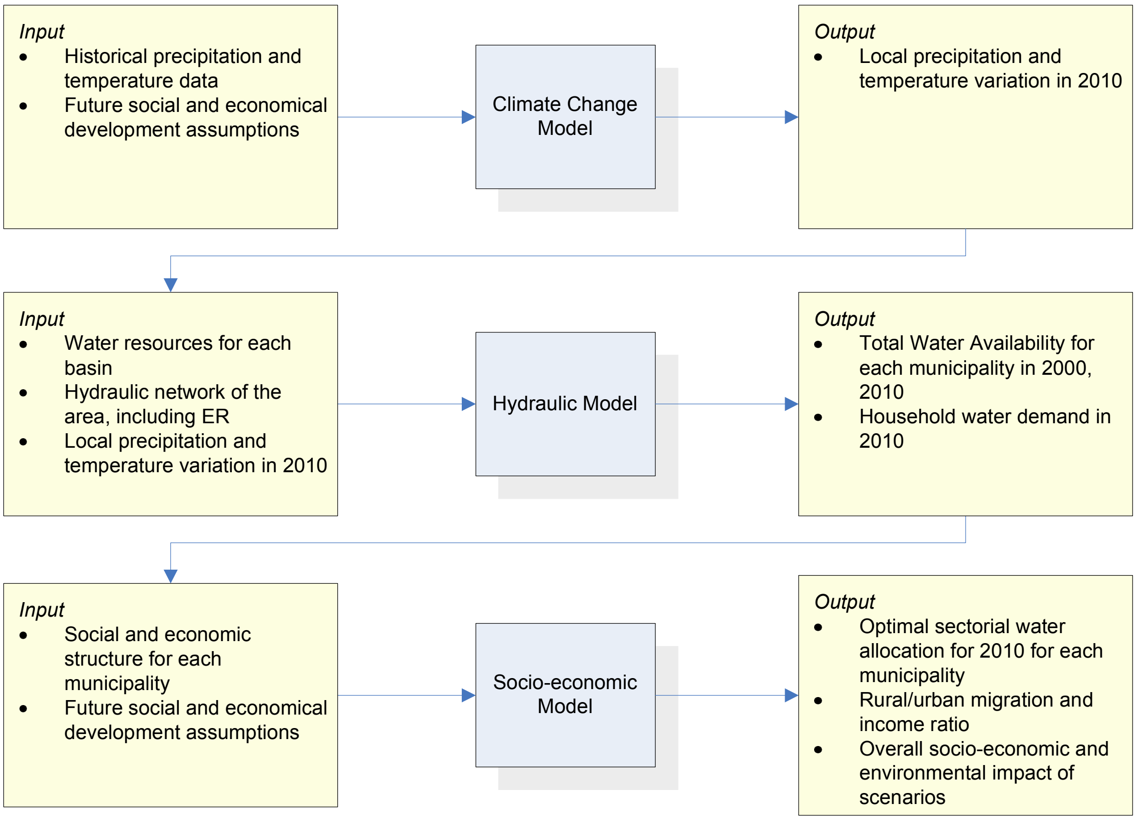


Figure 5: Integrated model schematisation

In order to truly integrate the different components, the above model has been adjusted and can been seen in the following diagram.

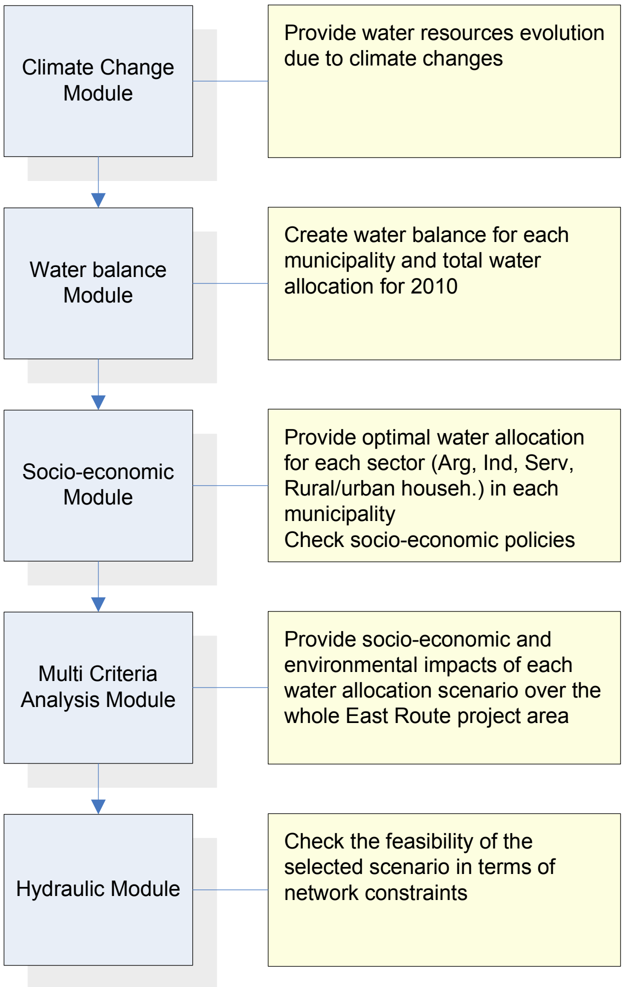


Figure 6: The five modules within the integrated model

The application of the final integrated model is twofold. Its first use is the optimisation of the allocation of additional water to each sector (agriculture, industry, urban/rural household, services) taking the total water allocation for each municipality as fixed. The second is a planning tool with which the water allocation schemes within the whole East Route Project area can be evaluated. The model is capable of maximising certain socio-economic objectives (i.e. which water allocation scheme will maximise the agricultural development in Municipality X and the industrial development in Municipality Y?). Each of the five modules is clarified shortly below:

Climate change module
The climate change module forecasts the temperature and precipitation changes in the next 30 years on the basis of historical data and socioeconomic assumptions for different scenarios. The predicted changes in precipitation are then converted in water resources availability variation for each municipality and added to the water balance model. Since the different climate change scenarios were not taken into account in this study, this subject will not be treated further.

Water balance module
The water balance module assesses all water resources available within each basin and combines this information with the water demands to come up with an overall water balance. The model used for this purpose is Rule-based Objected-oriented Water Resources System Simulation Model (ROWAS) and was developed by IWHR. This model is used to make a detailed analysis of the water cycle (natural, and man made) within the East Route area.

Based on the planned water allocation schemes for 2010 the water balance module produces the total water availability for each municipality and its relevant sectors (industry, agriculture, services, rural and urban household) which is the input for the socio-economic model. In the SWIMER model the water availability is strictly connected with rainfall. Therefore, two scenarios with different amounts of rainfall are considered, one for a dry year, and one for an average year.

Socio-economic module

Using the input from the water balance module, the socio-economic module produces the optimised water allocation for each sector (agriculture, industry, urban/rural household, services) based on the total water availability in 2010 in each municipality. For this use the Environmental Computable General Equilibrium Model (ECGE) has been developed. This tool allows the assessment of the impact of the East Route on economic, social and environmental indicators for any water allocation scheme. For this purpose, a number of indicators, subdivided into three categories, have been evaluated. The 6 criteria are GDP (economic), inefficiency of water usage and waste water (environmental) and income, rural-urban migration and unemployment (social).

The socio-economic module operates at municipality level and produces alternatives based on the structure of society and economy of each municipality. Since most of the obtained indicators are not directly comparable because they are not expressed in the same units, a multi criteria analysis is required to identify the optimal alternative.

Multi criteria analysis module

The multi criteria analysis module is the extension module that allows the aggregation of the results from each municipality in the socio-economic module. Most importantly however, it can help the decision making body to identify the optimal water distribution schemes for the whole East Route Area on the basis of certain policy priorities. The type of multi criteria analysis used in SWIMER is the multi-attribute value theory.

The values of the different indicators are transformed into a score that represents the extent in which the objective has been achieved. For example, in case of the planned sectoral GDP growth rates, the economic indicators will be expressed in terms of the percentages of the observed growth rates with respect to the objective growth rates. This is an interesting difference with this study's multi criteria analysis, in which values are determined by the position a particular indicator has on the range from worst to best scoring alternative.

Hydraulic Module

The optimal water allocation scheme obtained through the socio-economic model (the socio-economic module and the multi criteria analysis module) needs to be tested with the network constraints which characterize the East Route's hydraulic infrastructure. Another hydraulic module is hence required to test the feasibility of the optimised water allocation schemes. The model used for this purpose is REServoir SIMulation Model (ResSim) which was created by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers to perform reservoir system simulation. It was designed as a decision support tool, as well as a means to meet the needs of modellers doing reservoir projects studies.

Within the SWIMER project, the ResSim model is used to simulate several alternatives for the East Route. In particular, the model focuses on the rule based management of the diversion network and verifies the water allocation schemes suggested by the ROWAS model and the socio-economic module. The reservoirs along the route fulfil an important role in the network, acting as storage buffers by varying their water height. Moreover, the ResSim model is able to analyse the behaviour of the diversion network under different hydrological conditions. The model will be used as a final verification tool to complete the water allocation analysis.

1.3.3 Conclusions of SWIMER

The SWIMER project has yielded an optimal allocation alternative which could be implemented in the coming years. Furthermore, the following conclusions were drawn in the SWIMER report:

- The implementation of the East Route of the South to North water transfer will largely contribute to the reduction of water stress in the project area. The water shortages will diminish and water savings will be realised from the exploitation of the groundwater resources.
- The optimised allocation of the diverted water resources is compatible with the structural and operational constraints of the water diversion network under average and extreme drought conditions.
- The integrated management of the East Route water diversion project needs a centralised instrument capable of controlling the diversion of water resources. This could be built on the basis of the instruments developed under the SWIMER project.

All these findings lead to the conclusion that an integrated water management is required, in which information about economic, social and environmental objectives, defined in terms of indicator achievements, is combined in a model with a real time feed-back procedure. This model should combine hydrological information about feasibilities of water allocations suggested by the analytical model, with constraints for water allocations to be considered by the analytical model.

<u>The SWIMER project and this study</u>

The SWIMER project report is one of the most extensively used sources of information in this study. Since this study's main goal is to design a multi criteria analysis capable of assessing the different alternatives in the SWIMER project, the main focus was on the socio-economic model and the multi criteria analysis model in particular. Because the data used in both studies is the same, most boundary conditions in this study are logically the same as the ones used in the SWIMER report. However, only the source data used in SWIMER was used. The multi criteria analyses and methodologies used in both studies differ. Furthermore, the alternatives discussed in the SWIMER report were considered irrelevant to the goals set in this study. This meant that new alternatives had to be developed, partially based on SWIMER data and partially on new data obtained from many different sources.
Chapter 2 describes the basic methodology used in this study. Chapter 3 explains in detail how all the basic data was obtained. The Multi Criteria Analysis is elaborated upon in Chapter 4.

Chapter 2 Methodology

2.1 Introduction

In this chapter, the methodology used in this study will be discussed. Recalling from the introduction, the goals of this study are:

Main goal

The goal of this project is to produce an independent report containing a rapid assessment in which water-allocation scenarios within the SWIMER-project are compared by means of designing and applying a robust multi-criteria analysis (MCA). This allocation is specifically an allocation among sectors, e.g. industry, agriculture, drinking water, etc.

Additional goals:

- *Generation of measurable properties (social, economic, environmental) "in a scientifically founded way" for a situation in which the ERP has been fully implemented*

- *Performance of a sensitivity analysis on the choice of system boundaries and assumptions (which can differ depending on the designer of the MCA), because of the influence these choices have on the outcome of the MCA*

Although any MCA is incomplete without a sensitivity analysis, it was decided to mention as an additional goal to stress its importance. This leaves two actual goals: the design and application of the MCA and the collection and generation of the data needed for this MCA. Firstly, the choice of the particular MCA method used in this study will be explained after which a quick overview of the selected MCA method is given. This chapter ends with a discussion of the data required for this study.

2.2 MCA selection

The main role of any MCA is to enable the decision-maker to gain an increased understanding of the decision problem he or she is facing. Ultimately, its goal is to help the decision-maker in making a more rational decision.

The East Route Project is a large and complicated project. In making a decision as to which water allocation alternative is the optimal one, the consequences of a certain decision can impossibly be overseen without the use of some sort of decision-making tool. Furthermore, the relevant characteristics that are influenced by this project are expressed in many different units of measurement which makes direct comparison impossible. Therefore, the MCA is the appropriate tool to be used in this situation.

From the start, considering the size of the project, the amount of time available for this study was rather limited. Because of the limited availability of data, an unexpectedly large amount of time was consumed by data collection and creation. This reduced the time available for the MCA even more. Furthermore, the results of this study should be understandable to those who are not familiar with multi criteria analyses. For these reasons, one of the most important criteria on which to select the MCA was simplicity.
Keeping this in mind, two suitable methods were identified: SMART (simple multi attribute rating technique) and AHP (analytical hierarchy process). Methods like MAUT (multi attribute utility theory) and ELECTRE were considered but quickly deemed too complicated and time consuming for this study's purpose.

Both methods' structures are more or less the same. With both methods, one begins by determining the goal of the MCA. This will influence all choices from this point onwards. After that the different alternatives have to be identified along with criteria on which these alternatives are to be rated. After the criteria have been identified, they can be rated on value and weight. Once these are known, an overall score is obtained on which a choice between the different alternatives can ideally be founded.

As mentioned before, the basic principles of both methods are more or less the same, but the ways of obtaining the results differ. In rating one particular criterion, SMART uses value functions to obtain scores per alternative. After all the criteria have been rated, the per criterion weight is determined by using swing weights. AHP uses pair wise comparison matrices to determine the scores of alternatives per criterion, as well as criteria weights. Both methods' advantage is that they are fairly simple and transparent and hence easy to understand, even for those not familiar with decision making methodologies. Furthermore, the AHP's pair wise comparison matrices enable the user to deal with his judgment's inconsistencies in a formal way. Errors in the decision maker's judgment of the relative value of scores always occur. By giving a measure of inconsistency, AHP enables the decision maker to assess how inconsistent he has been in his judgment. The downside of AHP is the phenomenon of rank reversal. When an (almost) similar alternative is added, the former top alternative could move to second place, while it is in fact still the top alternative. Since AHP is a ratio method, it "spreads" the priority between two rather than one alternative. For a more elaborate description of AHP, please refer to Appendix B.

The use of SMART's value functions to judge the value of criteria seems slightly more transparent than AHP's pair wise comparison matrices. When using pair wise comparison matrices, it is still possible for those not familiar with this method to get lost in abstract mathematics. Because of this the SMART method was selected in the end. An overview of this method is given next.

2.3 SMART (simple multi-attribute rating technique)

SMART is especially useful due to its simplicity, both in the responses required from the decision-maker and the manner in which these responses are analysed. A lot of decision making methods are very mathematical and therefore very hard to understand, especially for outsiders. SMART offers a transparent view of the decision making process.

SMART typically consists of the following steps:

1. *Identify decision-maker(s)*
   In order to set the goal of the analysis, the decision maker should be identified to determine what results are most desirable. He or she should then proceed to identify the goal of the alternatives that will be assessed.
2. *Identify alternatives*
   Between which alternatives should a choice be made?
3. *Identify different criteria relevant for the problem on which the decision will be based.*
   These criteria should characterize the alternatives in order to measure the desirability of each alternative.
4. *Assess how well every alternative does on each criterion.*
   The performance of the alternatives on each of the selected criteria should be measured.
5. *Determine a weight for each criterion.*
   How important is each criterion to the decision-maker.
6. *Compute total score for each alternative.*
   For each alternative, take a weighted average of the values assigned to that alternative.

7. *Identify optimal alternative*
   With the obtained outcome, the preliminary optimal alternative can be identified.
8. *Sensitivity analysis*
   How does the outcome of the analysis change if the way of measuring performance or the weights are altered? Is the previously obtained optimal outcome still the best when the input variables are altered?

The above steps will be discussed in more detail in Chapter 4, with the exception of the sensitivity analysis which will be discussed separately in Chapter 5.

2.4 Data collection

A multi criteria analysis (MCA) which consists of several alternatives and their relevant criteria requires a large amount of data. Every alternative is to be tested on selected criteria and because all these alternatives represent an unknown future state, the value of each criterion for each alternative has to be simulated. This simulation's goal is to get a reasonable judgment of the values of the criteria so that a reasonable assessment of the alternatives' benefits can be made. The design and simulation of such an alternative should be done in as much detail and with as much care as reasonably possible and is therefore a time consuming and intricate process.

It is not in the scope of this study to conduct such a simulation. The original plan was to use readily available alternatives with corresponding criteria and scores and assess these alternatives with an MCA designed for this study. After doing some preliminary research, it became apparent that this sort of data was not available through the accessible sources. In order to still be able to carry out the MCA, a large amount of data had to be generated using available data and combining these into new data series.

The SMIWER report uses three main categories for the MCA, being economy, social and environmental, which is the same classification as was used in this study. Ideally, every relevant influence the project has on its surroundings should be taken into account. However, because of the limited amount of input data and the time constraint, data has only been generated for six criteria. These are GDP (agricultural and industrial) and agricultural production (economy), income and rural-urban migration (social) and groundwater level and untreated wastewater discharge (environmental). The choice for these criteria was primarily based on the availability of data needed to create data series for these criteria. All this means that the MCA in this study will not take all factors into account. Furthermore, the data collected for this study was collected in a strongly simplified manner and can only be seen as a rough approximation of reality. It can never be used as reliable input data for any study outside of this report.

The only variable that will be changed between the different alternatives will be the diversion water amount allocated to the different sectors (agriculture, industry) and between rural and urban areas within each municipality. Water demand and supply data is available for the base year 2000 and 2010 with (2010F) and without ERP (2010E), for every municipality and every sector. Therefore, each criterion for which data has to be generated can only be dependent on the water amount. In order to estimate the effects of different water allocation alternatives, the per m^3 diversion water contribution for the criteria for which no data is available has to be found. Once this number has been estimated, the outcomes of different water allocation alternatives can be computed easily after which the MCA can be carried out. A schematic display of the above is represented in Figure 7. Chapter 3 will explain phase 1 in more detail.

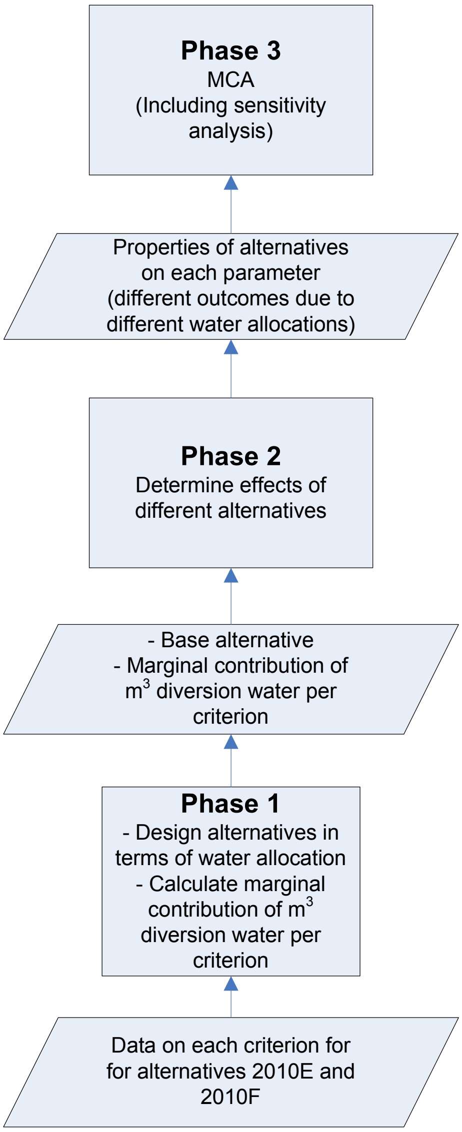


Figure 7: data and steps needed in preparation for MCA

All source data and the different outcomes are presented in Appendix C0.

Chapter 3 Data collection

As discussed in Chapter 2 the first step to be taken was the collection of data. This chapter will start by giving an overview of the basic data such as water amounts and population levels that are needed for this study. Next, the calculation methods of the different coefficients and the assumptions that had to be made for these calculations are discussed for all six criteria. The chapter ends with a short conclusion.

3.1 Basic data

3.1.1 Water demand and supply

The water demand and supply data is the basic data needed in order to be able to generate results of the different criteria in every alternative. This data has been obtained directly from the SWIMER report.

The water demand data have been provided to IWHR by the Huaihe River Committee. Subsequently they were processed by the IWHR to obtain water demand data in a uniform scale and format with which ROWAS simulations could be performed.

The ROWAS simulations have provided plausible data for the whole ERP area. They contain detailed numbers of water supply per source and per sector of usage. These results have been verified in the ResSim model.

Two extra assumptions had to be made to use the ROWAS data in this report. Firstly, the ROWAS results provide data divided into 6 sectors: Urban Life, Rural Life, Industry, Agriculture, Urban Ecology and Rural Ecology. Not all of these sectors were considered of importance in this report, which has been the reason to combine the results of certain sectors. Both ecologies showed small amounts of water, which did not represent the total ecological supply to either the Urban or the Rural ecology. This data mainly consisted of the amount of water added by man to e.g. parks and lakes. However most of the supply of these ecologies is natural. For these two reasons (whilst not losing any information), Rural Ecology has been added to Rural Life, and Urban Ecology has been added to Urban Life.

Secondly, a distinction between Urban water supply and Rural water supply was necessary to process certain results. Thus all industry is assumed to be urban, and all agriculture rural. Urban water supply is now the total of Urban Life and Industry, while Rural water supply is now the total of Rural Life and Agriculture. Figure 8 provides an overview of the now obtained water division.

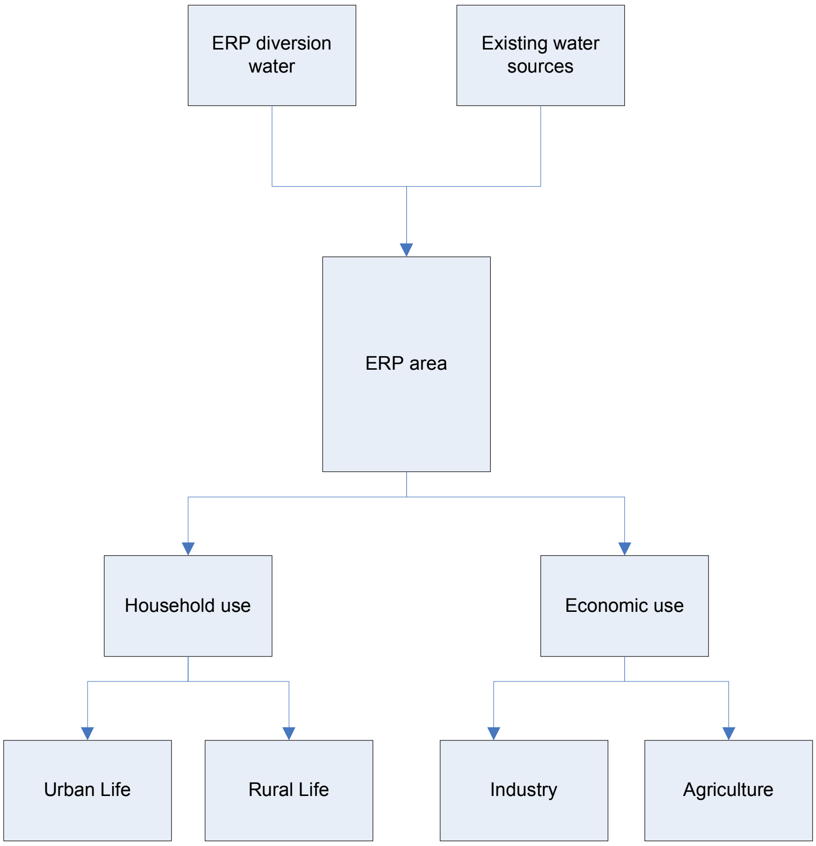


Figure 8: Water division

The difference between alternative E and F on all criteria was divided by a certain amount of water in order to be able to calculate the influence of one m^3 of diversion water. The following symbols will be used to indicate which denominator is used:

ΔW = Change in volume of Diversion Water (m^3)
ΔW_{Ind} = Change in volume of Industrial Diversion Water (m^3)
ΔW_{Agr} = Change in volume of Agricultural Diversion Water (m^3)
ΔW_{Urb}= Change in volume of Urban Diversion Water (m^3)
ΔW_{Rur} = Change in volume of Rural Diversion Water (m^3)

3.1.2 Population

No calculations were done to obtain information about the populations in 2000 and 2010. All the data was provided directly by IWHR, from the current statistics and predictions from the government 5-year plan. An assumption had to be made that there are no differences in population between 2010 due to the ERP: both alternative E and F have taken the same population into account.

The determination of the m^3 diversion water contribution to the different criteria will be explained next.

3.2 Economical data

3.2.1 Gross domestic product

The Gross Domestic Product (GDP) data available was limited to the 2010 with ERP situation, for each sector. This data was extracted from the Chinese Government's Five year plan. In order to calculate the 2010 without the ERP alternative GDP, the per sector GDP growth rates available in the SWIMER report were used. Using this number, the total GDP difference caused by the ERP for both agriculture and industry could be calculated. In order to be able to distribute the total GDP growth due to the ERP over the different municipalities certain assumptions had to be made. The relative proportion of m^3 diversion water per municipality was assumed to partially represent the GDP growth distribution. Furthermore, more developed municipalities were assumed to be able to convert the additional water into growth more efficiently; represented by the proportion of total GDP in alternative F per municipality. These two factors were combined to determine the per municipality GDP growth due to the ERP after which the per m^3 diversion water increase of the GDP per municipality could be calculated. This relation is represented by the formula:

$$\frac{\Delta GDP}{\Delta W} = \frac{GDP_{2010F} - GDP_{2010E}}{\Delta W}$$

Where $GDP_{2010E-i} = GDP_{2010E-Tot} \times \frac{\gamma_i}{\sum_{i-1}^{n} \gamma_i}$

and $\gamma_i = \frac{GDP_{2010F-i}}{GDP_{2010F-Tot}} \times \frac{\Delta w_i}{\Delta W}$ for every municipality i of n municipalities total.

These operations can be performed for the total GDP growth or for sectoral GDP growths (industry and agriculture). In the sectoral growth calculations only numbers for that specific sector should be used to compute the results. For example, when calculating the growth of agricultural GDP, only the agricultural GDP and agricultural water allocation data should be considered.

Because no industrial water is allocated to the Jining municipality in the 2010F alternative, it was not possible to calculate the per m^3 diversion water increase of GDP for this municipality. In the SWIMER report, the 21 municipalities in the ERP area are categorised as being either "agriculture-oriented" or "industry-oriented". Jining itself is an "agriculture-oriented" municipality. By taking the average "agriculture-oriented" industry GDP and "agriculture-oriented" industry GDP increase per m^3, and correcting it for Jining's GDP, the estimate for the per m^3 diversion water effect was obtained.

3.2.2 Agricultural production

Data on agricultural production was available for both agricultural area and total agricultural production. This data was provided for 2000 from national statistics and for 2010F from the governmental five-year plan. The total agricultural area varies between 45% and 85% of total area, which seems to be a credible amount. However, in agriculture it is not just the availability of water that influences total production. Urbanization, land degradation and technological developments are important factors to be taken into consideration. Data on these factors was not readily available so estimates had to be made.
Due to incompatibility of different data series, most methods producing detailed data per municipality did not yield satisfactory results. In the end, the overall rate of agricultural land loss (due to both urbanization and land degradation) has been assumed to be 5% in the period 2000 – 2010, as the 3H plain is one of China's fastest urbanizing regions[11,12]. This percentage made it possible to calculate the total agricultural area for 2010E.
After extensive research no usable data could be generated to model the influence of technological developments. Disregarding this factor, the productivity has been assumed to be equal in 2000 and 2010E. With this assumption the agricultural production for 2010E could be calculated. Dividing the difference between the 2010F and 2010E agricultural

production by the total agricultural diversion water assigned to each municipality gives the agricultural production increase per m^3 diversion water. This relation is represented by the formula:

$$\frac{\Delta AGR}{\Delta W} = \frac{AGR_{2010F} - AGR_{2010E}}{\Delta W_{Agr}}$$

AGR_{2010X} = Agricultural productivity * Agricultural Area (= Agricultural Production in alternative 2010X)

3.3 Sociological data

3.3.1 Income

The SWIMER report contained both rural and urban per capita income for 2000. Furthermore, a relative average income effect of the ERP was known for both rural and urban incomes.
In order to calculate the per m^3 diversion water income effect per municipality several assumptions had to be made. First of all, for the municipalities of Suzhou and Liaocheng no data was available on urban income. In order to still be able to use the data for these municipalities an estimate of their figure had to be made. This was done by multiplying the rural incomes by the average difference between rural and urban income figures. Again, the classification “agriculture-oriented” or “industry-oriented” from the SWIMER report was used. Both Suzhou and Liaocheng are “agriculture-oriented”, so the specific agriculture-oriented municipalities’ urban/rural income ratio was used, in order to increase the estimate’s accuracy.
The relative GDP increase from 2000 to 2010F is assumed to represent the income growth from 2000 to 2010F. For the calculation of rural income the agricultural GDP growth was used, whereas for the urban income the industrial GDP growth was used.
The income increase between 2010E and 2010F was assumed to change in proportion with the water increase, with an average income increase that matched the SWIMER report’s average income effect of the ERP. By dividing the monetary increase by the water increase, the per m^3 diversion water income effect was finally obtained. This relation is represented by the formula:

$$\frac{\Delta I_i}{\Delta w_i} = \frac{I_{2010F-i} - I_{2010E-i}}{\Delta w_i}$$

Where $I_{2010F-i} = I_{2000-i} \times \frac{GDP_{2010F-i}}{GDP_{2000-i}}$

and $I_{2010E-i} = \frac{I_{2010F-i}}{\left(1 + \lambda \frac{n\Delta w_i}{\Delta W}\right)}$ for every municipality i of total n municipalities.

In which λ is average GDP growth between 2010E and 2010F.

As with the GDP calculation, these operations can be performed for the overall average income or for sectoral average incomes (industry and agriculture) where again, for the sectoral growth calculations only numbers for that specific sector should be used.

3.3.2 Migration

Data on rural-urban migration rate was very hard to find. The SMIWER report included a diagram containing a graphical representation of the rural/urban migration change caused by Alternative F. From this, migration rates with a resolution of 5% intervals have been extracted. After that, the average migration rate which was also available from SWIMER, was used to correct the obtained results to match the average migration rate. Because absolute migration numbers where not available, the comparison is based on the change of the migration increase in Alternative F.
To get to a marginal increase per m^3 diversion water, an inversely proportional relationship between the migration rate and the amount of agricultural diversion water was assumed. This was done because of the assumed direct relationship between agricultural water and rural-urban migration. Farmers are directly dependent on agricultural water for their production. When they do not receive enough water to survive, they will often migrate to the city to find an alternative income. This relation is represented by the formula:

$$\frac{\Delta M}{\Delta W} = \frac{\Delta M_{2010F}}{\Delta W_{agr}}$$

3.4 Environmental data

3.4.1 Groundwater

In the same way that the data for many other criteria is described, the data on groundwater cannot be regarded as precise data, but is very rough data generated in an extremely simplified manner.
The ROWAS model has provided figures describing total usage of groundwater in both alternatives 2010E and 2010F. The SWIMER report also described the total volume of exploitable groundwater resources per municipality. Subtraction of the groundwater usage from the exploitable resources results in an indicator of how groundwater levels are developing. This data seems useful, but the difficulty is how to link this number to the water allocation in a certain municipality.
The man-induced factors that influence groundwater recharge are both agricultural seepage and urban seepage. Agricultural seepage is the part of irrigation water that infiltrates into the ground (most of the other part evaporates). Urban seepage is more complicated to explain. A large share of the water used by urban centres will eventually drain into rivers (whether the water has been treated or not). This river flow will also influence the groundwater level through seepage, especially in areas with an extraordinarily low groundwater level like in the project area. Rural water is assumed to be consumed completely due to a difference of lifestyle in comparison with urban areas.
To incorporate the above complication into the calculation, a certain percentage of the agricultural water should be used, as well as a certain percentage of the extra urban affluent. Factor α represents the relative influence of one unit of extra agricultural water to the groundwater. Factor β represents the relative influence of one unit of extra urban water to the groundwater. The following data (partially on a provincial level) has been used to obtain these multiplicators:

- α : evapo-transpiration, effective rainfall and the water quota for a representative plant (maize)
- β : percentage of urban water that becomes wastewater, seepage-factor of surface water to groundwater

0 provides a detailed description of the methodology used to calculate α and β.

The effect of the diversion water on the groundwater can now be calculated by using the formula:

$$\frac{\Delta GW}{\Delta W} = \frac{GW_{2010F} - GW_{2010E}}{\alpha \Delta W_{Agr} + \beta \Delta W_{Urb}}$$

GW_{2010X} = Groundwater use – Exploitable Groundwater (=Groundwater availability in alternative 2010X)

3.4.2 Untreated wastewater

The ROWAS model has provided total quantities of wastewater in alternatives 2010E and 2010F. Together with treatment rate the total amounts of untreated wastewater that are drained in the rivers of the North China Plain can be calculated. This untreated wastewater is the total amount of untreated wastewater from urban areas. Rural wastewater is assumed to be zero. This means the effect of the ERP allocation on the untreated wastewater can be obtained by dividing the difference in untreated wastewater quantity of 2010F and 2010E by the difference in how much of the diversion water has gone to the Urban (Life and Industry). The resulting number is a direct link between extra untreated wastewater and extra diversion water allocated to industry.
This relation is represented by the formula:

$$\frac{\Delta UWW}{\Delta W} = \frac{UWW_{2010F} - UWW_{2010E}}{\Delta W_{Urb}}$$

UWW_{2010X} = Wastewater volume * treatment rate (= Untreated Waste Water in alternative 2010X)

3.5 Conclusion data collection

Obtaining the data needed for the MCA proved to be a difficult and time consuming task. This was mainly due to the fact that for every criterion data had to be created from existing data which was available in very limited quantities. For this reason, data was created for only six criteria, these being GDP, agricultural production, income, rural-urban migration, groundwater level, and wastewater discharge. Furthermore, a lot of assumptions had to be made, which undermined the data's accuracy. Therefore, when interpreting data in this study one should always keep the rough manner in which the data has been obtained in mind.

Chapter 4 Multi criteria analysis (MCA)

4.1 Introduction

As mentioned in Chapter 2, the MCA method selected for this study is SMART. The general theory of which the SMART consists will be discussed in more detail in this chapter. Next, the step by step MCA procedure followed in this particular study is elaborated on. This includes a discussion of system boundaries, assumptions, criteria and the determination of weights. After that the different alternatives that were used in this study are described. Finally, the results of the MCA are presented and the relevant conclusions are presented.

4.2 SMART

1. Identification of decision makers
   It is of utmost importance to clearly identify who is the decision-maker first. The decision-maker normally represents a group of stakeholders and their priorities and can thus define what the ultimate objective of the project is, i.e. in which direction does the decision-maker want the relevant criteria to move. This is a determining factor in the MCA since it will influence the choice of criteria and the determination of weights.

2. Identification of alternatives
   After the goal is known, one must assess which alternatives are available, and will be considered in the MCA. From which options does the decision-maker have to choose?

3. Criteria
   The criteria chosen will be used to measure the performance of courses of action in relation to the objectives of the decision-maker. Therefore, a set of criteria that can be expressed in a numerical scale and that together form a reasonable representation of reality is needed. Some criteria may be too big or vague to express in one number. In that case it might be necessary to break a criterion down into lower level criteria. For example, it is not feasible to produce one single number for economic benefits out of the blue. However, one might be able to break economy down into GDP, unemployment rate, industrial growth, income levels, etc., which can all be expressed in numbers. If all these sub-criteria are aggregated by using relative weights, a single score for economy can be obtained.

   A helpful tool in this respect is the value tree, a graphical representation of the modelled problem environment; an overview of the criteria.

   Once the value tree has been created, one can check whether or not it forms an accurate and useful representation of reality. Keeney and Raiffa[13] suggested five criteria on which to judge a value tree's quality:

   - Completeness: a complete value tree includes every aspect that is of concern to the decision maker.
   - Operationality: all criteria should be broken down enough for the decision maker to able to evaluate and compare them with the different alternatives. If a criterion is still too vague to properly assess, it should be broken down into sub-criteria until it is assessable.
   - Decomposability: one should be able to rate the performance of an alternative on a certain criterion independently form that alternative's performance on other criteria.

- Absence of redundancy: if two criteria actually represent the same thing redundancy occurs. In this case, because both criteria have a certain weight attached to them, this may cause double counting.
- Minimum size: the bigger a value tree gets, the harder it gets to keep an overview and see the big picture. Therefore, one should not decompose criteria beyond the level where they can be evaluated. Furthermore, if one criterion does not distinguish between the alternatives, it will have no influence on the end result and can thus be eliminated.

In Figure 9 the value tree used in this study is presented.

4. <u>Determine scores of criteria</u>
   It is not possible to use the number associated with the criterion directly due to the presence of *utility* (if you have €10, an extra €10 would mean a lot more to you, than when you would have had €1M). Therefore, a value function is derived from the different scores on the criterion in question, by using the method of bisection. This is done by setting the 'real' value of the least and most preferred scores on a certain criterion to respectively 0 and 100. Then, the decision-maker is asked what he feels is worth half as much as the best alternative, i.e. which is the midpoint between value 100. This procedure is repeated for the 25 and 75 value points and the outcomes are plotted in a graph. An example of a value function can be seen in the graph below. The score of the worst alternative in this example is 200, while the score for the best is 1000. The decision-maker set the midpoint at 420; he feels that an increase from 0 to 420 is worth as much as an increase from 420 to 1000. This is repeated for the point with a value of 25 (which the decision-maker has set to 300), and 75 (580) and a graph was plotted.

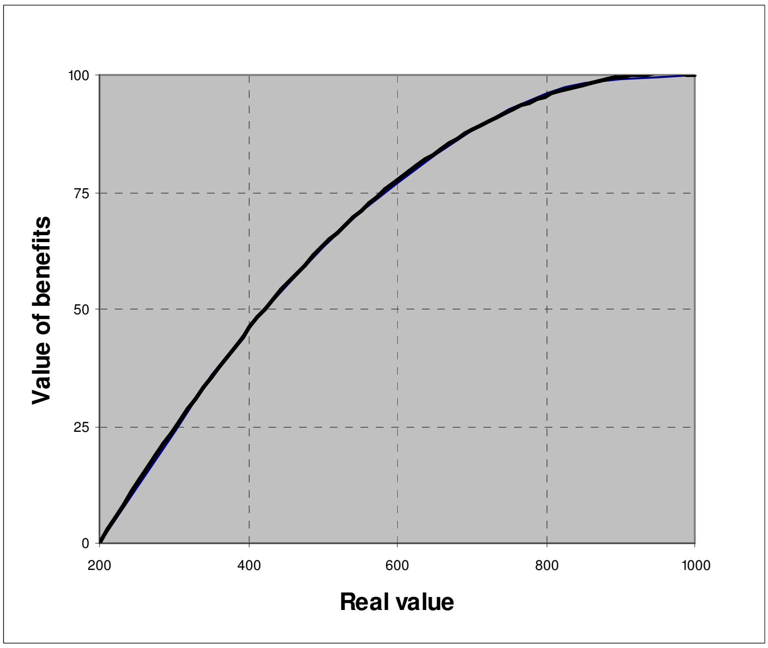


Figure 9: Example of a value function

Once the graph is obtained, a formula can be obtained from this graph which can be used to determine the value of all the different alternatives, or one can simply read which value a certain alternative has from the graph.

5. Determining weights
   Because the range between the most-preferred and least-preferred option on each criterion determines the importance of that criterion, one should take this fact into account when determining weights. If three options differ relatively little on a criterion, the weight should be smaller; when the difference is bigger (hence a big improvement can be achieved) the weight should be bigger. In order to incorporate this fact, one can use *swing weights* to determine these weights.
   Firstly, rank the different criteria in importance, starting with the most important and then going down. Now give the no.1 criterion (X) a weight of ‘100’. The other weights are assessed as follows: a hypothetical alternative is created with a score of 0 on each criterion. Next, the decision-maker is asked to compare a swing from the worst to the best score on the 2nd criterion (Y), with a swing from the worst to the best score on criterion X. The relative importance he associates with this swing is the weight for criterion Y. For example, he thinks swinging from the worst to the best on criterion Y is 80% as important as the swing from worst to best score on alternative X. In a similar fashion, determine the weights of all the other criteria. When all results have been obtained, these can be normalized to make them a little easier to understand.

6. Determine outcome
   The outcome of the MCA can now be easily determined by multiplying the weights with the scores on each criterion and aggregating the results for each option.

7,8.Identify optimal alternative & sensitivity analysis
   Now all the scores are known the preliminary best alternative is clear. However, before a definitive decision can be made, a sensitivity analysis should be carried out to determine the behaviour of the outcome when the different input parameters are altered. This will be discussed in detail in section Chapter 5.

4.3 Applied MCA

4.3.1 Goal

Normally, the goal of an MCA is defined by the decision-maker. He or she expresses his or her preferences which are later translated into weights. In this study the case is somewhat different. Since there is no clear decision maker in this project, the authors will have to assess what they feel is a good outcome of the project for China, its economy, its population and its environment in a rational and motivated fashion. To aim this assessment, an overview of the projects stakeholders will be given next.

4.3.1.1 Stakeholders

The ERP is an enormous project and the number of stakeholders is very large and diverse. However, not all these stakeholders have the same power to influence the decision-making process. In determining the weights for this study, the information on stakeholders and their assumed power position was used to estimate the eventual weight distribution that represents reality. The main stakeholders will be described next.

Central government
The central Chinese government is probably the main stakeholder. A project spanning several provinces and influencing the economy of a region with over 100 million inhabitants will influence the economy of the whole country. The central government is the main responsible for the social wellbeing of the people in the project area. Furthermore, the central government is the main initiator and coordinator of the project. It goes without saying that its

stake in the project is huge. Together with the provincial and local governments, this is also the main decision-maker.

Provincial governments
Since the project crosses several provincial borders all the provincial governments of the provinces it passes will naturally have a stake in it. A main issue between the provincial governments is the financing of the project. Who will carry the financial burden of a pumping station from which several other downstream provinces will benefit? Another important issue is the division of the water. Who will get which amount of water and who will get paid? Of course, there are also provinces that will lose water. How will they be compensated? In this study no attention was given to the above mentioned points. Every financial aspect was left out of consideration since the different alternatives all cost roughly the same in terms of infrastructure. Furthermore, the source-provinces and their water balance were not taken into consideration either.

Local governments
The local governments' stake is obvious since they represent their citizens and economical activities in their region. The question is how much influence they have on the eventual water allocation. It seems plausible that their influence is rather small. One of the central government's goals is to alleviate water shortage over the whole region. A province with a relatively small water shortage will not be as eligible for extra diversion water as one that has a relative large water shortage. Furthermore, the central government's main focus is on economic growth. It will want the provinces' economies in the project area achieve optimal average growth. This implies that provinces that can convert extra water into economic gains more effectively will probably receive more water than the ones that mainly rely on agriculture.

River basin committees
The river basin committees are responsible for a sound management of the water resources in their areas. As the water resources are in desperate demand at the moment, it is very difficult for the river basin committees to satisfy all the interests in the water. Extra water will alleviate many of these problems to some extent. However, it will also cause new problems, for example when waters of different degrees of pollution are mixed.
The river basin committees mainly assume an advisory role to the government, as they have more expertise than most people in government when it comes to water. In this way their role will be relatively important. They will try to steer the decision to allocate water to those parts of society where the needs are greatest.

Residents (rural, urban)
As far as living is concerned, the water availability in not a very serious problem yet. It may become a problem in the future, but if this happens other sectors will be hit first and it is fair to assume that measures will be taken before the water availability for domestic purposes will become a real problem. In this study the water allocation to rural and urban areas to support primary domestic usage has been assumed fixed and will not be of any influence in the weight determination of the MCA.
Not surprisingly, the residents also have large interests in the project socially and economically. It may provide extra jobs, larger harvests, less unemployment. These interests are represented by the governments or the economical sectors in which the gains or losses can be expected, so they do not have to be elaborated on further here.

Industry
Together with agriculture, the industry is one of the main stakeholders and probably also one of the main beneficiaries of the project. The amount of water available for industrial purposes is not sufficient at the moment. Since industry is one of the main drivers of China's economy, it will receive an amount of water that will largely solve the shortage.

Agriculture
As said before, the agriculture in the 3-H basin suffers from great water shortages. These will be alleviated to some extent by the ERP. However, since its influence on the economic growth is relatively small, the central government will probably not prioritize agriculture in the allocation of the diversion water.

Environment
The ERP will possibly have negative effects in the Yangtze River estuary due to declining water flows. However, this is left out of consideration in this study because alternative water allocations will still have the same effect on the Yangtze River estuary. Among the positive effects, the ERP may slow down ground water extraction and possibly even cause the groundwater levels to rise again in certain parts. Furthermore, a large number of new wastewater treatment plants is scheduled for construction along the ERP route. Some river flows in seriously dried-out rivers may be increased by the diversion project, and heavy toxic loads that currently prohibit a revival of the suffering ecology can be diluted. It again largely depends on the government how much the environment will benefit from the project in the end.

4.3.1.2 Description of Goal

China's economy is assumed to continue growing at more or less the same rate as it does now, focusing its efforts on economic growth primarily through industry. Since economy has been China's main point of focus in the last decade, this seems to be a reasonable and realistic assumption. However, the rural-urban migration is a big problem and Chinese policy makers will probably prioritise this issue. Some focus is assumed on environmental protection too, as many sectors of society show growing concern for the rapidly deteriorating environment.

Because of the lack of a real decision maker, several senior staff members of the IHWR's Department of Water Resources have been asked to determine the weights in this model. The results of this and a comparison with the authors' preferences can be found in Appendix G and H.

4.4 System boundaries and assumptions

Next, the system boundaries and assumptions that apply to this study are discussed. An attempt has been made to present these in a top-down order, i.e. from national to municipal level.

1. **ERP**
   Only affected areas in the East Route Project will be considered, to keep the project scale limited. This leaves the Middle and West Routes of the South North Water Diversion Project out of consideration. The ERP and the MRP do not overlap so both projects can be separated quite well.
2. **21 municipalities (Phase 1)**
   Of all 30 directly supplied municipalities within the ERP, the 9 most northern ones are still investigating the possibilities of receiving water. Only the 21 southern municipalities within Phase 1 of the ERP are sure to receive water. This is the reason that in SWIMER only data for these municipalities has been generated. With data only available for these municipalities, this creates a clear boundary for the MCA.
3. **Comparison between allocation alternatives, nothing else**
   Effects outside of this Phase 1 area are not taken into consideration, because they are not influenced by a different allocation within the project. This can include the effect of new wastewater treatment plants, the negative environmental influence of

the project in the Yangtze River estuary due to declining water flows, the positive influence on the Yellow River estuary due to rising water flows, or other effects mentioned on p. 250 of the SWIMER report. They do not depend on how much water will go to agriculture or industry, because the total amount of water does not change. Because nothing is known hydraulically about the alternative allocations, it can also be assumed that the costs for each alternative are equal. The same can be said for the influence of the ERP on the vulnerability to inundations, which occur frequently in the project area. These two influences do not vary between alternatives.

4. **Only transfer water will be allocated**
   This study will only consider the additional water supplied by the East route. Whatever the allocation will be, the relevant sectors in the municipalities will always receive at least the amount of water they would be receiving without the ERP.
5. **Scenario's with climate change**
   The scenarios including Climate Change are used. The differences between scenarios with and without Climate Change are very small (economic impact on average +0,11% difference). This means the differences are quite irrelevant within the scope of this project. Around the world most experts agree climate change will start to influence weather patterns, so this is why it has been included anyway.
6. **Water will be fixed per municipality**
   Every municipality receives the total amount of water given by the IWHR-excel document. This is an allocation among municipalities that is known to be hydraulically possible. From that point onwards, results will be generated for different allocations of water within the sectors themselves, varying per municipality. There are 2 reasons for this boundary: (1) Varying between municipalities makes the project significantly more complicated and time consuming. (2) IWHR has tested this allocation in ROWAS and Ressim, which means that these allocations can actually be realized, at least according to the hydraulic models. This can not be said for any alternative allocations.
7. **Municipalities will have 4 water demanding sectors**
   The water demand of every municipality will be divided into four categories: agricultural water, industrial water, urban life and rural life. Furthermore, for computational purposes two extra aggregated categories were created: rural total and urban total, which consist of respectively agricultural water and rural life and industrial water and urban life.
8. **Rural and Urban population water allocation is fixed**
   The need for water of the urban and rural populations is satisfied in Alternative F. Because this is water demand primarily for living, the water demand is assumed to be constant between different alternatives, as the population is also assumed to stay constant. Because water is one of the first necessities of life, this demand is assumed to be satisfied in all alternatives.

4.5 Criteria

The plan for this study was to review the SWIMER report and the data that was used to create it in order to obtain data series on different criteria from which a selection could then be made. Unfortunately, the actual amount of available data that was suitable for this study was rather small. In some cases data was available, but not in the suitable format. Because of this shortage, criteria were not selected by choice; instead all the criteria for which data was available were used for this study.

The criteria used in this study are: GDP (industrial, agricultural), agricultural output, income ratio, migration rate, waste water discharge and groundwater levels. For a more detailed discussion on the collection and generation of the data series used in this study, please refer to Chapter 3.

Below, the value tree of the MCA can be seen.

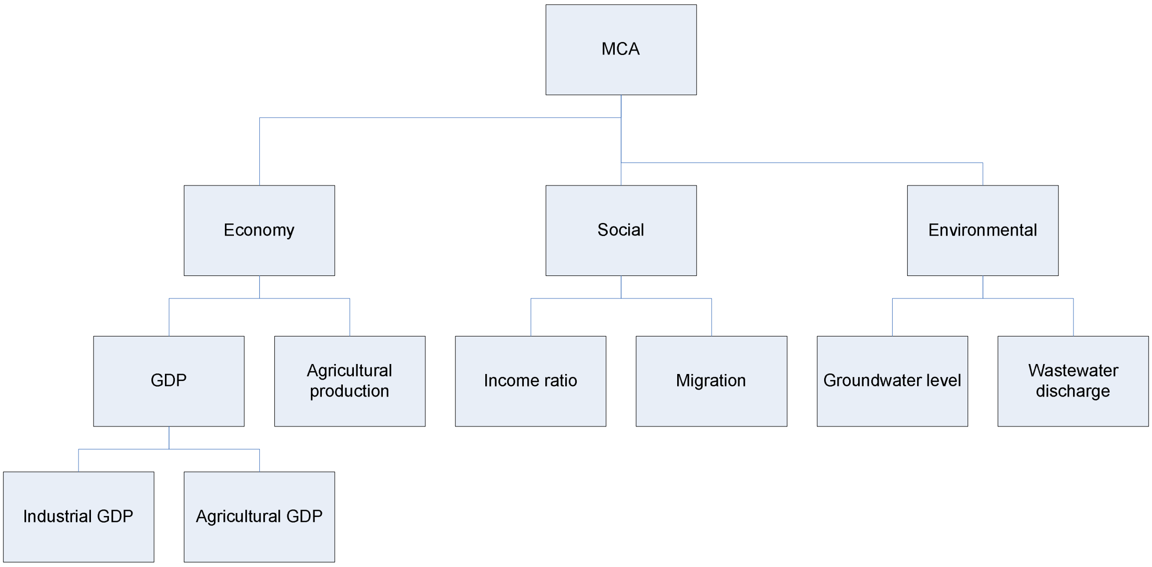


Figure 10: Value tree

The value tree's quality according to the five criteria of Keeney and Raiffa[13] can be interpreted as follows:

In terms of completeness, a lot of improvements could have been made if the extra data were available. Factors like unemployment and absolute migration rates are very important missing factors, as well as more detailed data on water quality. Another crucial factor is social or political acceptability of the alternatives. An enormous project like the ERP will influence a lot of different social groups and their acceptability towards the project might be a decisive factor in choosing a certain alternative. However, data on this is very hard to obtain let alone analyse, even in countries with more open and participative cultures than China.

The value tree is completely operational; criteria are all quantitative and seem to be specific enough to perform evaluations. Furthermore, the performance of an alternative on a certain criterion is rated independently from the performance of other criteria, so the decomposability requirement is also satisfied.

Data redundancy is a problem in this design. As agricultural GDP is indirectly responsible for rural-urban migration, this could be a redundant factor, because of the way it is calculated. Furthermore, one could argue that agricultural production and agricultural GDP are the same. However, because agricultural GDP is expressed in monetary terms and agricultural production in tons, one factor could be considered as wealth related, while the other is more concerned with the sufficiency of the food supply.

Redundancy is most clearly present as an overlap between rural/urban income ratios and rural/urban migration, as the former had to be used to be able to calculate the migration. This is an important factor to take into account in this report. However, both criteria were considered too essential to leave out of the report and have therefore been included. This is a problem that will have to be tackled if better data becomes accessible.

4.5.1 Determination of value functions

The satisfaction gained from a unit increase of a certain criterion can differ depending on how much the criterion has already increased. To express the difference in marginal value, the concept of utility can be used. Because every alternative's score on a certain criterion has a different utility, the real value to the decision maker should be assessed. This can be done though the use of value functions, which express the decision maker's utility over the whole spectrum of outcomes for a certain criterion. In the next section, the value function determination per criterion is explained. Most functions will have a diminishing marginal utility since the utility of an extra unit increase will usually be lower. Note that this method's outcome is, like the determination weights, based on the decision maker's preferences. Hence, the outcome can differ from person to person. Consult 0 Appendix F to see the value function figures that go with the descriptions below.

Groundwater
Since the groundwater situation is very serious in the ERP area, the marginal utility is assumed not to change for bigger amounts of water. Every extra m^3 of groundwater is equally valuable.

Wastewater discharge
An increase of untreated wastewater always has a negative influence. The value function has been determined so that it has a slightly decreasing marginal utility. This has been done to incorporate the possibility that new industry will pollute the scarce water that is not already contaminated. However, the marginal effect of waste water hardly changes along the scale. This represents the limitlessness of pollution levels; there is no point at which extra pollution does not matter that much anymore (in this scale).

GDP industry
The industry's GDP value function has a rather steep inclination at first which slows down towards the end. This represents the fact that a certain amount of industrial GDP growth is very desirable, but the marginal utility of extra growth from a certain point on quickly declines. Once a certain level of industry GDP growth has been achieved, the priority shifts to other issues like the balancing of GDP growth over several sectors and the improvement of the income ratio.

GDP agriculture
The agricultural population forms a majority in China, but their living standards still don't come close to the urban population. Because there is still a long way before the rural population's GDP levels will come anywhere close to that of the urban population a higher level increase of GDP is still valued almost as much a lower level one. This results in an almost flat value function.

Agricultural production
The food supply in China is sufficient at the time, but the food buffer is low[14]. At the same moment the level of wealth increases rapidly and the population continues to grow. Therefore, there is a very small decline of marginal utility; the marginal value of high output levels of grain is still reasonably high.

Income ratio
An income increase on the first part of the scale is assumed to be more valuable than an increase on the last part, so declining marginal utility is represented in the value function.
Migration rate
The reasons for the shape of the income ratio line are also valid for migration rate, although the migration rate value function is a little more flat.

From every value function a formula is derived, which in almost every case is a quadratic (polynomial) function of the form $f(x) = ax^2 + bx$. After this, the real value of the scores of the alternatives can be determined.

4.6 Alternative courses of action

4.6.1 Introduction

As the SWIMER report provides limited insight into different water allocation alternatives among sectors, these alternatives had to be defined and quantified. The SWIMER report does provide detailed results for the 2010F alternative, an optimized allocation according to the SWIMER Multi Criteria Analysis.
This alternative is used as a base alternative, from which alternatives are generated. The allocation of water does not change between municipalities, but varies among sectors within each municipality. This has been decided in order to try to meet the hydrological constraints: models indicate that this particular water allocation among municipalities is hydrologically possible. That can not be guaranteed for any other allocation and therefore it is justified to vary the allocation only among sectors within each municipality.

4.6.2 Water allocation alternatives

Three alternatives have been generated, each representing a preferred water allocation of a certain group of policy makers within society. It is difficult to determine what the policy makers prefer in reality without asking them, but an approximation can be made in which interests of different groups of stakeholders are taken into account. Furthermore, two extreme alternatives have been added in which all water is allocated to either agriculture or industry. Finally, for the sake of completeness and comparison, the original Alternative F from SWIMER is also tested in the MCA developed in this study. The alternatives will be described below in more detail. The MCA will help to determine the best alternative according to the decision makers.

- **Alternative 1**: An alternative in which maximum economic growth is achieved, but a minimal GDP-growth of 5% is guaranteed to all sectors. This alternative is in favour of the allocation of water to industry because most economic growth can be achieved there. It is in line with a continuation of the economic growth of the last decades in China and represents the will of the economists, the business world and the investors in the South – North Water Diversion Project.
- **Alternative 2**: This alternative aims at providing an equal rate of GDP-growth for all sectors. Even though the rate of return of extra water in agriculture is not as high as the rate of return in industry, equality should also be an important factor in the allocation of the water. The importance of this equality is amplified by the fact that more than two thirds of the population in the study area reside in rural areas. Therefore, in effect, most water will be allocated to agriculture.
- **Alternative 3:** This alternative represents the will of the agricultural sector and those in favour of egalitarianism. Because of current inequalities in rural- and urban incomes, all extra water should go to the reduction of this gap, with the exception of the water needed for a minimal overall GDP rise of 5% for all sectors. These measures will help to slow down rural – urban migration and could be a contribution to the large social problems encountered in the countryside.
- **Alternative 3.1:** In this alternative environmental problems play a central part. A 5% GDP increase should be achieved by all sectors, but all additional diversion water should go into the dilution of toxic wastewater concentrations, the recharge of the overexploited groundwater and the regeneration of natural ecosystems along rivers. In effect, in the current simplified allocation model this means a similar allocation to alternative C. In reality the goals of environmentalists, agriculture and egalitarianists will not be completely equal; this is only due to the extremely simplified model. In this research, these two alternatives will be treated as one.
- **Alternative 4:** Extreme case alternative 1. In this alternative, except for water needed for rural and urban life, all water is diverted to agriculture.

- **Alternative 5:** Extreme case alternative 2. In this alternative, except for water needed for rural and urban life, all water is diverted to industry.
- **Alternative F:** This is the base alternative that was used to compute the results for the other alternatives. According to the SWIMER report this is the optimized water allocation, but it remains unclear how these optimized results have been acquired. With which goal in mind were the optimized results computed? What criteria were used to obtain these optimized results? And what weights have been assigned to these criteria?

The next paragraph shows the results of these water allocations on all 6 modelled criteria.

<u>Methodology</u>
As said before, the alternatives generated for this study are all based on the SWIMER alternative F. This alternative was used to calculate all other alternatives with the use of Excel's solver.

First, an alternatives calculation sheet was created. This sheet contained the amounts of water allocated to each municipality, and yielded the outcomes for this water allocation for every criterion. Because the urban and rural life water demand and supply were assumed to be fixed; only the amount of agricultural water and industrial water could be varied. The relation between these two variables is $\Delta W_{agr} + \Delta W_{ind} = \Delta W_{agr+ind}$.

Thus, only one actual variable remained, arbitrarily chosen to be ΔW_{agr}.
In the base Alternative F, the allocation per municipality Δw_{agri} for every municipality i varied quite a lot from municipality to municipality, with an aggregate percentage to agriculture of

$$\frac{\Delta W_{agrF}}{\Delta W_{agrF+indF}} = 65\%$$

This percentage of agricultural diversion water is parameter α_j for every alternative j. Using this percentage and the water allocations from Alternative F, combined with the new total proportion of agricultural diversion water, the new alternatives could be calculated. The relation is expressed in the following formula.

$$\Delta w_{\arg i} = \begin{cases} \alpha_j \geq \alpha_F & \Delta w_{\arg F} + \Delta w_{indF} \times \dfrac{\alpha_j - \alpha_F}{1 - \alpha_F} \\ \alpha_j < \alpha_F & \Delta w_{\arg F} - \Delta w_{\arg F} \times \dfrac{\alpha_F - \alpha_j}{\alpha_F} \end{cases}$$

Once this was finished, the solver was used to determine the α_j for each alternative j by giving a certain value to certain objectives, e.g. 5% agricultural GDP growth. The water allocations this yielded for the different alternatives are listed in Appendix E0.

	Alternative 1	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative F**
	5% agriculture GDP	equal GDP growth	5% industry GDP	100% to agriculture	100% to industry	SWIMER
ind	64%	25%	12%	0%	100%	35%

agr	36%	75%	88%	100%	0%	65%

Table 2: Total water allocation between industrial and agricultural sectors

By inputting these numbers, the results for all criteria in all municipalities could be obtained. After that, the results were either aggregated or averaged in order to come up with a single number for the whole phase 1 of the ERP area. The results for Income ratio and Migration rate are weighted averages calculated using the relative population per municipality. These results are presented in the next table.

Environmental

Groundwater availability	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative F**
10^6 m^3 water	5032.4	5336.1	5422.5	5502.6	4742.2	5269.8
- minimum	290.2	593.9	680.3	760.4	0.0	527.6
normalized	38.2	78.1	89.5	100.0	0.0	69.4
adjusted utility	**38.2**	**78.1**	**89.5**	**100.0**	**0.0**	**69.4**

Untreated wastewater *	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative F**
10^6 m^3 water	3154.5	2869.5	2772.3	2682.2	3411.7	2944.2
- minimum	472.4	187.3	90.2	0.0	729.5	262.0
normalized	64.7	25.7	12.4	0.0	100.0	35.9
inversed	35.3	74.3	87.6	100.0	0.0	64.1
adjusted utility	**44.0**	**81.5**	**91.6**	**99.7**	**0.0**	**72.8**

Economic

GDP industry	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative F**
10^6 yuan	1306388.5	1167501.5	1110493.8	1057614.2	1422646.2	1211285.5
- minimum	248774.3	109887.3	52879.6	0.0	365032.0	153671.3
normalized	68.2	30.1	14.5	0.0	100.0	42.1
adjusted utility	**92.0**	**53.3**	**28.1**	**0.0**	**100.0**	**68.9**

GDP agriculture	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative F**
10^6 yuan	256686.0	269863.1	274001.4	277840.0	244463.1	266684.8
- minimum	12222.9	25400.1	29538.4	33377.0	0.0	22221.7
normalized	36.6	76.1	88.5	100.0	0.0	66.6
adjusted utility	**42.1**	**80.6**	**91.1**	**100.4**	**0.0**	**71.9**

Grain production	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative F**
1000 tons	56433.1	64442.8	67662.5	70649.0	49664.5	61970.0
- minimum	6768.6	14778.3	17998.0	20984.5	0.0	12305.5
normalized	32.3	70.4	85.8	100.0	0.0	58.6
adjusted utility	**44.6**	**82.1**	**92.4**	**99.7**	**0.0**	**72.3**

Social

Income ratio	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative F**
rural/urban income	0.32	0.35	0.36	0.37	0.29	0.34

- minimum	0.02	0.06	0.07	0.08	0.00	0.05
normalized	29.4	69.4	84.6	100.0	0.0	58.7
adjusted utility	**44.9**	**85.1**	**94.0**	**99.6**	**0.0**	**76.6**

Migration rate*	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative F**
change in migration rate	-1.6%	-3.7%	-4.8%	-2.8%	0.0%	-2.9%
- minimum	3.2%	1.0%	0.0%	2.0%	4.8%	1.8%
normalized	66.2	21.8	0.0	41.1	100.0	38.6
inversed	33.8	78.2	100.0	58.9	0.0	61.4
adjusted utility	**51.7**	**91.8**	**100.0**	**78.2**	**0.0**	**80.3**

Table 3: Alternative outcomes on different criteria

* = Higher number depicts more negative effect

4.7 Weights

As explained before, the weights were determined by using 'swing weights'. The different criteria and their range from worst to best score are given in the table below in no particular order.

Criterion	**Unit**	**min**	**Max**	**difference**
Groundwater availability	10^6 m^3 water	4742.2	5502.6	16%
Untreated wastewater *	10^6 m^3 water	3411.6	2682.2	27%
GDP growth	10^6 yuan	1302077.2	1700486.2	31%
Grain production	1000 tons	49664.5	70649.0	42%
Income ratio	Rural/urban	0.29	0.37	27%
Migration rate*	Change in %	0.00%	-4.79%	5%

Table 4: Criteria and their range

* = Higher number depicts more negative effect

Reference point for the determination of the weights was steady continuation of Chinese economic growth with an increased emphasis on environment and social issues. Firstly, using the above table and keeping the absolute improvements in mind, the criteria were ranked in importance. Next, again comparing the improvement possible on the different criteria, the swing weights were determined as explained in section 4.7.

For example, the decision-maker (the authors) felt that a movement from a 0.29 to 0.37 income ratio was 50% as important as a movement from a GDP growth of 1302 billion Yuan to a GDP growth of 1700 billion Yuan. In this way all the weights were determined. The outcomes have been normalized after that for easy interpretation and further use. The results can be seen in the following table.

Ranking	**swing weight**	**normalized**
GDP	100	0.43
income ratio	50	0.22
waste water	25	0.11
grain production	25	0.11
Groundwater	20	0.09
Migration rate	10	0.04
	230	1.00

Table 5: Criteria and weights

The choice for the different weights will be explained next.

GDP
One of the main reasons for this project was the need for water in the 3-H area, to fuel this area's economy. Furthermore, the alternatives' outcomes indicate that considerable gains can be achieved on the industrial GDP; one of the highest among the criteria. Therefore, it seems only logical to rank the GDP growth as the most important goal of the ERP project. Because of this, the GDP will receive a swing weight of 100 and will be the reference point for the determination of the swing weights of all other criteria.

Income ratio
Although the Chinese economy has been flourishing for the last couple of years, a lot of problems still remain unresolved. One of the biggest problems is the income disparity which has only widened in the last decades. The Gini coefficient, a means for measuring inequality of a distribution, increased from 0.33 in 1980 to a level of 0.46 in 2002, which is considered a very high level. The main reason for this disparity is the rural-urban income gap[15]. Although the income of the rural population has been rising along with the economic growth, the urban populations' wealth increase is much faster. This makes it more difficult for the rural population to notice the improvement of their social position in terms of wealth.
The swing weight for income ratio has been set at 50; the swing on income ratio is deemed worth 50% of the swing on GDP. This is a high weight, considering an almost 400 billion Yuan increase on GDP. However, an income ratio increase from 0.29 to 0.37 implies a considerable improvement for the rural part of the population and seems justifiable.

Wastewater
The river-water quality is currently one of the main concerns for the Chinese water resources authorities. According to the 2001 World Bank report on north China's water agenda, more than 80% of all river lengths in the 3-H basin is seriously polluted. A majority of these rivers was classified into class IV or higher pollution, which makes the water unusable for most purposes. Industrial and urban wastewater are the cause of 77% of the pollution in the Huai basin.[6]
According to the estimates in this study, untreated wastewater increase could rise by 27% due to additional industries and urban use. The fact that many water treatment plants are currently being planned to tackle this problem has been left out of consideration for the moment, as it does not influence the difference between allocation alternatives.
The swing weight of wastewater has been set at 25. This may seem quite small, but it is actually quite a significant weight if compared to the effect that the enormous potential increase in GDP would have on the population and the country's economy. The effect of going from the most polluting alternative to the least polluting one has thus been estimated to be worth as much as one quarter of the GDP effect, as it will change the water intake sources of many residential areas and farmers' irrigation water. Possibly it will also cause health problems in the project area.

Grain production
The increase of grain production is potentially very large; an increase of more than 30,000 tons or 30% can be achieved in the best case. However, the swing weight has only been set at 25. This is due to the fact that China's food supply at the moment is not a major issue. Unlike some years before, the food supply is currently in a general balance against total demand, with some surplus in good harvest years[16]. Therefore, instead of increasing the food supply, the emphasis should be on GDP growth and improving social equality.
Some weight has been given to this criterion because from the start, the ERP was designed to support agriculture. The possible big increase that can be achieved is another reason to give it some weight.

Groundwater
Groundwater levels have been falling steadily for many decades. In vast areas levels have dropped to depths of 50 m or more. Salt water intrusion, land subsidence and the drying up of wells cause large-scale problems for all water users, but mainly for agriculture in areas where surface water is scarce[6]. According to this study, the ERP could alleviate these problems, slowing the groundwater depletion down and possibly turning the tide to gradual groundwater rises in some areas. This would be an important development, especially in the long term.
The maximum difference between alternatives on this criterion is 16%. This is considered a more important effect than a decrease of 5% in migration. It is however not as important as the possible increase in wastewater, so the swing weight has been determined at 20, partially because many farmers indicate the falling groundwater levels to be their greatest concern.

Migration rate
China's rural-to-urban migration is at a very high level. Estimates of the number of people that will have moved to urban areas from 2000 to 2020 vary from 300 to 500 million. The number of people moving to the urbanised areas is too high for the cities to accommodate. The government has tried to control migration by taking several measures which make it harder for the rural population to move to the city. This has resulted in a large number of illegal migrants. In an attempt to control this, the government has taken extra measures. One of these is the denial of education to children of illegal migrants. They can still receive education upon the yearly payment of 10000 Yuan, which amounts to more than one year's salary for a construction worker. Several more harsh measures are taken in an attempt to control migration[17].
From the above, it becomes clear that the rural-urban migration rate is too high. However, the urbanisation rate in the project area is not greatly influenced by the construction of the ERP, with a maximum change of 5%. Therefore, this criterion is set to a low swing weight of 10.

The GDP was further divided into agricultural and industrial weight. The gains that can be achieved on industrial GDP are many times higher than those on agricultural GDP; the per m^3 water monetary increase on GDP is much higher. This should lead to a much higher weight on industry. However, because a lot of farmers depend greatly on the water availability and the social inequality between urban and rural areas is already rather large, a relatively large weight has been given to agricultural GDP. The agricultural and industrial GDP weights were eventually set to respectively 20 and 80 percent which together thus represent 43.5 percent of the total.

4.8 Results and conclusion MCA

Multiplying the weights with the before obtained total scores and subsequently adding them up yielded the scores per alternative. The outcome of the MCA for the weights discussed in the above is presented below. This weight configuration is called Weights A.

Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative F
60.31	72.21	70.03	65.09	34.79	71.78

Table 6: MCA outcome for Weights A

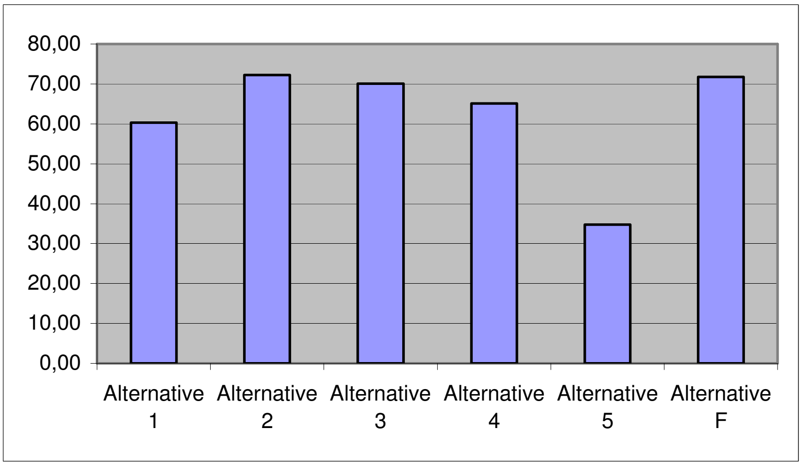


Figure 11: MCA outcome for Weights A

Alternative 2, which is the alternative pursuing equal relative GDP growth between agriculture and industry, has the highest score of all alternatives. However, the difference between alternative 2 and alternative 3 and F is too small to make a decision based on these outcomes. The decision maker might have to look at how the results will change when the used parameters (weights, value functions, input data, etc.) are adjusted. This can be done by means of a sensitivity analysis. Furthermore, the sensitivity of the input data should be assessed. If changing a certain input parameter has a large influence on the outcome, its accuracy should be assessed though an uncertainty analysis. Should this parameter be inaccurate of uncertain, while greatly influencing the outcome of the MCA, it can lead to the wrong decisions.

If the reliability of the data has been confirmed and the sensitivity analysis shows that alternative 2 is still the best when adjusting the parameters, it is probably justified to choose this alternative. However, if the other alternatives exceed alternative 2 when the used parameters are adjusted, the decision maker knows that one out of these three is the best. Possibly a new analysis with different criteria and just these three alternatives has to be carried out to assess which alternative really is the optimal alternative.

The above mentioned sensitivity and uncertainty analyses will be described in Chapter 5.

Chapter 5 Sensitivity analysis[18]

5.1 Introduction

A sensitivity analysis is an important part of any modelled representation of reality. An MCA is also a representation of reality, although this study is a very rough one. In an MCA, especially in the simpler types of MCA such as the SMART analysis used in this research, the sensitivity analysis is of utmost importance because it provides a powerful tool to test the model's behaviour and reliability. By varying certain parameters, the eventual outcome of the MCA can change. The sensitivity analysis will provide insight into how changes in parameter values, assumptions and boundary conditions, can tip the scales from one MCA outcome to another. Furthermore, it will provide insight into the complexity of the model and yield valuable information about the sensitivity of separate components of the model.
This is especially important in situations in which certain parameters or relations are not precisely known or cannot be determined exactly at all. If a certain factor is very sensitive and thus has great influence on the results of the MCA, the quality of the MCA will ameliorate more if the measurement of this factor is improved, than if the measurement of an insensitive factor is improved. As the SMART uses the decision maker's opinion to determine both the weights of the criteria and the value functions (which are very difficult, if not impossible to quantify), the importance of this sensitivity analysis cannot be underestimated. The outcome of the sensitivity analysis regarding these weights and value functions will be an important indicator for the applicability and trustworthiness of the model. Furthermore, it will give the decision maker a clear understanding of the influence of the choice of his weights on the MCA's outcome.
Apart from this, the parameters that *can* be measured (instead of estimated by a decision-maker) will also benefit from a sensitivity analysis, as it will provide insight into which parameters need further research to improve data precision and thus improve the MCA.
This leads to the following problem definition:

The goal of the sensitivity analysis is to determine how much the results of the MCA change with variation of the "factors of importance". How does this influence the conclusion of the MCA?

What these factors comprehend is explained in section 5.2. The methodology used to vary these factors differs for all inputs; this is explained next in section 5.3, followed by the results in section 5.4 The MCA is more sensitive to changes in some factors than others. There are factors that can change the outcome, depending on how they are chosen. The interpretation of these results is discussed in section 5.5. Paragraph 5.6 discusses the uncertainty involved in this study.

5.2 Factors of importance

To determine which factors are of importance in the sensitivity analysis, a good insight into the model structure is necessary.
Figure 12 shows the conceptual model for the MCA, including only those boundary conditions that can possibly be changed in the sensitivity analysis.

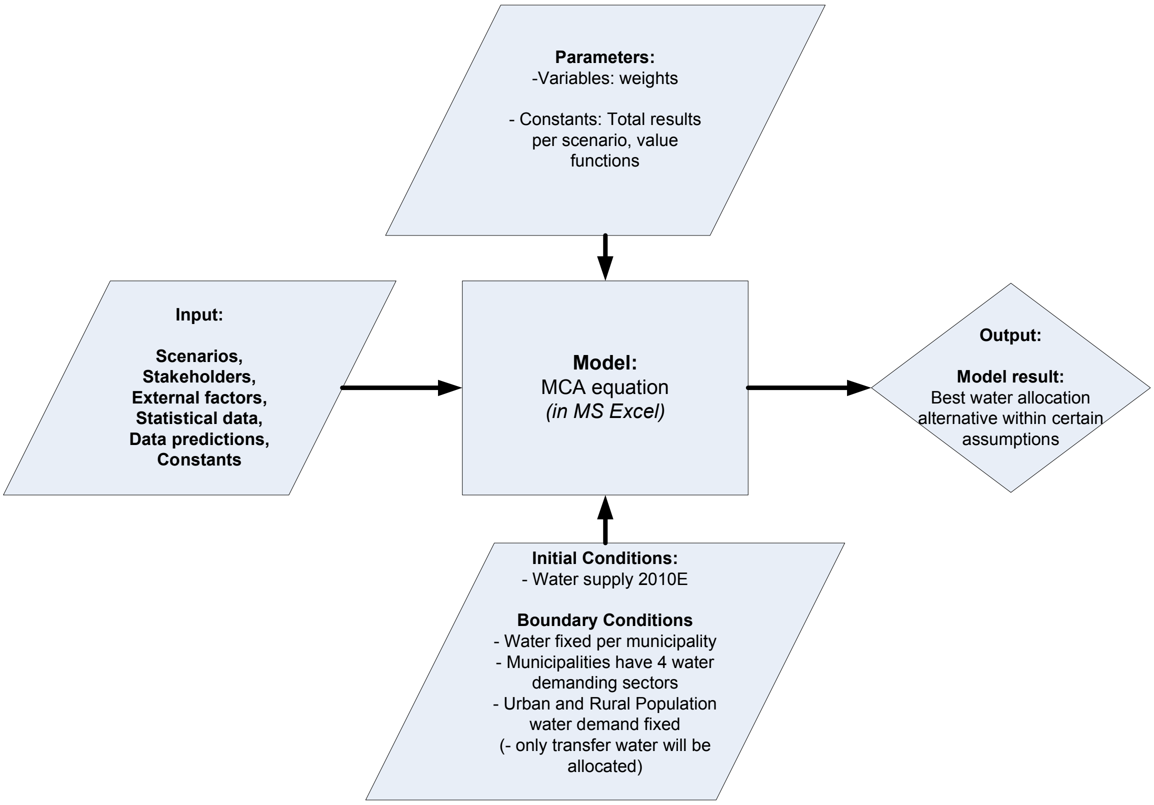


Figure 12: Conceptual model MCA

There are four different factors of importance. These are:

a. **Model structure:**
The model structure is very simple, as it is only one equation. Chances of errors are negligible, as the equation has been checked and double checked. All calculations are very straightforward and no simulations with randomized variables were used, so the outcome will be the same every time it is calculated. The model structure will not be looked into any further for the sensitivity analysis.

b. **Constants:**
In this report the value functions remain equal for all inputs of the model, so they can be classified in the category of constants. This is only a simplification though, as they have been determined in a similar fashion as the weights: by opinion of the stakeholder. However, this time no other stakeholders have been consulted, as it was considered too laborious to explain the usage of the utility functions in the available time. This does not mean that the value functions will have these exact shapes in reality, so it is very important to find out how sensitive the results are to changes in the value functions.
The other group of constants is the data per alternative. In the MCA model only the weights can change; changes in the results per alternative or the way in which they are generated have to be done one step before the MCA model, in the so called alternative generator. Therefore, the alternative results are considered constants. As explained in Chapter 3, the alternatives have been calculated using a per m^3 diversion water coefficient for each different criterion. It is very important to determine how dependent the MCA results are on this data. How much do the results change if the per m^3 diversion water coefficients are increased/decreased?

c. **Boundary conditions, initial conditions:**
All alternatives have been calculated using the water allocation of alternative 2010E as a base calculation value. It is very difficult to apply another approach, so this is not included in the sensitivity analysis.
However, it is very interesting to test what happens to the model results if changes are made in the boundary conditions. Among the boundary conditions that could be included in the sensitivity analysis, there is only one that is analysed in this report. Another two are only named here, but not tested, because they are not compatible with the current alternatives. Other alternatives would have to be generated in order to test the influence of these two boundary conditions.
    - Water is now fixed per municipality, what happens to the results if this is not fixed, but can be allocated without geographical constraints? This is tested in the sensitivity analysis.
    - In this study, municipalities have 4 water demanding sectors. This is of course a large simplification of reality. What will happen to the MCA's best alternative if more, or less sectors are used?
    - Currently, both rural and urban water demand does not change. This is also a large simplification of reality, although it can be justified if modelling on a large scale. What will happen if these sectors are also allowed to vary?

d. **Parameters:**
The parameters may be the most important factor to test. As mentioned before, the weights are determined by the decision maker and cannot be assumed to be invariable in any situation. It is extremely important to find out how much influence these weights have on the outcome of the MCA.

5.3 Specification of basic values and methodology of variation

The sensitivity analysis will be divided into three sections, following the above specified factors of importance (b,c and d). Sensitivity analyses often use a value of 10% variation to test the sensitivity of certain factors. Unfortunately this is not always possible, especially if factors are not quantifiable. With such non-quantifiable factors, it is difficult, if not impossible, to vary 10% up or down because this has no meaning. Due to the different natures of the factors of importance, the sensitivity will be tested using different methods. Each method and the required basic values and variations are explained below.

Constants (b):

<u>Value functions</u>
Each criterion's individual score is calculated using a value function, to incorporate the changing marginal effects of adding diversion water. Will the first m^3 of diversion water have the same value to the decision maker on this criterion as the last m^3 of diversion water? These six value functions differ for every criterion; they can be viewed in Appendix F. All value functions are varied from using a straight line (all extra water has the same marginal effect) to using an extremely parabolic line. It can reasonably be assumed that the actual value function will always lie between these two extremes, so this is considered a representative variation around the basic value. There is one possible exception to this rule: when the basic value function equals a linear line. It has however been assumed that a linear curve is an extreme, as a rising rate of return is often rather improbable.
Each criterion has its own basic value (value function) and the sensitivity of these value functions can be tested using the extremes. An example is given in Figure 13, using the value function of the migration rate. The blue line represents the chosen value function in this study (basic value). The sensitivity analysis provides a figure showing how much the results of the MCA change, if the extreme lines (yellow and pink) are applied instead of the blue line.

In the case of migration rate this results in Figure 14 (very flat because of the small weight of migration in the analysis).

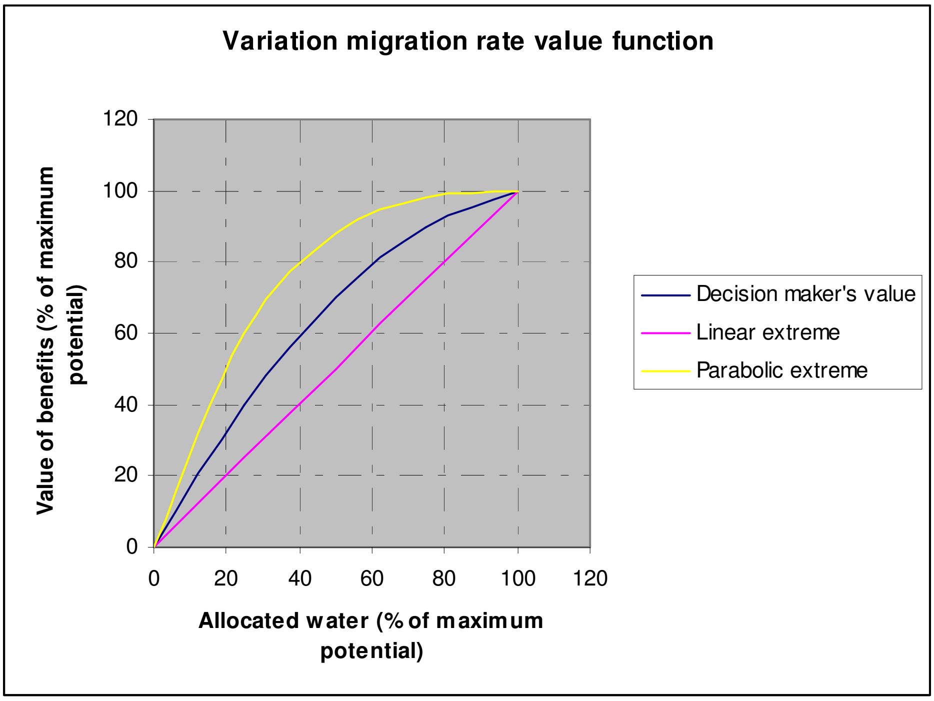


Figure 13: Variation of Migration rate value function in sensitivity analysis

This method of modelling the sensitivity presents a problem. Value functions are functions, depending on various parameters. Therefore, their sensitivity is not as easy to analyse as that of a “normal” single constant.
This means that this method is not one hundred percent mathematically sound, as it is impossible to indicate the exact location of the basic value in the sensitivity results. However, the method has been accepted as yielding satisfactory results, because the basic value functions always lie between the extremes. This can be seen in the last diagram in Appendix F. The described predicament can also be noticed in the definition of the x-axis in the sensitivity results’ figure (Figure 14). To be able to plot the results, and to give some sort of indication, the x-axis has been scaled from 0 to 1. 0 indicates a value curve resembling the extremely parabolic shape of the yellow curve in Figure 13. Departing from the shape of that curve, the value functions can resemble ever more linear curves; the extreme being a 100% linear curve. This linear value function (pink line) is represented by the number 1.

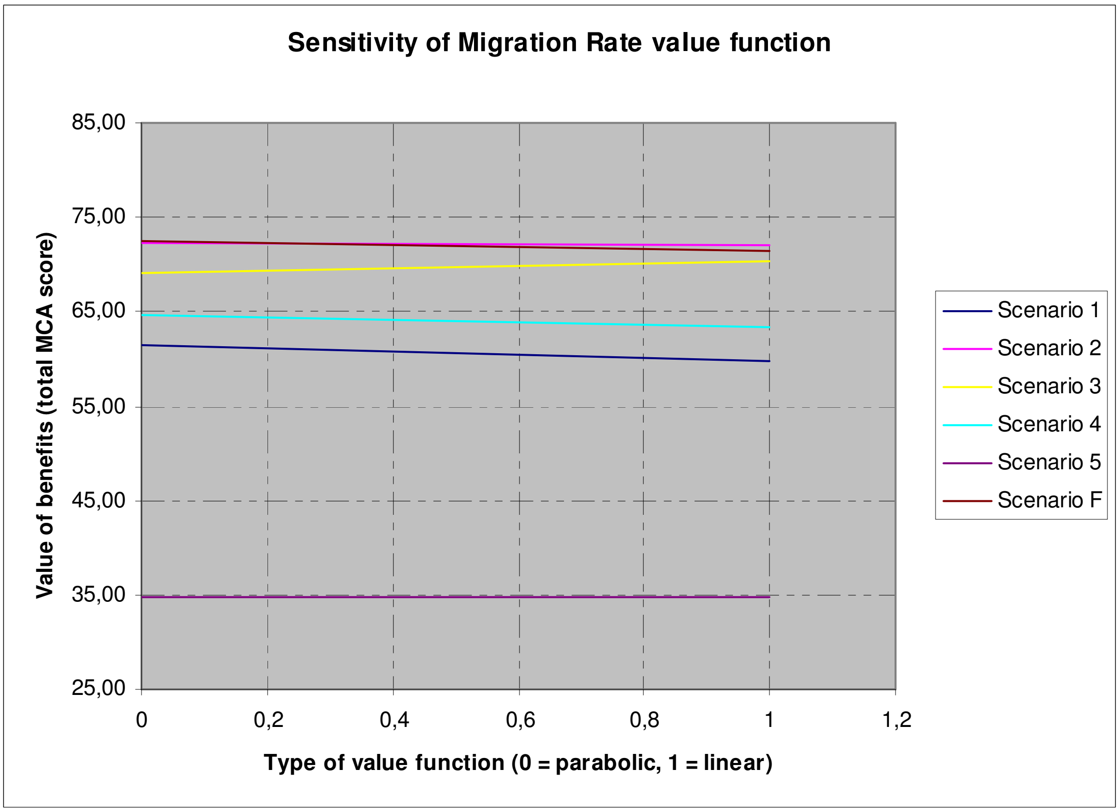


Figure 14: Sensitivity results of migration rate value function

Data per alternative

Since the amount of data available for this study was rather limited, a lot of data had to be generated and derived from other known data sets. Furthermore, the available alternatives from the SWIMER study were not applicable to this study so new alternatives had to be generated. The only way in which this was possible was to determine a per m^3 diversion water coefficient for each different criterion with which the outcomes of the different alternatives could be calculated. For a more detailed discussion on this, refer to Chapter 3. Because the methods that were used to determine the data are rather simplified and a lot of assumptions had to be made, the reliability of the data is questionable. Therefore, it is very important to assess the influence of a change in the source data on the outcome.
The sensitivity of the coefficients used, is assessed by varying each criterion by 10% up and down. This is done for every criterion and for every alternative which yields a total of 14 new MCA outcome sets (7 criteria, 2 variations per criteria). The results are compared to the original outcome to see how much the sensitivity was.

Boundary conditions, initial conditions (c):

The water allocation was regarded as fixed per municipality. This means that the total amount of water going to a municipality was not subject to change, only the division of that water between sectors within the municipality. The reasons for this are that this municipality-level allocation has been proven to be hydrologically viable, and that it has been assumed that there were demand induced reasons for this allocation. However, partially because this is based on assumptions, it is important to test what happens to the allocation results if this boundary condition is changed.
The total amount of allocated water will not change, but it will vary among the municipalities based on the amounts of water the respective sectors receive in alternative F. For example, in a alternative favouring industry, a municipality that received a lot of industry water in alternative F will receive more water than a municipality that mainly received agriculture water. In the extreme alternative 5, allocating 100% of the diversion water to industry, this

leads to water allocation shown in Table 7. This shows the water allocation in comparison to alternative F. Xuzhou municipality in Jiangsu province gains 134.52 x 10^6 m^3 of water for industry. But because the municipality was receiving more water for agriculture, the net water amount received is negative as no diversion water goes to agriculture in alternative 5. This means that there is more industry in other municipalities needing water; therefore water will be allocated from Xuzhou to other municipalities, even though the industry in Xuzhou also gains a net rise in diversion water.
This is tested for the alternatives 1 through 5.

	Municipality	Extra water to industry (10^6 m^3)	Extra water to agriculture (10^6 m^3)	Extra water to municipality (10^6 m^3)
Jiangsu	Xuzhou	134,52	-229,29	-94,8
	Lianyungang	16,97	-84,09	-67,1
	Huai'an	391,42	-277,18	114,2
	Yangzhou	36,94	-49,75	-12,8
	Suqian	124,38	-91,05	33,3
	Subtotal	704,22	-731,36	-27,1
Anhui	Bengbu	206,39	-102,73	103,7
	Huaibei	86,39	-105,18	-18,8
	Suzhou	22,71	-334,48	-311,8
	Subtotal	315,49	-542,39	-226,9
Shandong	Ji'nan	52,14	-51,79	0,3
	Qingdao	182,82	-15,99	166,8
	Zi'bo	0,02	-40,10	-40,1
	Zaozhuang	80,95	-32,12	48,8
	Dongying	199,75	-15,53	184,2
	Yantai	46,43	-25,36	21,1
	Weifang	11,55	-45,44	-33,9
	Ji'ning	0,00	-60,26	-60,3
	Weihai	37,25	-78,62	-41,4
	Dezhou	78,36	-53,64	24,7
	Liaocheng	46,98	-50,43	-3,4
	Binzhou	63,93	-76,86	-12,9
	He'ze	0,00	0,00	0,0
	Subtotal	800,19	-546,14	254,0
Total		1819,89	-1819,89	0,0

Table 7: Water allocation for alternative 5 with different boundary condition

Parameters (d):

Weights
As explained in section 4.7, each criterion has a certain weight, defining its relative importance in the MCA according to the decision maker. This weight is very difficult to

determine because it cannot be not done by exact measurement, but has to be estimated on the basis of experience and/or consensus. Furthermore, a choice for a certain weight usually represents a feeling/opinion of the decision maker and is therefore uncertain by definition. Thus, it is very important to know to which extent the weights influence the outcome of the MCA. If the MCA is very sensitive to the weights, extreme caution should be taken both in the determination of the weights and the evaluation of the outcome. If the weights have a small influence, such cautiousness is not as important because the choice of weights may not change the outcome: the same alternative will always score best whichever weights are chosen. Unfortunately, this is a situation that does not occur frequently in this type of MCA. The basic values for the weights in this study are the values used in section 4.7, in which the results of the MCA are discussed. Section 4.7 also explains how these weights have been chosen. These weights are shown in Table 8.

Category	**Weight**	**Criterion**	**Weight**	**Sub-criterion**	**Weight**
Economic	0,54	GDP	0,44	Agricultural	0,09
				Industrial	0,35
		Agricultural production	0,11		
Social	0,26	Income ratio	0,22		
		Migration rate	0,04		
Environmental	0,2	Untreated wastewater	0,11		
		Groundwater	0,09		
Total	**1,00**	**Total**	**1,00**		

Table 8: Basic values of weights

To test the sensitivity, the total MCA score of each alternative is plotted against the changing weight per criterion. This plot shows the MCA scores with the weight of this particular criterion varying between 100% and 0%. For all values in between, the balance between the weights of all other criteria remains equal. An example is given in Figure 15, showing the results of the sensitivity of the weight given to GDP. This figure shows that many alternatives can be interpreted as being the best, depending on how much weight is given to GDP. In this study the GDP has received a weight of 44%. Alternative 2 is the best alternative there, closely followed by alternative F.

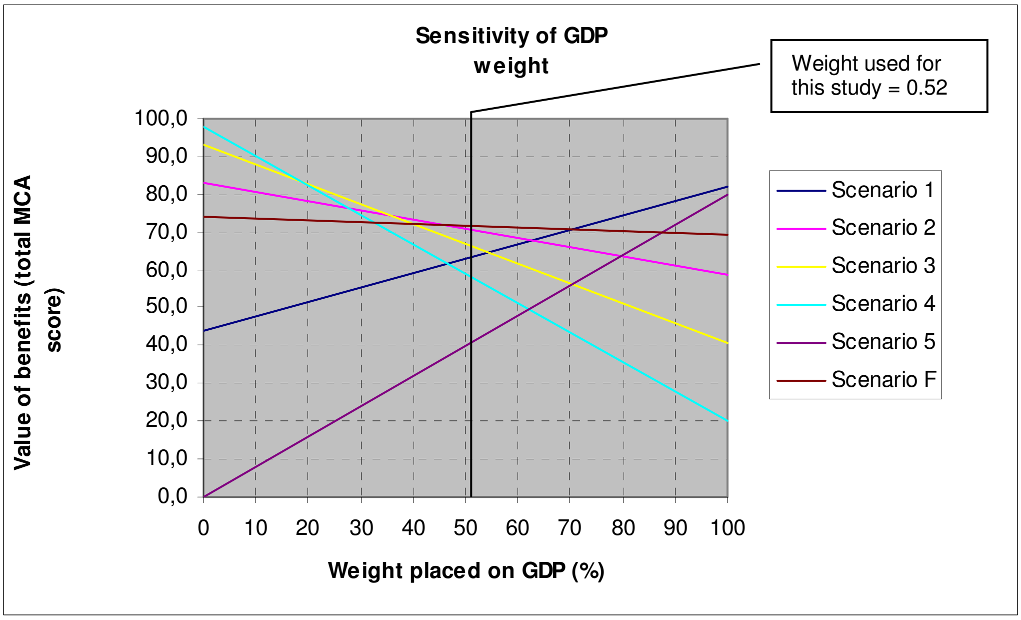


Figure 15: Sensitivity of GDP weight

The results are also calculated numerically, using the method of 10% variation explained earlier on. The weight of every criterion is varied from -10% relative to the current value, to +10% relative to the current value, leaving the balance between all other weights intact. For example, the weight of grain production currently has a weight of 10.9%. This weight is varied from 9.8% to 12.0%. The results are subsequently compared to the current result, resulting in the percentage difference between the two variations.
It would be interesting to test what would happen to the outcome of the MCA if more than one weight is changed. The method explained above leaves the balance between all criteria but one equal. This shows the influence of one factor, but fails to show completely how sensitive the MCA outcome is. However, it would go too far to test all the possible combinations. Instead, a number of alternative decision-makers has been asked to determine the weights, as explained in Appendix H. The outcomes are also discussed in this chapter, as they are very interesting for the sensitivity analysis.

5.4 Results

The results of all of the sensitivity analyses explained above are discussed in this paragraph. They are presented in the same three groups as in the last section (b, c and d).

Constants (b):

Value functions
Changes in value functions from extremely parabolic to completely linear do not cause very large changes in the outcome of the MCA compared to the variation of the weights, but the sensitivity is not negligible. The highest sensitivity is shown by the industrial GDP value function, with a maximum of 18% change in the total MCA score. The smallest sensitivity is shown by the migration rate value function, with a maximum of 2.7% change in the total MCA score. The 18% may seem relatively large, but it has to be taken into account that the range of the variation in value functions is considerable as it is a variation from one extreme value to another (much more than 10%, although it is impossible to quantify exactly). The results do not provide any grounds on which to justify certain choices, as the best solutions are all very close together. Because the sensitivity of the value functions is not as large as that of some other factors, only the two most influential factors will be discussed: industrial GDP and income ratio.

Industrial GDP
The industrial GDP is an influential factor in the current MCA equation, because its weight is relatively large (35%) and according to the model large improvements can be achieved (35% increase from the worst to the best alternative). These numbers are smaller for the other criteria, making them less influential in the MCA.
Going from the extremely parabolic shape to the completely linear line, both shown in Figure 13, the six alternatives' scores vary as shown in Figure 16. Note that the view of the relevant part of the figure has been magnified in order to enhance the visibility of the sensitivity. Alternative F varies 18.2%.

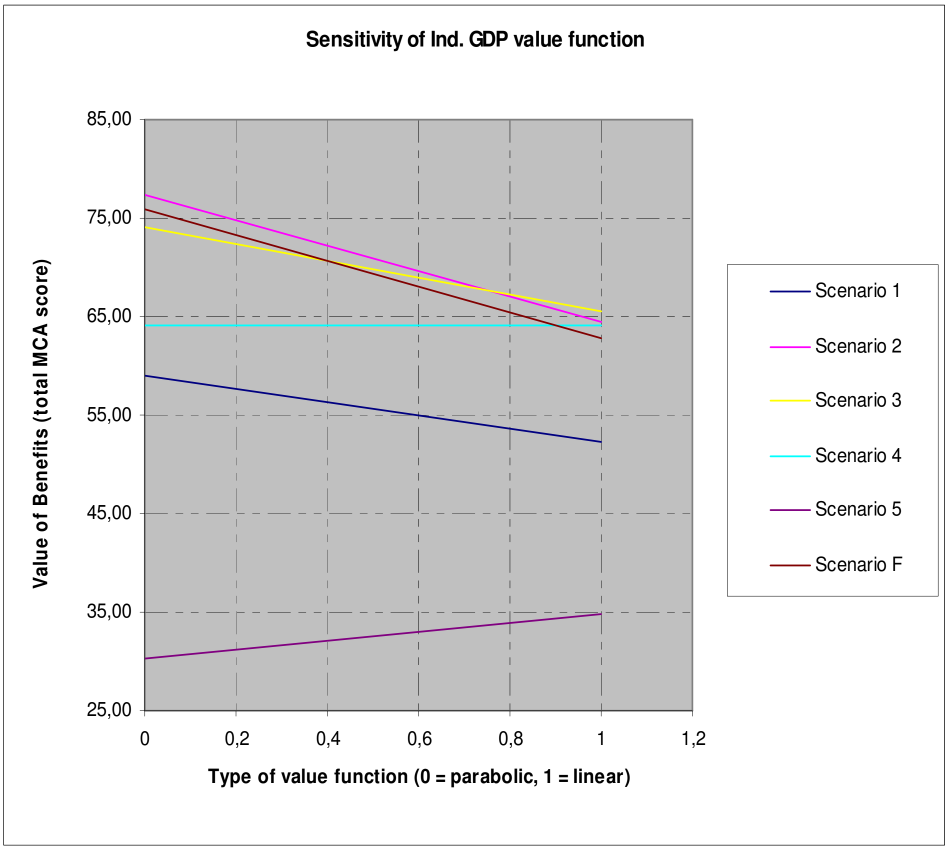


Figure 16: Sensitivity of industrial GDP value function

The inclination of the lines shows that this factor is not very sensitive in comparison to some other factors such as the weights, as can be seen in the following paragraphs. Furthermore, alternatives 2, 3 and F all show similar behaviour and scores: their lines run practically parallel to one another. This does not give any serious indication as to where the balance between best alternatives is located, at least not if this factor is varied.

Income ratio

Everything that can be said about the sensitivity of the Industrial GDP value function also applies to the Income ratio value function, but to a lesser extent (multiplied by 2/3). The weight of Income ratio is 22% and the difference between the worst and the best alternative 22%. It is hardly surprising that the results of the sensitivity analysis are very similar too: the maximum change in MCA score is 13.1% and the lines 2 and F run almost parallel once again. Of the best scoring alternatives, only alternative 3 shows differing behaviour, but the differences remain small. Figure 17 illustrates the variance of the scores. Again nothing can be concluded about where the balance between best alternatives is located; the scores are too much alike.

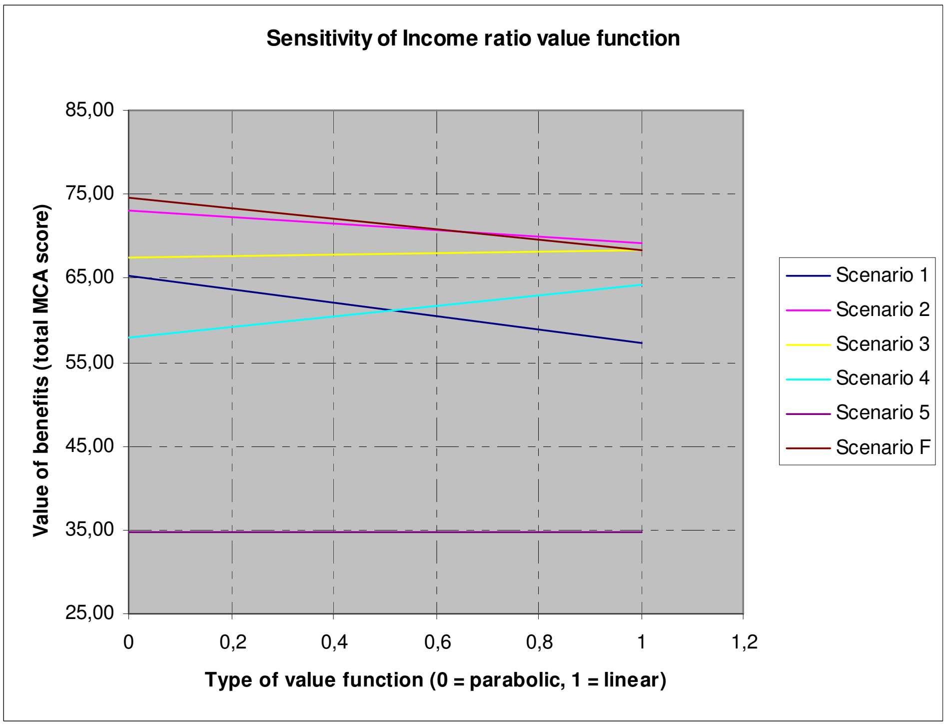


Figure 17: Sensitivity of the Income ratio value function

<u>Data per alternative</u>
As explained in Chapter 3, the scores obtained by using the coefficients and the water quantities are only dependent on the water quantities. Because this method was used for every criterion, every criterion is directly or indirectly dependent on the same parameter: the available amount of diversion water. This implies that by changing the value of a coefficient by a certain percentage, the outcomes for the different alternatives will change in that same percentage, retaining their relative proportions. This means that after normalization the results per criterion will be exactly the same. Hence, there is no difference between the original value and the plus or minus 10% variety in terms of MCA outcome. This hypothetical result was affirmed by the sensitivity analyses.
For a few criteria, the calculation was a little bit more elaborate and included more factors (again, refer to Chapter 3 for more detail). Consequently, the relative proportions did not stay the same. However, in the cases in which there was a change, the influence of a change of the coefficient with 10% on the MCA scores did not exceed 0.2 %. Unfortunately, this problem with assessing the sensitivity of the input data is inherent to the method chosen to calculate it and therefore inevitable. For a good sensitivity analysis, the way in which the source data is calculated should be altered. This had already become clear when calculating the data; the sensitivity analysis has only confirmed this fact.

Boundary conditions, initial conditions (c):
In changing the boundary condition it was not possible to make a variation as shown for the other factors of importance, because the boundary condition (water fixed per municipality) is either present or not. Thus the results are plotted in a bar diagram (Figure 18).
In almost every alternative the original version shows better MCA results, although the differences in the scores are very small. The maximum sensitivity is 4%, in the case of alternative F. Clearly this boundary condition does not have a very large influence on the results.

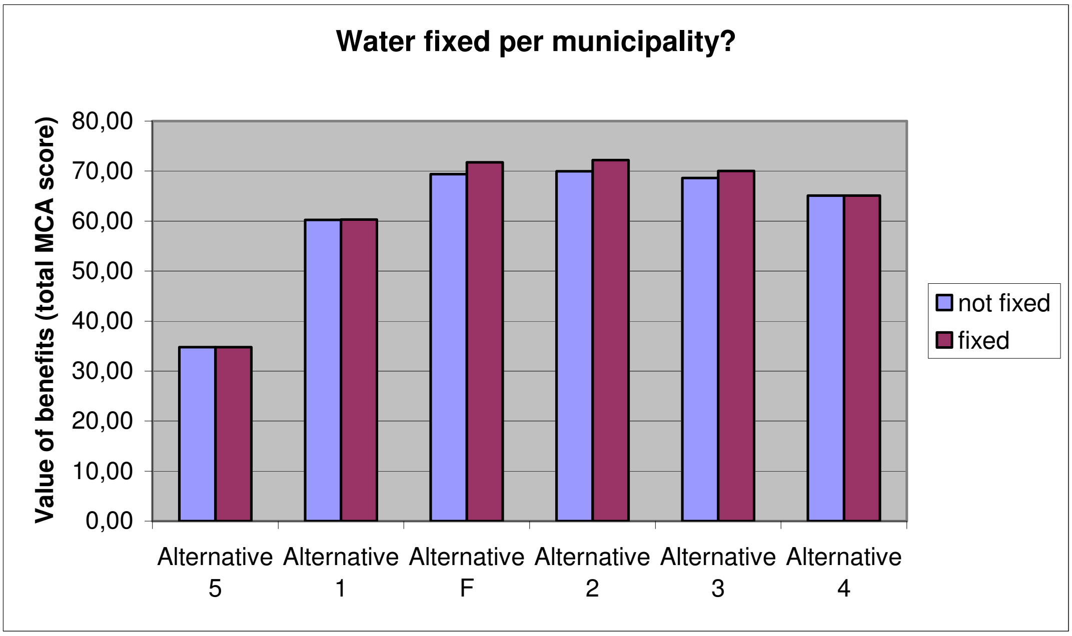


Figure 18: Sensitivity of boundary condition

Parameters (d):
The analysis shows that the MCA is very sensitive to changes in the weights. This is not surprising, judging by the fact that the weights have an important role in the model, but however still an important conclusion. The results of the weights-sensitivity analysis are presented graphically for the three main criterion categories and numerically for all criteria. Not all criteria have been shown graphically, because all criteria show similar graphs as can be seen in the three presented graphs.

Three categories
For the completion of this study, data was collected representing three sectors influenced by the ERP: economy, social and environment. Each of these is represented by two criteria. The graphs are presented below, in Figure 19 through Figure 21.
The gradients of the lines in all three figures are grounds for two important conclusions. Firstly, the steep gradients of the lines indicate a high sensitivity to changes of these weights in every category; the steepest gradients are visible in the economic category, while the social category shows slightly steeper gradients than the environmental category.
The second important conclusion that can be drawn from these graphs, is that the three alternatives that score best around the weights chosen in *this* study (alternatives 2,3 and F), are least sensitive to changes in the weights. Especially alternative F shows a very flat line, which means that the MCA score of this alternative is not very sensitive to the choice of weights. The significance of this is that the less sensitive alternatives satisfy stakeholders with all kinds of interests, while the very sensitive alternatives like alternatives 4 and 5 only satisfy the interests of part of the stakeholders. Depending on the weight given to the criteria that represent these interests, alternatives 4 and 5 can score very well or very poorly.

The three graphs all have a similar shape, although Figure 19 has an inversed shape compared to the two graphs below it. This is due to the fact that there is only one variable that differentiates the alternatives: the amount of water allocated to agriculture. This shows the major weakness of the model, as it cannot represent reality accurately.
A final conclusion that can be drawn when assessing these graphs is that the final decision of the MCA depends greatly on the choice of weights. In the given examples, four or in Figure 19 even five different alternatives attain the highest score, depending on the weight given to the category. This means it is important to take extreme care when determining the weights, and that the uncertainty of this determination needs to be reduced as far as possible. With weights being chosen by a decision-maker, this presents a large problem, as is further elaborated upon in section 5.6.

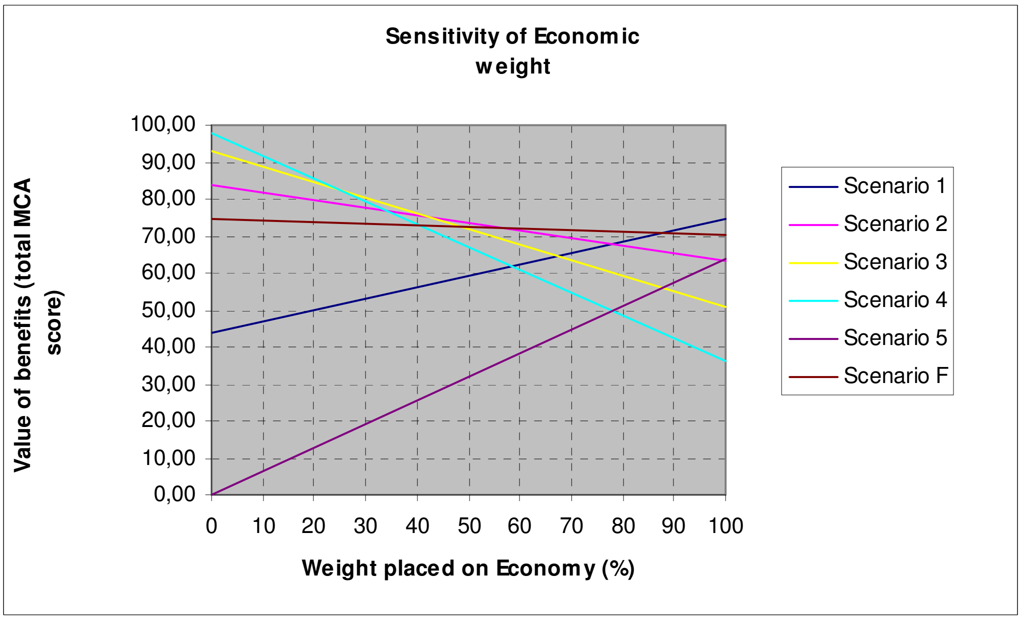


Figure 19: Sensitivity of Economic weight

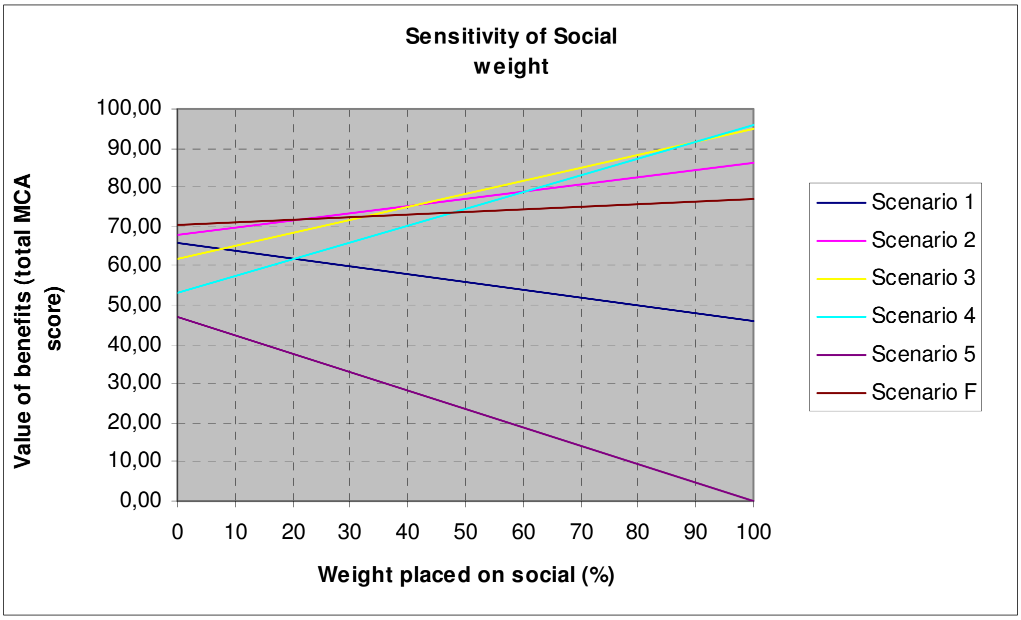


Figure 20: Sensitivity of Social weight

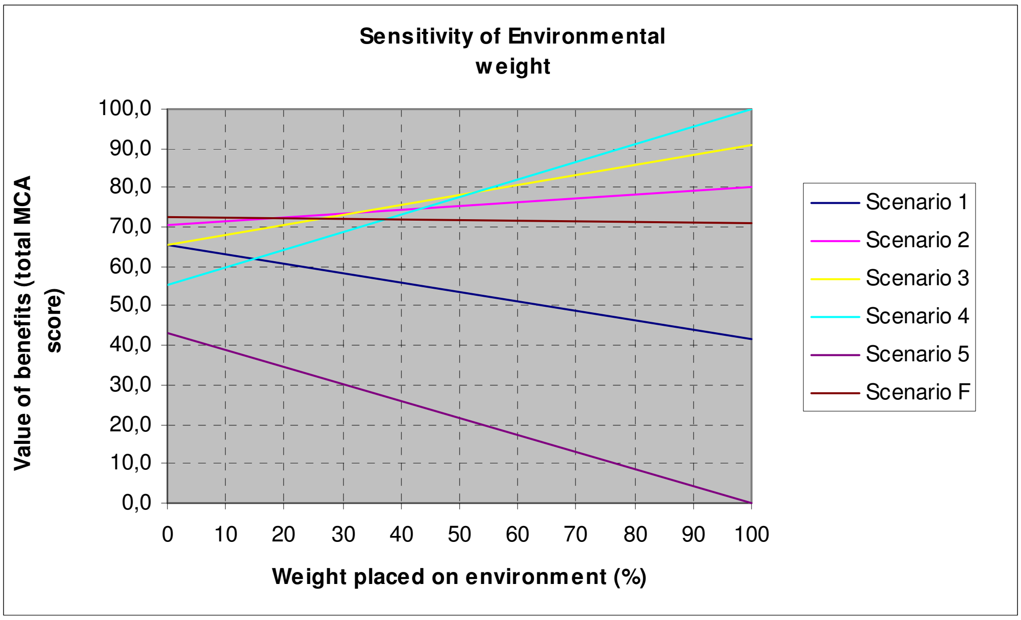


Figure 21: Sensitivity of Environmental weight

Table 9 and Table 10 show an overview of the relative sensitivity of the weights given to different criteria. These tables show how much the final MCA results change, if the weights are changed from the current value –10% to the current value +10%. Only the results for alternatives 1, 2, 3 and F are shown, as the two other alternatives are extreme alternatives and are therefore not likely to be carried out. Furthermore, these alternatives are very sensitive due to the reason explained earlier this chapter: they only represent the wishes of part of the stakeholders. For these reasons they are left out of the further analysis. Table 9 shows the same three categories as the figures above, while Table 10 shows the results of all the criteria separately.

	Economic	Social	Environmental
Alternative 1	5,5%	1,7%	1,5%
Alternative 2	3,0%	1,3%	0,5%
Alternative 3	6,5%	2,5%	1,4%
Alternative F	0,7%	0,5%	0,1%

Table 9: 10% sensitivity of three weight categories

Once again, the economic category shows to be most sensitive to changes in the weight. This is because the achieved improvements due to the south – north water transfer are largest in the economic indicators. This gives them a higher multiplier in the MCA, so changes in the weights will have more effect. A second reason is that the current weight of this category is much larger than of the other categories, so a 10% change will be larger numerically.
Alternatives 2 and F are the most stable alternatives. In the current weight determination, they also score highest. This indicates that a choice for either of these alternatives is relatively secure, as it satisfies the interests of most stakeholders to the same extent, even if the weight distribution may not seem satisfactory to every stakeholder at first glance.

	GDP	Grain production	Income ratio	Migration	Untreated wastewater	Groundwater
Alternative 1	5,4%	0,2%	1,4%	0,1%	0,7%	0,7%
Alternative 2	2,9%	0,8%	1,0%	0,2%	0,3%	0,1%
Alternative 3	6,5%	1,2%	1,9%	0,4%	0,7%	0,5%
Alternative F	0,6%	0,5%	0,3%	0,1%	0,0%	0,1%

Table 10: 10% sensitivity of weights of the 6 criteria

All conclusions explained in the paragraph above, are also valid for the separate criteria. The most sensitive criterion is GDP, followed by respectively Income ratio, Grain production, Untreated Groundwater, Groundwater and finally Migration. This shows that the weight currently given to a criterion is of stronger influence in the sensitivity than the actual percentage change in results for that category. This can be concluded from the fact that the order of sensitivity is the same as the order of relative weight, even though the results achieved in grain production (42% rise) are better than in income ratio (27% improvement). This factor is important too though, as can be concluded from the fact that the sensitivity of grain production (42% rise) is higher than that of untreated wastewater (27% deterioration), while their weights are equal.

Alternative weight determination decision-makers
The results obtained when processing the weights given by alternative decision-makers enhance the view that the MCA results are very sensitive to the weight determination. No alternative weight determination gave the same results as the results presented above. In fact, two outcomes showed a highest score for Alternative 4, in which all water is allocated to agriculture. This is obviously not a very credible option, as all stakeholders need to profit from the project to some extent.
Figure 22 shows the outcomes graphically. All alternatives have similar scores for all decision-makers (DM's), although the original scores used in this study (Weights A) obviously differ most. This graph shows that the outcome of this MCA is too volatile to rely on as a decisive factor when determining the final water allocation.

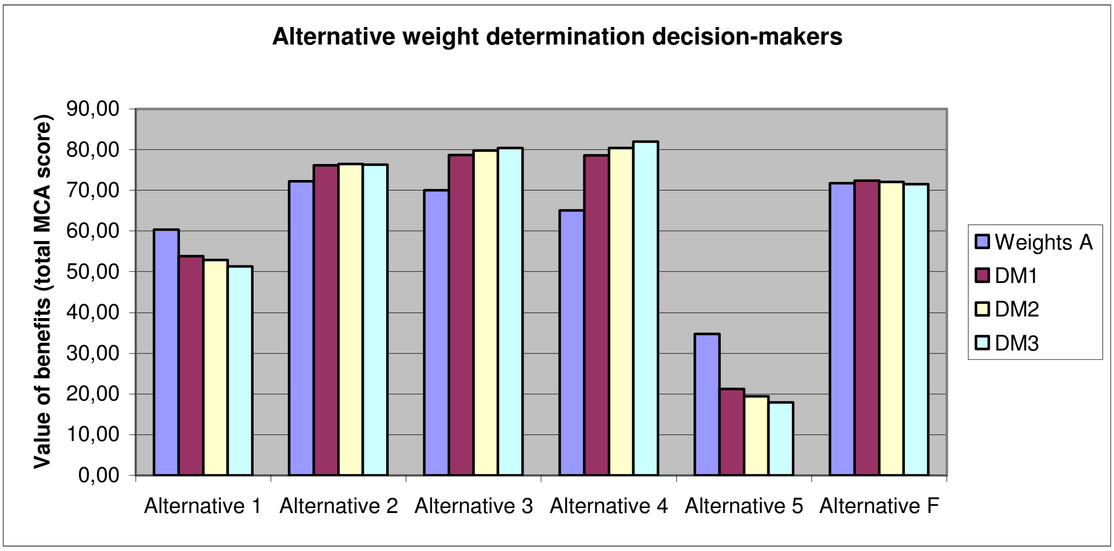


Figure 22: Comparison of outcomes different decision-makers

In all alternative weight determinations, more weight went to the non-industrial criteria relatively. This not only creates higher scores in general; it also pushes the balance of the best alternative towards a more social and environmental one. This is illustrated well in the figure above, as alternatives 3 and 4 win invariably, while the scores of alternative 2 and F (earlier indicated as the most probable outcomes) are very similar to the scores obtained with the Weights A configuration.

5.5 Conclusion sensitivity analysis

The model is more sensitive to variation of some factors of importance than others. The choice of weights is the most sensitive factor, followed by the choice of value functions. This is partially due to the fact that the model structure makes it impossible to properly measure

the sensitivity of the data per alternative. However, it is still an important conclusion because the determination of both the weights and the value functions is dependent on the opinion and experience of the decision maker. The importance of this is clearly illustrated by presenting the results obtained when using other decision-makers' alternative weight configurations. This is a problem for the reliability of the model, because the most influential factors cannot be calculated in an exact way. However, this is a known and accepted fact of MCA techniques like the SMART. Therefore they should be used mainly as a tool to support decision-makers in their understanding of the problem, rather than be used to make the actual decision.
The model is not very sensitive to application of another boundary condition considering the fixed allocation of water per municipality.

Although the model is very sensitive and thus cannot be assumed to be very reliable, the sensitivity analysis also shows that the two most probable alternatives according to the authors (2 and F), are least prone to variation of MCA results due to the sensitivity of their input values. This is an indicator of stability, showing that these alternatives attend to the interests of many different groups in society to some extent. Alternative F is the optimised alternative according to the SWIMER report. It can be accepted as a confirmation of this SWIMER-conclusion that alternative F scores almost equally well in this study.

5.6 Uncertainty analysis

The section describing the sensitivity analysis has made clear that the outcome of the model (which alternative is best according to the MCA) is very dependent on a number of factors. Of these factors, the weight determination seems to have most influence. It is important to assess the uncertainty in the model: what is the uncertainty of the sensitive factors? What is their influence on the model results?
The results can give useful indications as to the applicability of the model in its current state, as well as recommend what additional research is necessary to improve the quality of the MCA. If for example most factors are reasonably certain, but the value functions are very uncertain, a better estimation of value functions is necessary to improve the quality of the model.
The uncertainty analysis is normally performed by determining the probability distributions of the relevant factors of importance. What are the 95% confidence intervals of these factors?

The difficulty in this study is that many factors have been determined by the decision-makers and are thus uncertain by definition. Both the determination of the weights and the determination of the value functions are dependent on the opinion of the decision maker. This makes an estimation of the uncertainty of these factors rather meaningless, because in the best case they will also be based on the opinion of the decision maker.
The other most probable factor of volatility in the results is probably the data per alternative. Unfortunately this cannot be confirmed by the sensitivity analysis due to the structure of the model; refer to section 5.4 for a more elaborate explanation. These results have been generated in a very inaccurate manner. This makes an uncertainty analysis practically meaningless, as it is almost 100% certain that accurate data will differ greatly from the current data.

The above stated facts indicate an extremely large uncertainty. There are ways to reduce this uncertainty, but these are not within the scope of this study. Nor are they executable within the time-constraints for this study. They are named here however as possible recommendations on how to improve this study.
Firstly, the method of data collection (explained in Chapter 3) has to be improved for all criteria. The methods used for this study are strongly simplified and do not match reality, as they are based on incomplete information and necessitate the acceptation of many assumptions. Furthermore, the difference of outcomes of data between alternatives cannot be dependent on one factor, as is the case in this study with the amount of diversion water going to agriculture.
Secondly, the estimation of value functions and weights has to be improved greatly. In this study the authors attempted to estimate the weights that would actually represent the real world weights for this project as given by the Chinese government. However, because this is just an estimate there is a lot of uncertainty involved. It is possible to enhance the reliability and accuracy of these estimates, for example by interviewing more stakeholders on their opinions as was done on a small scale in Appendix H. The results from these interviews can then be subjected to an elaborate statistical analysis. If there is enough congruence in these results, mean weights and value functions can be assumed which give less uncertainty.
Even with all these possible improvements, the Multi Criteria Analysis is inherently a decision-making tool that is prone to uncertainty. This should always be kept in mind when decision-makers resort to the MCA as a tool in their problem solving process.

Chapter 6 Conclusion and recommendations

6.1 Conclusion

The main goal of this study was to determine the optimal water allocation alternative among sectors for the project area, using a multi criteria analysis. Although results have been achieved in this direction, it cannot be stated that an optimal allocation has become clear, at least not one with a sufficiently low level of uncertainty. First the designed water allocation alternatives are presented, after which the outcome of the MCA is summarized. Next, the sensitivity analysis and its results will be discussed. Finally, the background and reasons are given as to why this goal could not be achieved with the available data resources and time constraints.

Alternatives

Assuming the role of decision makers, the authors have tried to identify the main goals that the Chinese government would pose to evaluate the quality of each water allocation alternative. Since economic development has been China's main point of focus in the last decade, it seems to be reasonable and realistic to assume the conservation of current growth rates as the main goal (mainly through industry). However, social issues like (e.g. rural-urban migration) and the rapidly deteriorating state of the environment are big problems and awareness of these issues among Chinese policy makers has increased considerably in the last years. Therefore, it is assumed that some weight will be given to these issues as well.

Using the optimal allocation alternative as stated in the SWIMER report (alternative F) as a base alternative, three other allocation alternatives were generated with different political agendas in mind (alternatives 1 – 3). Furthermore, two extreme alternatives were created to test the volatility of the MCA (alternatives 4 & 5). Because large fluctuations in water demand are not expected in most sectors (e.g. households), all water receiving sectors except for industry and agriculture are determined to receive fixed amounts. This resulted in a simplified water allocation as presented below in Table 11.

	Alternative 1	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**	**Alternative F**
	5% agriculture GDP	equal GDP growth	5% industry GDP	100% to agriculture	100% to industry	SWIMER
Ind	64%	25%	12%	0%	100%	35%
Agr	36%	75%	88%	100%	0%	65%

Table 11: Total water allocation between industrial and agricultural sectors

Results MCA

The MCA-technique applied in this study (SMART) takes into account not only the relative importance of a parameter sec, but also the relative change it undergoes when the water allocation is changed. Thus, the weights assigned to the different criteria are based on the decision makers' judgment of the criteria's importance combined with its relative effect. For example, the decision maker feels GDP growth is more important than reducing rural-urban migration so he assigns a lower weight to the latter. Because the GDP effect is much stronger than the migration effect, the decision maker decides that the GDP weight should be even higher.

The results of the MCA with its parameters and weights determined as stated above are shown in Table 12 and Figure 23.

Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative F
60.31	72.21	70.03	65.09	34.79	71.78

Table 12: MCA outcome for Weights A

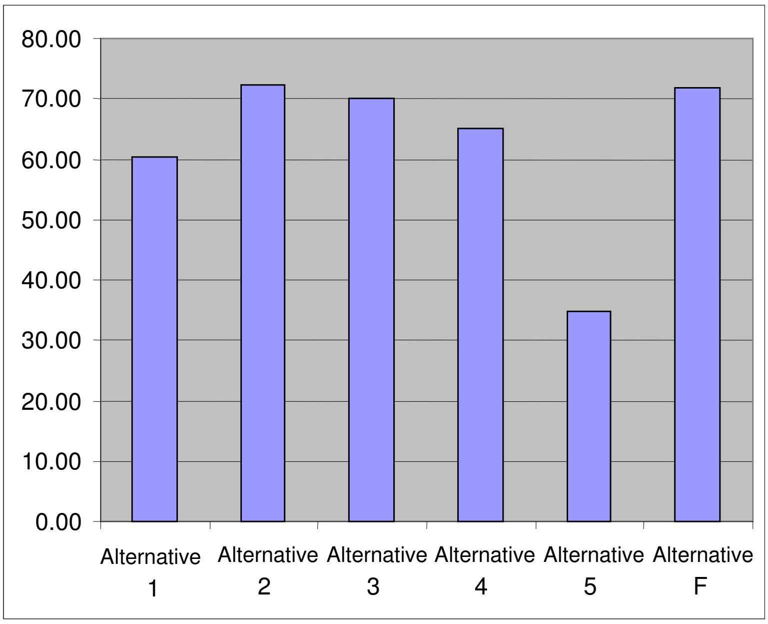


Figure 23: MCA outcome for Weights A

Alternative 2 achieves the highest score according to this MCA. However, alternative 3 and especially alternative F show very similar values. Before further conclusions can be drawn, the results of the sensitivity analysis should be discussed.

Sensitivity analysis

Several factors of importance can be observed to influence the results of the MCA. The choice of weights is the most sensitive factor, followed by the choice of value functions. Due to the structure of the model used to generate the MCA's input data, no conclusion could be reached about the sensitivity of the input data, although it is also expected to have a large influence. The determination of both the weights and the value functions is dependent on the opinion and experience of the decision maker. The importance of this is clearly illustrated by assessing the differing final results obtained when using other decision-makers' alternative weight configurations. The MCA's outcomes have been proven to be very prone to change and this does not provide much confidence in the results presented above.

Final conclusion

Although the model is very sensitive and thus cannot be assumed to be very reliable, the sensitivity analysis also shows that the two most probable alternatives according to the authors (2 and F), are least prone to variation of MCA results due to the sensitivity of their input values. It can be accepted as a confirmation of the optimised SWIMER alternative that alternative F scores almost equally well in this study.

Considering the results of the sensitivity analysis, this study should be used mainly as a tool to support decision-makers in their understanding of the problem, rather than be used to determine the actual decision. It also provides a valuable starting point for more detailed studies that dispose of more reliable data sources. When engineered in collaboration with the responsible decision makers, the identification of a reasonably reliable "best alternative" is achievable. The most important points of improvement of this study have been summarised in the next paragraph Recommendations for further study.

Even with possible improvements, the Multi Criteria Analysis is inherently a decision-making tool that is prone to uncertainty. This should always be kept in mind when decision-makers resort to the MCA as a tool in their problem solving process

6.2 Recommendations

Previous chapters have clearly indicated that many sections of this study can be improved. These improvements represent the minimum necessary measures to achieve a satisfactory scientific value. They are discussed below.

The measurement of data for the quantification of variables needs to be improved considerably. All criteria have been quantified using simplified methods. In grain production for example, the influence of technological developments increasing yield per unit of area have not been considered. Also, it has been assumed that the entire area is planted with grain, even though this is a large simplification. In untreated wastewater, all diversion water allocated to industry and urban areas is assumed to cause extra volumes of untreated wastewater, dependent on the current rate of treatment. This rate of treatment can change however, due to the south – north diversion project. Many new treatment facilities have been planned and will be constructed. The results of migration rate presented here have been derived from results from the SWIMER report. They were not given in numbers however, but had to be estimated from diagrams with an inaccuracy of 5%. Similar problems have been encountered in the generation of data for all criteria. These results have been used mainly to complete the study, but since the results are so inaccurate, not much value can be given to the conclusions.

There is a number of criteria that have not been included in this study, because no data was available to measure them. However, to conduct an MCA, all relevant criteria have to be included in order to make a decision based on all the effects of the chosen solution. If certain criteria are left out, this model will not be a complete representation of reality. In this study the effects on (un)employment have not been considered, nor have the effects on ecology or the public satisfaction. There are undoubtedly more criteria that could be included, although it has to be mentioned that some of these may be impossible to measure. In any case, the addition of new, well measured criteria will invariably improve the quality of this study.

Different methods should be used to calculate what the effects of the diversion water are on the criteria. In this study results in all criteria have been linked to the amount of diversion water given to certain sectors. This makes the results for all criteria linearly dependent on the amount of water coming in. In fact, with extensive mathematical operations, all equations in this study can be joined to make one final equation determining the score of the MCA, using the amount of diversion water allocated to agriculture as the only variable. This cannot properly represent reality. Firstly, more than two sectors will be receiving water from the diversion project. Secondly, it is very well possible that some criteria will have another type of relationship with extra water: e.g. quadratic, lognormal, etc. These relationships need to be examined.

The given alternatives need to be researched hydraulically. Is it physically possible to allocate the water as proposed? How much money is needed to construct the infrastructure to facilitate this? If there are large differences in this, it is probable that the hydrological viability of the alternative will become a new criterion in the study.

The determination of value functions and MCA-weights should be performed by the actual decision-maker responsible for the project. This can be a person or a decision-making body. The decision-maker is most capable of making a well balanced consideration of all the interests involved. If this is not within the reach of the study, a survey should be conducted among a large number of respondents (100+), in which they can give their opinion on a just determination of weights and value functions. This survey should be conducted among people with a full understanding of the project and the interests involved. If a statistical analysis of the results of this survey proves satisfactory, the results can be used to define the weights and value functions for the study.

List of Appendices

Appendix A
China Institute of Water Resources and Hydropower Research - 中国水利水电科学研究院

A description of the traineeship hosting organization[19]

China has an extremely diverse and complex water environment. Some regions are prone to flooding, others have drought problems and there are even areas that have to cope with both issues. China has a more than 18 000 km long coastline[20] and some of the world's longest and most uncontrollable rivers. At the same time the country is undergoing fast changes in economical sense, which causes a rising demand for (hydro-) power and a better controlled and more consistent water supply. The above issues and many which have been left unmentioned, provide a large demand for scientific research.

The China Institute of Water Resources and Hydropower Research (IWHR) is China's main research institute addressing these issues at a national level. Affiliated with the Chinese Academy of Sciences, the Ministry of Water Resources and the State Electric Power Corporation, the IWHR is positioned at the highest administrative level of research. The institute is responsible for research tasks in major hydro projects, state five year plan key programs of science and major programs funded by the above organizations. These programs vary widely: from engineering of hydraulic machinery to water environment and from earthquake engineering to sedimentation. Apart from this the IWHR does technical consulting in China and abroad.

The institute was formed in 1958 as a merger of the Water Resources Research Institute, the Institute of Hydraulic Research and the Hydropower Research Institute, which were all administered by a different governmental department. It received its current name in 1994.

The institute is composed of 15 research departments and centres. It has 1383 employees (2003), a majority of which is technical or scientific personnel. The IWHR is proud to present that some of its staff belongs to the most decorated section of Chinese scientists. Academic training is integrated in the institute's research activities as it frequently offers Doctors and Masters Programmes. The institute experiences constant growth and reached an annual revenue of 0.21 billion Yuan in 2001, comparable to 21 million Euro.

Department of Water Resources – 水资源研究所
A description of the hosting department[21]

The department states its mission is "to serve the country by implementing studies of strategic water resources issues and providing consultation for decision making, hence promoting water resources undertakings in China". This implicates support to the highest levels of the Chinese government in macro water resources decision making. Furthermore research is done in many fields of water resources investigation, e.g. physical, ecological and chemical processes, methodologies for water resources management, flood control and flood forecasts, modelling river basins, eco-environmental issues and the development of automated tools like Decision Support Systems for water allocation and flood control.

The department has 39 mid and high level staff members. There is intense cooperation with other national research institutes and more local research groups on provincial or municipal level. Since the 1980's the department has also participated or been in charge of in many international cooperation projects.

Recent projects in which the department was involved include feasibility studies for the Three Gorges Project on the Yangtze River, water resources planning for the Heihe River Basin and the South to North Water Transfer Project. One of the main issues at the moment is the development of a water resources information system, which will drastically change possibilities of water resources monitoring and allocation. Table 13 gives an overview of the department's current projects.

	Project	**Sponsor**
1	Sustainable Water Integrated Management of the East Route in the South – North Transfer Project (SWIMER)	Sino-Italy cooperative project
2	Sustainable Water Integrated Management in the South – North Transfer Project (SWIM)	Sino-Italy cooperative project
3	Water Resources Demand Management	DFID
4	Hai Basin Integrated Water and Environment Management Project	GEF (Global Environment Foundation)
5	Water Demand and Supply Trend Analysis and Rational Allocation in Northeast China	China Academy of Engineering
6	Research on Water Balance and Water Consumption in Ning-Meng Irrigation Zone	China National Nature Foundation Committee
7	Standard System for Sustainable Utilization of Water Resources	Ministry of Science and Technology
8	Integrated Assessment on Macro Economic Effect for Yellow River of the West Route in the South-North Transfer project	Yellow River Committee
9	National Integrated Planning on Water Resources-Water Demand Projection	Ministry of Water Resources (MWR)
10	National Integrated Planning on Water Resources-Database	MWR
11	Integrated Water Saving Planning on the Recipient Area of the Middle Route in the South – North Transfer Project	MWR
12	Water Right Project on Song-Liao River Basin	Song-Liao River Committee
13	Integrated Water Resources Planning of Xinjiang	Water Resources Bureau of Xinjiang Uger Autonomous Region
14	Integrated Water Resources Planning of Hainan Province	Water Resources Bureau of Hainan Province
15	Water Resource Rational Allocation between Ecosystem and Economic System in Ningxia	Water Resources Bureau of Ningxia Hui Autonomous Region

Table 13: Ongoing projects by IWHR

Appendix B
Analytical Hierarchy Process

In this appendix the Analytical Hierarchy Process (AHP) is discussed, since it was strongly considered to be used as the MCA tool for this study. The basic principles of the AHP are the same as those of the SMART method, but some methods of obtaining results differ. For more information on SMART, please refer to Chapter 4. The most important differences with SMART can be found in the analysis of input data and in the determination of weights. This appendix will only cover the parts of the analysis that differ with the SMART method.

The AHP method is based on pair wise comparisons between the decision alternatives on each of the criteria. After all the ratings for the alternatives have been determined, a similar set of comparisons is made to determine the relative importance of each criterion and thus the weights are produced. One of its advantages over other MCA methods is that the AHP provides a measure for judgment consistency.

Methodology

Rating criteria

The different alternatives' scores for a certain criterion are determined by creating a pair wise comparison matrix. The alternatives are compared with each other and the decision maker expresses his preference of one alternative over another.

Usually, the following rating system is used:

Numerical Values	Definition
1	Equal importance or preference
3	Slightly more important of preferred
5	Strongly more important of preferred
7	Very strongly more important of preferred
9	Extremely more important of preferred
2,4,6,8	Intermediate values to reflect compromise
reciprocals	Used to reflect dominance of the second alternative as compared with the first.

These value judgments are reciprocal so if the decision-maker decides that alternative X is 3 times better than alternative Y then alternative Y should be 1/3 as good as alternative X.

Example of pair wise comparison matrix

	X	Y	Z	Average
X	1	1/4	3	0.221
Y	4	1	6	0.685
Z	1/3	1/6	1	0.093

After filling out the pair wise comparison matrix the mean preference and thus the score of an alternative can be assessed. This is done by normalizing the columns and calculating the mean row score. This mean score is the score of the alternative on this particular criterion. The decision-makers judgment is not consistent however. If he would have been completely consistent, the relative column weights would have been the same for every column. If we look at the example more closely, we can see that Y is 6 times better than Z and X is 3 times better than Z. This implies that Y is 2 times better than X if the decision maker was consistent. As can been seen in the matrix, the decision-maker rated Y 4 times better than X. If these judgments differ too much, the results are not reliable enough to assume that this assessment is a true representation of the decision-maker's real preferences. In order to see if the decision-maker has been consistent enough, a consistency ratio C.R. can be calculated. The details of this calculation will not be discussed here. If the C.R. is under 0.1 the errors are fairly small and thus, the final estimate can be accepted.

The weights associated with the different criteria can also be determined in a similar fashion. The criteria are listed in the columns and rows and the decision-maker assesses the relative importance of the different criteria with respect to each other.

Advantages
The AHP is the only decision making method that takes into account that errors can be made in judgment and it provides a check to measure the acceptability of these errors. Other decision making methods require the decision-maker to make no errors in providing the preference information. This implies that assumptions have to be made on which alternative is to be treated as a base for comparison. The AHP uses every single alternative as a base for comparison and checks afterwards if the judgments are consistent enough, thus dealing with the inconsistency formally instead of assuming it away.

Disadvantages
One thing the user of AHP and any other ratio rating method should be very aware of is the phenomenon of rank reversal. This is best illustrated by an example. Suppose there are three alternatives (X, Y and Z) with ranking X, Y, Z from best to worst. If another alternative X2 is added that is exactly or almost similar to alternative X, it is possible that these best alternatives X and X2 will not be the best anymore and the alternative which originally ranked 2nd, Y, will now rank first. How is this possible?
The problem is that there is nothing that distinguishes the 2 similar alternatives X and X2, and therefore, since the AHP is a ratio method, "spreads" the priority between two rather than one alternative. To avoid this, it is important to make sure that any alternative that is a close copy of another alternative with respect to the criteria is removed from the set. That is, the set of alternatives should form a basis on which all other alternatives can be measured.

Appendix C
Source data used in data creation

All source data used in the generation of the data used to calculate the per m^3 diversion water contribution (as explained in Chapter 3) is presented in this appendix.

General data

		Population					
		2000			2010		
		Population total	Urban	Rural	Population total	Urban	Rural
Jiangsu	Xuzhou*	9077.1	2981.8	6095.3	10244.8	4229.6	6015.2
	Lianyungang*	4653.5	1280.3	3373.2	5288.6	1988.0	3300.6
	Huai'an*	5130.4	1448.5	3681.9	5718.2	2136.7	3581.5
	Yangzhou	4672.5	1959.0	2713.5	5032.0	2603.1	2428.9
	Suqian*	5154.2	1289.7	3864.5	5781.4	2052.0	3729.4
	Subtotal	**28687.7**	**8959.3**	**19728.4**	**32065.0**	**13009.4**	**19055.6**
Anhui	Bengbu*	3288.0	1010.0	2278.0	3490.7	1612.8	1877.9
	Huaibei	1878.0	777.0	1101.0	1993.8	988.7	1005.1
	Suzhou*	5517.0	848.0	4669.0	5857.1	1332.0	4525.1
	Subtotal	**10683.0**	**2635.0**	**8048.0**	**11341.6**	**3933.5**	**7408.1**
Shandong	Ji'nan	5975.7	3351.5	2624.2	6261.5	3868.0	2393.5
	Qingdao	7562.5	4305.4	3257.1	7913.7	4826.6	3087.1
	Zi'bo	4222.9	2221.6	2001.2	4419.0	2615.6	1803.4
	Zaozhuang	3578.9	1396.7	2182.1	3745.1	1894.8	1850.3
	Dongying	1809.4	869.9	939.5	1893.2	1062.5	830.7
	Yantai	6696.2	3052.4	3643.8	7007.2	3994.1	3013.1
	Weifang*	8572.7	3465.6	5107.1	8970.9	4665.1	4305.8
	Ji'ning*	7810.8	2693.7	5117.1	8173.4	3841.2	4332.2
	Weihai	2620.6	1297.7	1322.9	2742.3	1480.9	1261.4
	Dezhou*	5341.9	1499.7	3842.2	5590.0	2347.8	3242.2
	Liaocheng*	5461.2	1432.5	4028.7	5714.8	2228.8	3486.0
	Binzhou*	3596.5	873.6	2722.9	3763.5	1580.7	2182.8
	He'ze*	8171.8	1698.1	6473.7	8550.3	2981.7	5568.6
	Subtotal	**71421.1**	**28158.5**	**43262.6**	**74744.8**	**37387.8**	**37357.0**
Total		**110791.7**	**39752.8**	**71039.0**	**118151.4**	**54330.7**	**63820.7**

* = denotes municipality classified as agricultural. For more information, see Chapter 3, GDP.

Table 14: Population per sector of society and municipality (1000 persons)

Source: IWHR

		Additional water supply			
		City Life	Rural Life	Industry	Agriculture
Jiangsu	Xuzhou	23.9	0.0	72.6	229.3
	Lianyungang	2.1	0.0	9.1	84.1
	Huai'an	66.8	-22.8	211.1	277.2
	Yangzhou	32.9	-14.1	19.9	49.8
	Suqian	84.2	-4.3	67.1	91.0
	Subtotal	**209.9**	**-41.2**	**379.8**	**731.4**
Anhui	Bengbu	1.2	-3.7	111.3	102.7
	Huaibei	7.7	-7.9	46.6	105.2
	Suzhou	0.9	0.0	12.3	334.5
	Subtotal	**9.8**	**-11.5**	**170.2**	**542.4**
Shandong	Ji'nan	8.8	0.7	28.1	51.8
	Qingdao	34.6	0.0	98.6	16.0
	Zi'bo	0.0	0.0	0.0	40.1
	Zaozhuang	9.6	0.0	43.7	32.1
	Dongying	13.9	0.0	107.7	15.5
	Yantai	6.0	2.0	25.0	25.4
	Weifang	1.8	0.0	6.2	45.4
	Ji'ning	0.0	0.0	0.0	60.3
	Weihai	4.8	4.7	20.1	78.6
	Dezhou	4.9	0.0	42.3	53.6
	Liaocheng	4.1	0.0	25.3	50.4
	Binzhou	5.1	0.0	34.5	76.9
	He'ze	0.0	0.1	0.0	0.0
	Subtotal	**93.6**	**7.5**	**431.6**	**546.1**
Total		**313.3**	**-45.2**	**981.5**	**1819.9**

Table 15: **Additional water supply due to ERP under Alternative F per sector of society and municipality in $10^6 m^3$**

Source: IWHR

Economical indicators

		Gross Domestic Product			
		Industry		Agriculture	
		2000	**2010F**	**2000**	**2010F**
Jiangsu	Xuzhou	31037.6	73236.4	11639.8	19882.5
	Lianyungang	13385.6	32846.6	7186.6	12345.7
	Huai'an	12481.4	26171.9	8606.6	14397.6
	Yangzhou	24307.6	66048.7	6171.5	10119.9
	Suqian	7712.4	17127.9	7418.6	13173.3
	Subtotal	**88924.5**	**215431.5**	**41023.1**	**69919.0**
Anhui	Bengbu	8273.2	22908.6	5432.1	9447.3
	Huaibei	6148.9	18400.0	1541.4	2680.7
	Suzhou	4744.8	12918.9	8093.7	14076.3
	Subtotal	**19166.9**	**54227.5**	**15067.2**	**26204.3**
Shandong	Ji'nan	42151.2	106110.4	8491.2	13831.2
	Qingdao	56260.6	151798.5	12501.2	20363.2
	Zi'bo	37897.2	101490.3	4137.9	6740.2
	Zaozhuang	12376.7	25624.3	3725.0	6067.6
	Dongying	38114.3	103925.0	2692.8	4386.2
	Yantai	45713.2	127956.5	11273.3	18363.0
	Weifang	33094.6	92177.3	13030.3	21225.0
	Ji'ning	24987.9	51803.0	10259.8	16712.1
	Weihai	29582.5	81205.4	7674.3	12500.6
	Dezhou	15879.0	33389.9	7918.3	12898.1
	Liaocheng	11762.2	25120.8	8164.9	13299.8
	Binzhou	13123.6	27491.2	5484.7	8934.0
	He'ze	5659.3	13533.9	9356.3	15240.4
	Subtotal	**366602.2**	**941626.5**	**104709.9**	**170561.4**
Total		**474693.6**	**1211285.5**	**160800.3**	**266684.8**

Table 16: GDP per sector and per municipality in 10^6 Yuan for 2000 and 2010(F) with ERP

Source: 2000: IWHR, 2010F: P.R. China 5-year plan

GDP growth due to East Route Difference between 2010 and 2010F	
Industry	14.53%
Agriculture	9.09%

Source: SWIMER report, section 4.3.2.1, figure 113

		Grain production				
			2010F		2000	
		Total land area (km^2)	Agricultural area (km^2)	Grain production (1000 tons)	Agricultural area (km^2)	Grain production (1000 tons)
Jiangsu	Xuzhou	11155.9	6079.6	3287.0	6343.6	3195.0
	Lianyungang	7376.7	3135.7	2130.0	3173.4	2070.3
	Huai'an	9994.6	4724.2	3113.0	4829.6	3026.1
	Yangzhou	6647.9	3045.7	2316.0	3093.8	2251.6
	Suqian	8545.3	4626.8	3004.0	4977.5	2920.6
	Subtotal	**43720.4**	**21612.1**	**13850.0**	**22417.8**	**13463.6**
Anhui	Bengbu	5961.9	3855.4	4186.0	3875.8	3439.7
	Huaibei	2733.0	2302.3	4045.0	2314.5	2002.3
	Suzhou	9937.3	6853.9	7492.0	6890.1	5891.9
	Subtotal	**18632.2**	**13011.6**	**15723.0**	**13080.4**	**11333.9**
Shandong	Ji'nan	7999.1	3701.1	2537.0	3738.9	2332.8
	Qingdao	10936.6	5448.5	2936.0	5495.6	2699.6
	Zi'bo	5981.9	2328.3	1406.0	2348.0	1292.3
	Zaozhuang	4569.1	2406.4	1378.0	2424.6	1266.5
	Dongying	7063.5	2257.6	855.0	2275.8	785.8
	Yantai	13558.7	4601.7	2098.0	4645.7	1928.7
	Weifang	15738.5	7772.6	3882.0	7840.9	3569.2
	Ji'ning	11150.0	6093.6	4370.0	6145.8	4017.2
	Weihai	5505.0	1908.5	992.0	1925.3	911.9
	Dezhou	10326.0	6203.1	4843.0	6257.9	3300.6
	Liaocheng	8653.9	5656.0	4747.0	5710.3	3213.1
	Binzhou	8568.9	4424.9	2353.0	4463.2	2163.4
	He'ze	12199.6	8362.7	4562.0	8431.1	3426.9
	Subtotal	**122250.9**	**61164.9**	**36959.0**	**61703.2**	**30907.7**
Total		**184603.4**	**95788.6**	**66532.0**	**97201.4**	**55705.2**

Table 17 **Agricultural area (km^2) and Grain production (1000 tons) per municipality for 2000 and 2010(F) with ERP**

Source: IWHR

Social indicators

		Income	
		Rural	Urban
		2000 (yuan)	2000 (yuan)
Jiangsu	Xuzhou	3230.0	9339.0
	Lianyungang	2597.0	8006.0
	Huai'an	3234.0	6715.0
	Yangzhou	3464.0	9732.0
	Suqian	2886.0	6813.0
Anhui	Bengbu	2460.2	5672.2
	Huaibei	2932.1	5311.1
	Suzhou	2176.0	4380.4
Shandong	Ji'nan	4011.1	9564.9
	Qingdao	5394.2	8730.5
	Zi'bo	4138.5	7275.4
	Zaozhuang	3617.6	5956.2
	Dongying	4434.7	8847.0
	Yantai	4504.7	8261.1
	Weifang	5094.4	7303.4
	Ji'ning	3874.1	6296.2
	Weihai	5036.9	8736.3
	Dezhou	3780.2	5756.9
	Liaocheng	3269.3	6581.2
	Binzhou	3653.6	6901.1
	He'ze	3083.3	5425.3
Average		**3660.6**	**7219.2**

Table 18 **Average per capita income per municipality in Yuan for 2000**

Source: IWHR

Income increase due to ERP Difference between 2010 and 2010F	
Urban	7.06%
Rural	6.94%

Source: SWIMER report, section 4.3.2.1, figure 113

		Migration
		Change in rural/urban migration rate
Jiangsu	Xuzhou	-8%
	Lianyungang	-15%
	Huai'an	40%
	Yangzhou	-8%
	Suqian	0%
Anhui	Bengbu	-15%
	Huaibei	-8%
	Suzhou	-20%
Shandong	Ji'nan	-8%
	Qingdao	-8%
	Zi'bo	-3%
	Zaozhuang	-8%
	Dongying	-8%
	Yantai	-8%
	Weifang	-8%
	Ji'ning	-8%
	Weihai	3%
	Dezhou	-8%
	Liaocheng	-8%
	Binzhou	-20%
	He'ze	-8%
Average		-6%
"Real" average change		-3.12%

Table 19 **Change in migration rate per municipality due to ERP**

Source: SWIMER report, section 4.3.2.1, figure 113

Environmental indicators

		Groundwater usage		Exploitable groundwater
		2010F	2010E	
Jiangsu	Xuzhou	662.9	669.0	1304.0
	Lianyungang	116.3	125.3	401.0
	Huai'an	129.2	214.3	837.0
	Yangzhou	86.2	114.6	418.0
	Suqian	148.6	198.0	860.0
	Subtotal	**1143.2**	**1321.2**	**3820.0**
Anhui	Bengbu	66.3	98.9	593.0
	Huaibei	28.8	129.8	284.0
	Suzhou	158.5	253.8	1029.0
	Subtotal	**253.6**	**482.5**	**1906.0**
Shandong	Ji'nan	495.7	562.3	518.0
	Qingdao	204.7	206.1	205.0
	Zi'bo	422.8	473.5	366.0
	Zaozhuang	211.3	240.1	231.0
	Dongying	193.6	201.4	182.0
	Yantai	143.5	146.1	142.0
	Weifang	598.6	613.3	639.0
	Ji'ning	773.2	858.4	948.0
	Weihai	2.0	2.0	0.0
	Dezhou	848.2	920.7	971.0
	Liaocheng	1019.2	1101.7	1207.0
	Binzhou	400.8	450.4	443.0
	He'ze	872.7	963.8	1275.0
	Subtotal	**6186.4**	**6739.7**	**7127.0**
Total		**7583.2**	**8543.4**	**12853.0**

Table 20: **Estimated groundwater usage for 2010(F) with, and without (E) ERP, and 2005 exploitable groundwater availability in $10^6 m^3$ per municipality.**

Source: IWHR

For a more elaborate discussion on the calculation of the groundwater coefficients, please also refer to Appendix D.

		Urban water usage		Urban Water Use/Wastewater factor	Treatment rate
		2010F	2010E		
Jiangsu	Xuzhou	1226.0	1129.5	1.4	0.7
	Lianyungang	675.5	664.2	1.3	0.5
	Huai'an	775.3	497.4	1.2	0.5
	Yangzhou	542.1	489.3	1.2	0.5
	Suqian	402.8	251.6	1.3	0.5
	Subtotal	**3621.7**	**3032.0**		
Anhui	Bengbu	535.0	422.5	2.7	0.5
	Huaibei	282.8	228.6	5.1	0.5
	Suzhou	346.7	333.5	4.5	0.4
	Subtotal	**1164.5**	**984.5**		
Shandong	Ji'nan	661.1	624.2	1.6	0.5
	Qingdao	574.1	440.9	1.6	0.9
	Zi'bo	551.8	551.8	1.8	0.5
	Zaozhuang	411.7	358.4	1.7	0.5
	Dongying	664.1	542.5	1.8	0.5
	Yantai	514.5	483.5	1.7	0.9
	Weifang	661.3	653.2	1.7	0.5
	Ji'ning	681.9	681.9	1.7	0.6
	Weihai	186.3	161.4	1.6	0.5
	Dezhou	448.4	401.2	1.5	0.5
	Liaocheng	367.0	337.6	1.5	0.9
	Binzhou	387.8	348.2	1.6	0.5
	He'ze	401.2	401.2	1.6	0.5
	Subtotal	**6511.1**	**5986.0**		
Total		**11297.3**	**10002.4**		

Table 21: **Urban water usage for 2010(F) with, and without (E) ERP in $10^6 m^3$ and Urban water use/wastewater factor and Treatment rates per municipality.**

Source: IWHR

Appendix D
Determination of α and β

This appendix provides a short explanation of the method in which α and β, used to calculate agricultural production, have been calculated. Factor α represents the relative influence of one unit of extra agricultural water to the groundwater. Factor β represents the relative influence of one unit of extra urban water to the groundwater.

α

For the calculation of α, data was needed on evapo-transpiration, effective rainfall and the water quota for a representative crop (maize). This data was provided by IWHR and can be found in Table 22. Firstly, the evapo-transpiration has to be compared to the effective rainfall (aggregate). If the evapo-transpiration is larger than the effective rainfall, this means the crops will need to be irrigated in order to achieve an optimal growth. It is also known how much irrigational water is assigned per unit of area (1 mu = 0,666 km^2) in every province (quota). However, this is much more than the water absorbed by the plant; the water that will eventually be lost to evaporation and transpiration. Logically, the rest of this water infiltrates into the ground, replenishing the groundwater.
If the aggregate is subtracted from the quota, this is the number indicating how much water will infiltrate. If this is divided by the total amount of irrigational water, a percentage is obtained indicating how much of the used water goes into the groundwater. This is the factor α. It is represented by the following equation:

$$\alpha = \frac{Quota - (ETm - Peff)}{Quota}$$

Province	**Precipitation (P eff) and Evapo-transpiration (ETm) maize(mm)**			**Quota (m^3/mu)**	**Quota (mm)**	**GW infiltration (%)**
	ETm	P eff	Aggregate			
Jiangsu	489,9	424,3	65,6	182	273	76%
Anhui	466,1	388,2	77,8	166	249	69%
Shangdong	604,0	368,6	235,4	265	398	41%

Table 22: Data for calculation of α

β

β indicates which percentage of water used in urban centres eventually infiltrates into the groundwater. The data needed to generate this percentage is data on the wastewater rate in urban centres and on the so called overlap between groundwater and surface water during groundwater measurements (seepage from the river to the groundwater).
These last figures are especially important in areas with extremely low groundwater levels such as the 3-H plain. When assessing the total quantity of available groundwater in an area, the surface water will influence the measurement because part of the flow passing through the testing well originated in the river. The water level in the river is higher than the groundwater level around, so this will induce a flow. The quantity of water that was originally not groundwater but was surface water is called the overlap, or better known as seepage. These quantities are shown in Table 23.
The other data needed was an indicator as to how much urban water becomes wastewater. The other part is assumed to disappear during use (evaporation, part of industrial products, drinking water, etc.) This data was known in detail for every municipality, and is called the wastewater factor.
Since both of these numbers are percentages, the equation representing this relation is:

$$\beta = wastewaterfactor * overlap$$

surfacewater (10^9 m^3)	groundwater (10^9 m^3)	overlap (10^9 m^3)	River infiltration in groundwater
24,9	11,5	3,8	16%
61,7	16,6	10,6	17%
26,4	15,4	8,3	32%

Table 23: Data for calculation of β

Appendix E **Different water allocation alternatives**

The following table contains the different water allocation alternatives, with the per sector and per municipality water allocation. A detailed discussion about the different alternatives and how they are calculated can be found in section 4.6

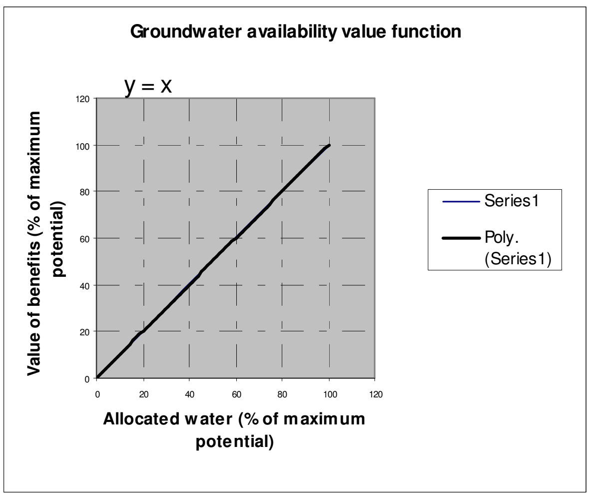
		Alternative 1		Alternative 2		Alternative 3		Alternative 4		Alternative 5		Alternative F	
		5% agriculture GDP		equal GDP growth		5% industry GDP		100% to agriculture		100% to industry		SWIMER	
		Ind.	Agr.	Ind.	Agr.	Ind.	Agr.	Ind.	Agr.	Ind.	Agr.	Ind.	Agr.
Jiangsu	Xuzhou	175.7	126.1	51.9	250.0	25.0	276.9	0.0	301.8	301.8	0.0	72.6	229.3
	Lianyungang	47.0	46.3	6.5	86.7	3.1	90.1	0.0	93.2	93.2	0.0	9.1	84.1
	Huai'an	335.8	152.5	151.0	337.3	72.6	415.6	0.0	488.3	488.3	0.0	211.1	277.2
	Yangzhou	42.3	27.4	14.2	55.4	6.9	62.8	0.0	69.7	69.7	0.0	19.9	49.8
	Suqian	108.0	50.1	48.0	110.2	23.1	135.0	0.0	158.1	158.1	0.0	67.1	91.0
	Subtotal	**708.9**	**402.3**	**271.6**	**839.6**	**130.7**	**980.5**	**0.0**	**1111.2**	**1111.2**	**0.0**	**379.8**	**731.4**
Anhui	Bengbu	157.5	56.5	79.6	134.4	38.3	175.7	0.0	214.0	214.0	0.0	111.3	102.7
	Huaibei	93.9	57.9	33.3	118.5	16.0	135.7	0.0	151.8	151.8	0.0	46.6	105.2
	Suzhou	162.7	184.0	8.8	338.0	4.2	342.5	0.0	346.7	346.7	0.0	12.3	334.5
	Subtotal	**414.2**	**298.4**	**121.7**	**590.9**	**58.6**	**654.0**	**0.0**	**712.5**	**712.5**	**0.0**	**170.2**	**542.4**
Shandong	Ji'nan	51.4	28.5	20.1	59.8	9.7	70.2	0.0	79.9	79.9	0.0	28.1	51.8
	Qingdao	105.8	8.8	70.5	44.1	33.9	80.7	0.0	114.6	114.6	0.0	98.6	16.0
	Zi'bo	18.1	22.1	0.0	40.1	0.0	40.1	0.0	40.1	40.1	0.0	0.0	40.1
	Zaozhuang	58.1	17.7	31.2	44.6	15.0	60.8	0.0	75.8	75.8	0.0	43.7	32.1
	Dongying	114.7	8.5	77.0	46.2	37.1	86.2	0.0	123.3	123.3	0.0	107.7	15.5
	Yantai	36.5	13.9	17.9	32.5	8.6	41.8	0.0	50.4	50.4	0.0	25.0	25.4
	Weifang	26.7	25.0	4.5	47.2	2.1	49.5	0.0	51.7	51.7	0.0	6.2	45.4
	Ji'ning	27.1	33.1	0.0	60.3	0.0	60.3	0.0	60.3	60.3	0.0	0.0	60.3
	Weihai	55.5	43.2	14.4	84.3	6.9	91.8	0.0	98.7	98.7	0.0	20.1	78.6
	Dezhou	66.4	29.5	30.2	65.7	14.5	81.4	0.0	95.9	95.9	0.0	42.3	53.6
	Liaocheng	48.0	27.7	18.1	57.6	8.7	67.1	0.0	75.8	75.8	0.0	25.3	50.4
	Binzhou	69.1	42.3	24.7	86.7	11.9	99.5	0.0	111.3	111.3	0.0	34.5	76.9
	He'ze	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Subtotal	**677.3**	**300.4**	**308.6**	**669.1**	**148.5**	**829.2**	**0.0**	**977.7**	**977.7**	**0.0**	**431.6**	**546.1**
	Total	**1800.3**	**1001.1**	**701.9**	**2099.5**	**337.8**	**2463.6**	**0.0**	**2801.4**	**2801.4**	**0.0**	**981.5**	**1819.9**

Table 24: Water allocation per municipality in $10^6 m^3$ of diversion water, Alternatives 1 – 5, F

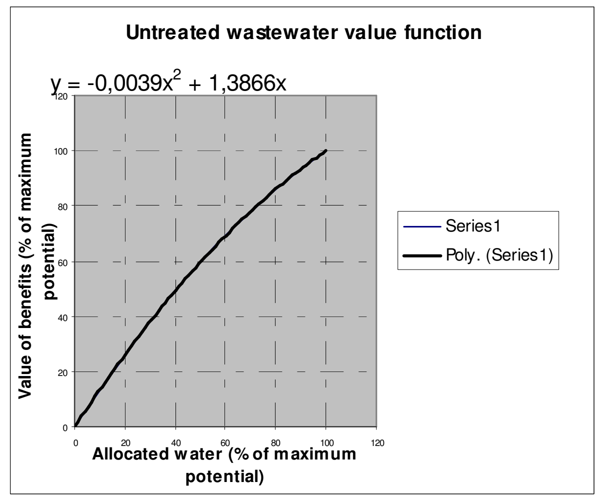
Appendix F
Value functions

This appendix provides an overview of the value functions that have been used for the calculation of the MCA results for every criterion. The grounds for the choice of these functions are provided in section 4.5.1. The last figure shows the value functions that were used to calculate the sensitivity of the value functions; refer to Chapter 5 for more information.

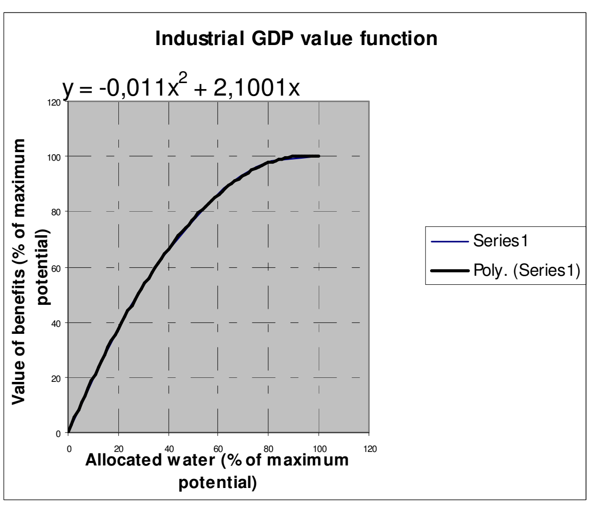
Groundwater:



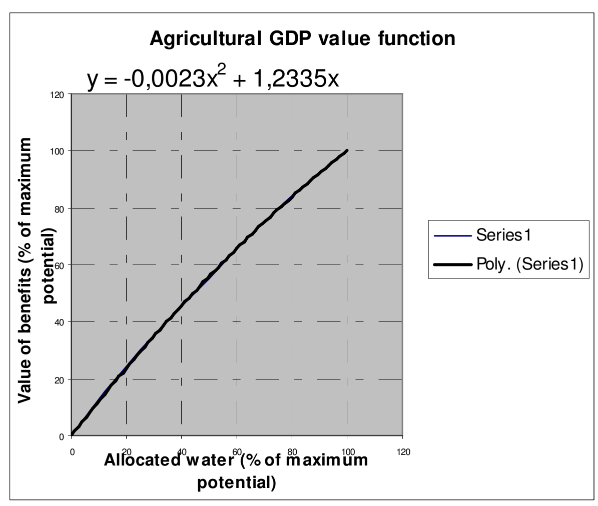
Wastewater:



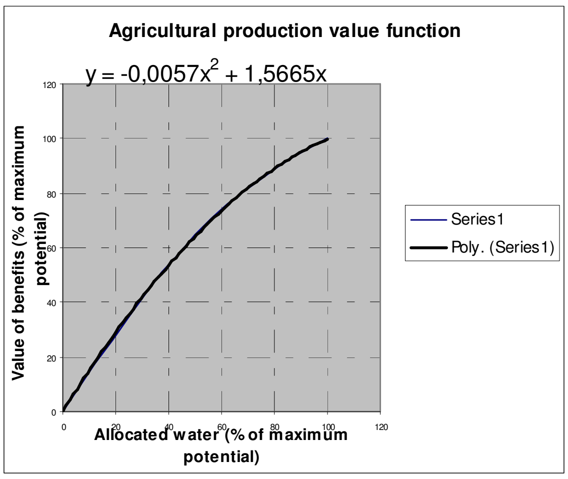
Industrial GDP:



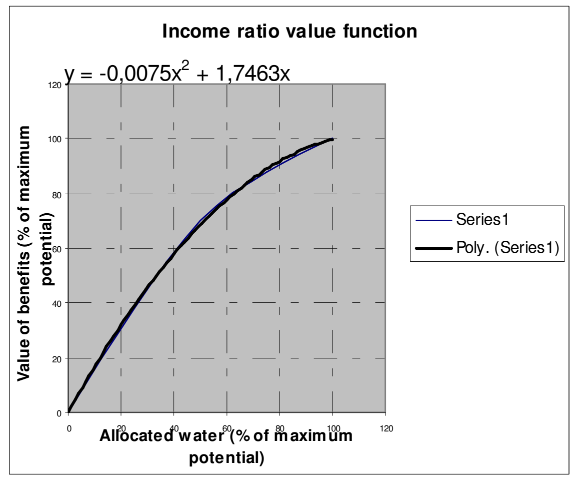
Agricultural GDP:



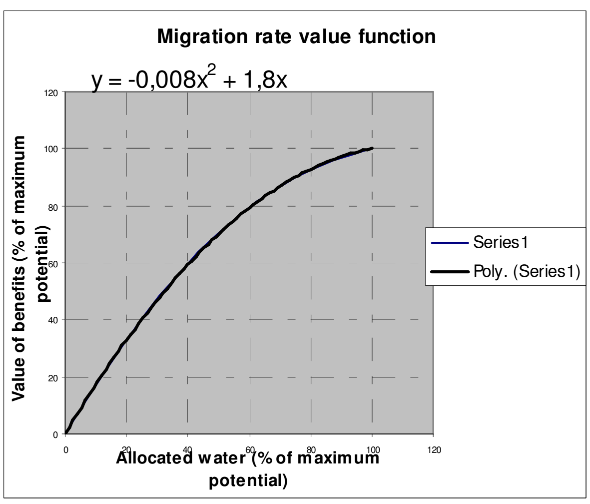
Agricultural production:



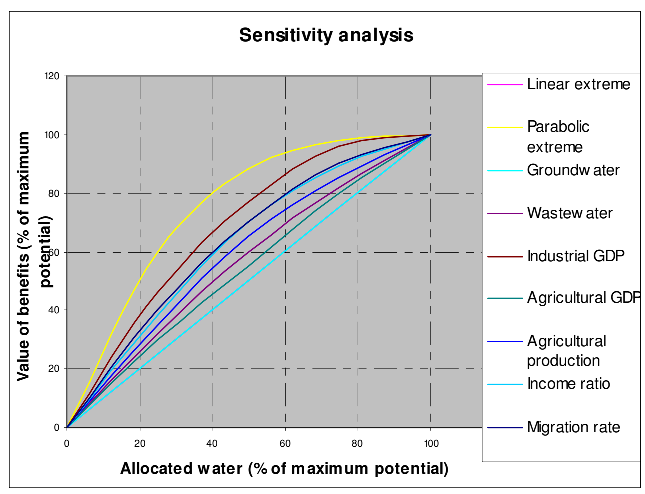
Income ratio:



Migration rate:



Extreme value functions used for sensitivity analysis:



Appendix G
Determining weights

1. Rank the criteria from most important to least important.
2. Imagine a hypothetical alternative with a score of 0 for every criterion except for the criterion ranked 1st, which gets a score of 100. This means, an improvement from worst to best on criterion 1 is weighed as being 100%.
3. Take a look at the criterion ranked 2nd and make a judgment about how much importance should be given to the 2nd criterion, compared with the 1st. This can be done by looking at a swing of criterion 2 from worst to best as compared to a swing of criterion 1 from worst to best. For example, if criterion 2 is given a swing weight of 60, this means that: an improvement from worst to best on criterion 2 is 60% as important as an improvement from worst to best on criterion 1.
4. Do this for every criterion.

Criterion	Unit	Min	Max	difference
Groundwater availability	10^6 m^3 water	4742.2	5502.6	16%
Untreated wastewater *	10^6 m^3 water	3411.6	2682.2	27%
GDP	10^6 yuan	1302077.2	1700486.2	31%
Grain production	1000 tons	49664.5	70649.0	42%
Income ratio	Rural/urban	0.29	0.37	27%
Migration rate*	Change in %	0.00%	-4.79%	5%

* Higher number depicts more negative effect

	Ranked by importance	*Swing weight*
1		
2		
3		
4		
5		
6		

5. Please also indicate preference between industrial GDP growth and agricultural GDP growth. Use the same method as before.

Criterion	Unit	Min	Max	difference
GDP industry	10^6 yuan	1057614.1	1422646.2	35%
GDP agriculture	10^6 yuan	244463.1	277840.0	14%

	Ranked by importance	*Swing weight*
1		
2		

Example
The minimum and maximum values of the criteria in all different alternatives a presented.

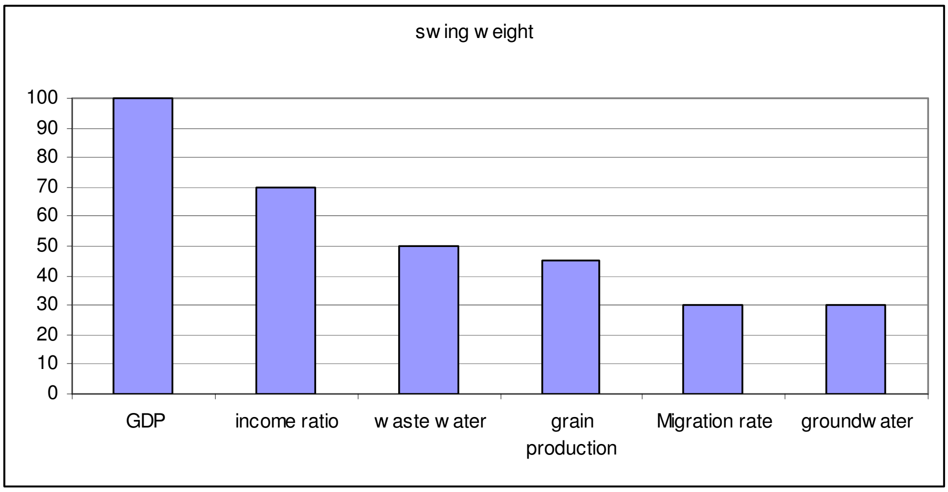
Criterion	Unit	Min = 0	Max = 100	difference
Groundwater availability	10^6 m^3 water	4742.2	5502.6	16%
Untreated wastewater *	10^6 m^3 water	3411.6	2682.2	27%
GDP growth	10^6 yuan	1302077.2	1700486.2	31%
Grain production	1000 tons	49664.5	70649.0	42%
Income ratio	Rural/urban	0.29	0.37	27%
Migration rate*	Change in %	0.00%	-4.79%	5%

The criteria are ranked in preference, by assessing their value and the absolute change.

	Ranking
1	GDP
2	income ratio
3	waste water
4	grain production
5	Migration rate
6	groundwater

GDP receives score of 100 as the top ranked criterion. After that, the second criterion has to be assessed. The movement of GDP from worst to best (from 1302 billion Yuan to 1700 billion Yuan) is compared with the movement of income ratio from worst to best (from 0.29 to 0.37). The decision maker decides that this movement of income ratio from worst to best is worth 70% of the movement from worst GDP to best GDP. Next, he considers waste water, etc., every time keeping the magnitude of the absolute movement in mind.

With all weights assessed, this gives the following overview.



Ranking	swing weight	normalized
GDP	100	0.308
income ratio	70	0.22
waste water	50	0.15
grain production	45	0.14
Migration rate	30	0.09
groundwater	30	0.09
	325	1.00

Appendix H
Alternative Decision-makers

The determination of weights is a very personal matter and will vary from person (or decision-making body) to person. The weights presented in Chapter 4 are just one of an endless number of possible weight distributions. Several senior engineers from the IHWR were asked to determine the weights according to their own opinion. These weights were subsequently used to determine alternative MCA outcomes.

Criterion	Weights A	DM 1	DM 2	DM 3
GDP	100	100	100	100
income ratio	50	80	65	50
waste water	25	60	55	70
grain production	25	50	70	30
groundwater	20	30	40	90
migration rate	10	10	30	50
total	230	330	360	390
industrial GDP	0.8	0.7	0.6	0.7
agricultural GDP	0.2	0.3	0.4	0.3

Table 25: Weights determined by alternative decision-makers (1 – 3)

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt F
Weights A	60.31	**72.21**	70.03	65.09	34.79	71.78
DM1	53.80	76.12	**78.69**	78.62	21.21	72.39
DM2	52.83	76.45	79.81	**80.40**	19.45	72.04
DM3	51.32	76.29	80.40	**81.94**	17.95	71.48

Table 26: Outcomes of MCA for different weight distributions

One thing that immediately becomes clear from observing these results is that there is a lot of variation in which alternative scores best, even with the smallest change in weights. The difference in weights is not very large but the outcome of the MCA differs between the different decision-makers. However, keeping in mind that Alternative 4 is actually a hypothetical alternative (it is not realistic to assume that 100% of the water will go to one sector only), Alternative 3 seems to score better than every other alternative for decision-makers two and three. Nevertheless, it is clear that a slight alteration in the weights can tip the scales from one alternative to another. Therefore, a lot of care has to be taken in actually assessing the weights and once the weights are determined, its sensitivity thresholds should be analysed.

This method of surveying experts on the project on the determination of weights can be extended to a larger group of respondents in order to obtain an amount of data that is statistically analysable. This was discussed in more detail in section 5.6.

List of References

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