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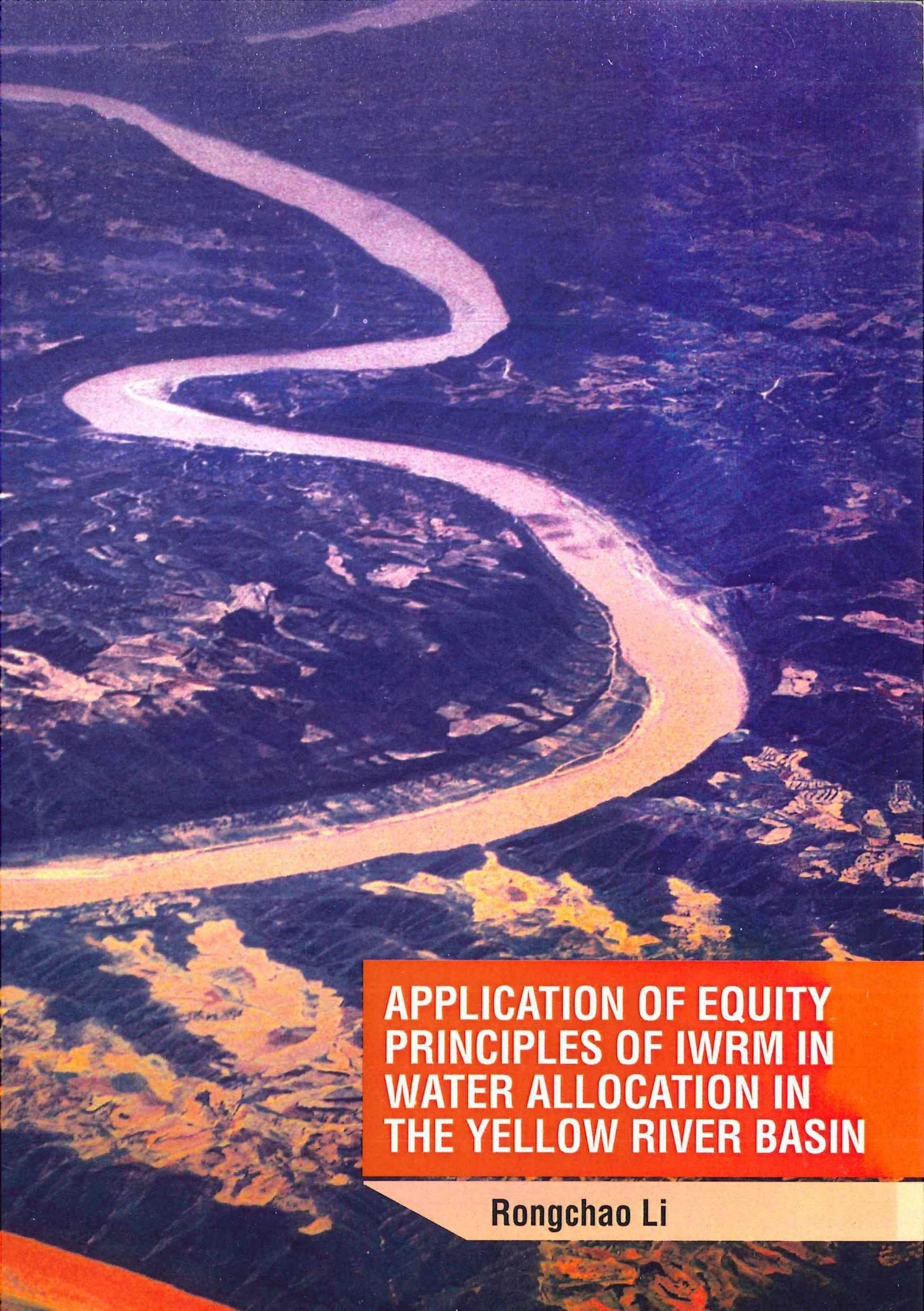

APPLICATION OF EQUITY PRINCIPLES OF IWRM IN WATER ALLOCATION IN THE YELLOW RIVER BASIN

Rongchao Li

Propositions

Propositions with the thesis *Application of equity principles of IWRM in water allocation in the Yellow River Basin* of Rongchao Li, Delft University of Technology, 19 July 2008.

1. It is a fact that rivers were the cradle of first human civilizations. It is not a fiction that rivers could be the tomb of human civilizations if human do not care enough of their rivers.

2. Without an ethical approach, the so called technical and scientific approaches will sometimes cause problems instead of solve them.

3. Awareness raising is not the best way to influence people, but the only way.

4. Public attention becomes powerful when it gains political attention. Political attention becomes powerful when it leads to public action.

5. Miscommunication by speaking a foreign language is sometimes not caused by mispronunciation or misinterpretation but by misassumption.

6. Sometimes it is difficult to draw a line between culture difference and personal opinions. It happens often that culture difference is misused to excuse personal opinions.

7. Immigration policy is not only applied to human society but also to the ecosystem. The immigration policy of integration in the local culture in the Netherlands compares for example with the control of invasive species in the ballast water convention from the International Maritime Organization (http://globallast.imo.org). The similarity is that both policies try to keep the local bio-diversity as original as possible.

8. The Chinese culture encourages individuals to make a choice from the group's point of view, while the Western culture encourages individuals to have their own opinion independent from the group. Therefore, the combination of Chinese and Western cultures offers an opportunity to harmonize the relationship between the group and the individual.

9. Do not do evil things though they may be insignificant. Do not give up good things though they may be minor matters (Chinese saying). If everybody can act like this in his daily life to take care of nature, then the world will be more sustainable.

These propositions are considered defendable and as such have been approved by the supervisor Prof. ir. E. van Beek.

Stellingen

Stellingen bij het proefschrift *Application of equity principles of IWRM in water allocation in the Yellow River Basin* van Rongchao Li, Technische Universiteit Delft, 19 juli 2008.

1. Het is een feit dat de rivier de bakermat was van de eerste menselijke beschavingen. Het is geen fictie dat de rivier het graf kan worden van de menselijke beschaving als de mens niet genoeg voor de rivier zorgt.

2. Bij gebrek aan een ethische benadering, zullen zogenoemde technische en wetenschappelijke benaderingen eerder problemen veroorzaken dan deze op te lossen.

3. Bewustmaking is niet de beste manier om mensen te beïnvloeden, maar de enige.

4. Publieke aandacht wordt krachtig als deze politieke aandacht krijgt. Politieke aandacht wordt krachtig als het tot publieke actie leidt.

5. Soms is het moeilijk om onderscheid te maken tussen culturele verschillen en persoonlijke opvattingen. Het gebeurt vaak dat cultuurverschil wordt misbruikt om persoonlijke opvattingen te verexcuseren.

6. Soms wordt miscommunicatie door het spreken van een vreemde taal niet veroorzaakt door een verkeerde uitspraak of interpretatie, maar door een verkeerde veronderstelling.

7. Immigratie politiek wordt niet alleen toegepast op de maatschappij maar ook op het ecosysteem. Het beleid om te integreren in de locale cultuur in Nederland komt bijvoorbeeld overeen met de controle op vreemde soorten volgens de ballastwater conventie van de Internationale Maritieme Organisatie (http://globallast.imo.org). De overeenkomst is dat beide de locale biodiversiteit zo oorspronkelijk mogelijk proberen te houden.

8. De Chinese cultuur moedigt het individu aan om een keuze te maken uit de opvattingen van de groep, terwijl de westerse cultuur het individu aanmoedigt om een mening te hebben onafhankelijk van de groep. Daarom biedt de combinatie van de Chinese en de westerse cultuur de mogelijkheid om de relatie tussen de groep en het individu te harmoniseren.

9. Doe geen slechte dingen ook al zijn ze onbetekenend. Laat de goede dingen niet na ook al zijn ze slechts klein (Chinees gezegde). Als iedereen dit kan doen in zijn dagelijkse leven met betrekking tot de natuur, dan zou de wereld duurzamer zijn.

Deze stellingen worden opponeerbaar en verdedigbaar geacht en zijn als zodanig goedgekeurd door de promotor Prof. ir. E. van Beek.

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Application of equity principles of IWRM in water allocation in the Yellow River Basin

Cover: Dragon jumping over the Plateau (The Loess Plateau in Yanchuan County of Shaanxi Province), by Hui Huaijie, Scenes in the Yellow River, Yellow River Conservancy Press, Zhengzhou, China, 2003

Application of equity principles of IWRM in water allocation in the Yellow River Basin

Proefschrift

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus prof. dr. ir. J.T. Fokkema,
voorzitter van het College voor Promoties,
in het openbaar te verdedigen
op dinsdag 9 september 2008 om 15:00 uur
door

Rongchao LI

Master of engineering aan de Hohai University, Nanjing, China
geboren te Hai'an, Jiangsu province, China

Dit proefschrift is goedgekeurd door de promotor:
Prof. ir. E. van Beek

Samenstelling promotiecommissie:

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.....to my mother

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Last but not least, I would like to express my special gratitude to my family in Delft and in China for their continuous support and encouragement.

Rongchao Li
Delft, July 2008

Abbreviations

ADB	Asian Development Bank
AGWAT	AGricultural WATer demand model
AIS	Administrative and Institutional System
ASCE	American Society of Civil Engineers
BAHC	Biospheric Aspects of the Hydrological Cycle
BAU	Business As Usual
BCM	Billion Cubic Meter
CAS	Chinese Academy Of Sciences
CERES	California Environmental Resources Evaluation System
CSIR	the Council for Scientific and Industrial Research in Africa
DMI	Domestic Municipal and Industrial
DWAF	Department of Water Affairs and Forestry (in South Africa)
FAO	Food and Agriculture Organization of the United Nations
GCMs	Atmospheric Global Circulation Models
GDP	Gross Domestic Product
GW	Ground Water
HMSO	Her Majesty's Stationery Office
IFPRI	Initiative of the International Food Policy Research Institute
IHP	International Hydrological Programme
IIASA	International Institute for Applied Systems Analysis
IRRI	Irrigation
IWA	International Water Association
IWHR	Institute of Water Hydraulics Research
IWMI	International Water Management Institute
IWRM	Integrated Water Resources System
MWR	Ministry of Water Resources
NCWR	Net Crop Water Requirements
NRS	Natural Resource System
PCCP	Potential Conflict to Cooperation Potential
PWS	Public Water Supply (Note: in this study PWS is similar to DMI)
RIBASIM	RIver BAsin SImulation Model
RMB	Ren Min Bi, Chinese currency unit
SDPC	State Development Planning Commission
SES	Socio-Economic System
SW	Surface Water
SWIM	System-Wide Initiative on water Management
UNCED	the United Nations Conference on Environment and Development
UNESCO	United Nations Educational, Scientific and Cultural Organization
WCED	World Commission on Environment and Development
WRPM	Water Resources Planning and Management
WWAP	World Water Assessment Programme
YR	Yellow River
YRB	Yellow River Basin
YRCC	Yellow River water Conservancy Commission
YRCC PDSB	YRCC Planning, Design and Survey Bureau
YRSIM	Yellow River water resources SImulation Model developed by YRCC Planning, Design and Survey Bureau

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Summary

The 21st century is a new era for integrated water allocation in the Yellow River Basin in China. For the first time the Yellow River Conservancy Commission (YRCC) is putting into practice an inter-provincial water allocation scheme with the intention that no zero flow situations will occur anymore in the downstream part of the river. These zero flow situations result from the serious water shortages in this basin caused by increased withdrawals by the provinces. This scheme, named as the '1987 Scheme', was already approved by the State Council early in 1987 (as the name suggests), but not implemented yet. The 1987 Scheme gives high priority to environmental flow demands (mainly for sediment flushing) in the downstream part of the river and regulates the annual surface water withdrawal quantity for the nine provinces in the basin and the two regions outside the basin. Although zero flow was indeed prevented as of the year 2000, the 1987 Scheme was not considered successful. The reasons for that were the huge (and increasing) gap between supply and demand, and the different opinions of the stakeholders involved on the allocation of the water. An appeal for the application of the concepts of Integrated Water Resources Management (IWRM) was made with a particular focus on the alleviation of the conflicts among provinces and between human and nature in this basin.

What can we learn from history? The Yellow River has a history as long back as the 21st century BC with colourful but also painful periods of human's survival from frequently occurring natural disasters such as floods and droughts. Re-examination of its water management history and a deep reflection of culture, philosophy, science and technology applied by the people to live with floods and to prevent floods in this specific basin, might be the starting point of a wise application of the concepts of IWRM in the Yellow River. Those thoughts of reflections should be linked with the current modern water allocation practices in this basin and to other IWRM experiences around the world. It is then perceived that an ethical approach should be (re-)established in the basin, providing a proper philosophical basis for IWRM. This ethical approach should be combined with a scientific and technical approach which should be seen as the embodiment of the philosophical base. The combined two approaches will provide an in-depth understanding and an innovative perspective on how to wisely apply the concepts of IWRM and to formulate a rational inter-provincial surface water allocation scheme to mitigate the conflicts among provinces and to harmonize human and environment in the basin.

The ethical approach proposed in this thesis is based on the return of the indigenous Taoism philosophy in the Yellow River. Taoism is in favour of the harmoniousness of human and nature and let nature follows its way. Particularly, Taoism also pursues equity and this equity can provide a base to avoid the conflicts on water allocation. Taoism philosophy should replace the other prevailing indigenous Confucian philosophy which is more control oriented (harnessing the river) and which basically was the management philosophy for the basin in the last decades.

Both approaches have alternately dominated the flood management history in the river.

Next, the thesis explores the possibility to interpret the Taoism based ethical approach into operational steps in water allocation. The Taoism approach stands for application of equity principles of IWRM with the consideration of 'reserve water' taken out of the water allocation negotiation to guarantee vital ecosystem health and primary human water needs. Alternative inter-provincial surface water allocation guidelines are created by defining different equity criteria (i.e. in proportion of the provincial population, the present provincial water demand or the provincial catchment area) combined with various sets of reserve water components (i.e. environmental low flow, environmental low flow plus domestic water demand, or environmental low flow plus domestic, municipal and industrial water demand).

The proposed scientific and technical approach consists of the development of a water allocation model to simulate various possible water allocation schemes in the Yellow River basin. A schematization of the study area was made in which the nodes represent physical entities in the basin and the links represent the connections between them. The supply side includes variable inflow nodes presenting natural runoff and groundwater reservoir nodes presenting groundwater aquifers. Water demand includes public and industrial water supply nodes and irrigation nodes. Along the main channel, key mainstream reservoirs are included as well as flow constraints and losses (i.e. ice-jam flood control, low flow requirement, channel seepage, etc). Analysis showed that available time series of climatological conditions proved to represent the dry and wet years occurring in the basin very well. The system, including water availability, water demand and the performance of the backbone (= main) reservoirs, were analysed and calibrated for several historical years. The model includes a detailed description of irrigation (the main water user) with variable cropping calendars and cropping patterns, irrigation efficiencies, effective rainfall utilization, etc. The validated water allocation model can be used as analysis tool to gain overall and detailed information on the water allocation in the Yellow River under alternative management schemes.

The scientific and technical approach was combined with the ethical approaches by using different inter-provincial water allocation guidelines for the design of equitable inter-provincial water allocation schemes. The allocation algorithm of those guidelines is simple and straightforward and provides flexibility for policy makers and provinces to update equitable schemes under changing hydrological, social economic and demographic conditions.

The resulting allocations were analysed with a river basin model, taking into account the current and projected water demands, the interaction among provinces, the hydrological regime, storage possibilities and infrastructural capacities. Compared to the 1987 Scheme and projections based on a business-as-usual scenario (case BAU) it appeared that some of the equitable schemes indeed can increase the overall provincial economic benefits. On the other hand, the calculations also revealed that a certain amount of provincial surface water apportionments from these schemes (and from the 1987 Scheme) can not be fully realized under the current engineering conditions (capacity constraints, etc.) and the projected water use patterns. Looking at economic benefits only, these equitable schemes are very promising to replace the

1987 Scheme. At the same time they help to mitigate the conflicts among provinces. This shows the successfulness of the combined two approaches in the context of IWRM.

A detailed analysis of the results of the calculations at basin level clarified critical contradictions in the provincial benefits from the equitable schemes compared to the 1987 Scheme and the BAU case. The positions from a basin point of view (YRCC) and from the individual province of view will be clearly different. These contradictions on basin cooperation can be illustrated by a diagram in which the basin preference is marked by a number and the preference of the provinces is presented by their attitude. The basin preference is simply a sorting of the results based on the total economic benefits of the water allocation (from highest to lowest). The provincial attitude is categorized in: supportive, standing by, slightly against, against and strongly against. Such cooperation analysis diagram can help YRCC to easily clarify the main conflicts involved and can help the provinces to become aware of the point of view of YRCC who looks at the whole basin.

Unfortunately but not surprisingly, consensus can not be easily reached by all the provinces, also not for the preferred equitable scheme due to the large gap between water demand and supply. To reach basin cooperation, three surface water compensation mechanisms are proposed that make use of the unrealized surface water apportionments from an equitable scheme. This was done based on a realistic interpretation of the opinions from the economic affected provinces (i.e. whose economic benefit is less than that from the 1987 Scheme). They i) would *claim* to uphold their provincial economic benefit from the 1987 Scheme, ii) would *claim* to uphold their provincial surface water allocation quantity from the 1987 Scheme, or iii) would *insist* on the realized 1987 Scheme. For the first two mechanisms, the allocation of unrealized surface water to the economic affected provinces was determined iteratively based on a combination of an optimization algorithm and the river basin simulation. The third surface water compensation mechanism did not require an optimization routine. Each surface water compensation mechanism is followed by a direct economic compensation of the remaining 'damages' that economic affected provinces still suffer from the new scheme. Such compensation would mean a transfer of money from economic benefited provinces (whose economic benefit is higher than that from the 1987 Scheme) to the economic affected provinces.

The combination of the ethical approaches and scientific and technical approaches has resulted in several acceptable compensated equitable inter-provincial water allocation schemes. The equity objectives can be made compatible to the economic objectives and the environmental sustainability is not affected. Such compensated equitable schemes can be used to ensure basin cooperation under the condition that all provinces agree on a certain equity guideline (a combination of a certain equity criteria and a certain composition of reserve water). Compared to the 1987 Scheme, all provinces will be satisfied after compensation and are motivated for basin cooperation. It is therefore concluded that the compensated equitable schemes could replace the 1987 Scheme to mitigate the water shortage deduced conflicts among the provinces in the Yellow River basin. It is also suggested to develop a strong institutional capacity and proper legislation to facilitate and stimulate the provinces to obey to these schemes.

In the end, it is concluded that ethical approaches combined with scientific and technological approaches can result in a successful integrated water allocation for the Yellow River basin. It is believed and shown that a harmonized relation between human and nature is possible by combining the two approaches in the Yellow River.

Samenvatting

Met de 21ste eeuw is een nieuw tijdperk aangebroken voor integraal waterbeheer in het stroomgebied van de Gele Rivier in China. Het is voor het eerst dat de Yellow River Conservancy Commission (YRCC) een inter-provinciaal water allocatie schema in de praktijk brengt dat als doel heeft het droogvallen van de benedenloop van de rivier te voorkomen. Dit droogvallen is het resultaat van ernstige watertekorten in het stroomgebied veroorzaakt door de toegenomen water onttrekkingen van de provincies. Dit schema, het '1987 Schema' genoemd, was al in 1987 goedgekeurd door de overheid (zoals de naam al aangeeft), maar nog niet geïmplementeerd. Het 1987 Schema geeft een hoge prioriteit aan een minimum 'Environmental flow' in de rivier (voornamelijk voor het doorspoelen van sediment) en reguleert de jaarlijks gevraagde hoeveelheid oppervlakte water van de negen provincies in het stroomgebied en de twee regio's buiten het stroomgebied. Hoewel vanaf het jaar 2000 het droogvallen inderdaad werd voorkomen, wordt het 1987 Schema niet als een succes beschouwd. De redenen hiervoor zijn dat er een groot (en toenemend) verschil is tussen vraag en aanbod en dat de betrokken belanghebbenden verschillende meningen hebben over de watertoedeling. Een oproep is gedaan voor het toepassen van de concepten van integraal waterbeheer met als doel het verminderen van de conflicten tussen de provincies en tussen mens en natuur.

Wat kunnen we leren van het verleden? De Gele Rivier heeft een geschiedenis die teruggaat tot de 21ste eeuw BC, met kleurrijke, maar ook pijnlijke perioden in de menselijke strijd om het bestaan met veel voorkomende natuurrampen als droogte en overstromingen. Bestudering van de geschiedenis van het beheer van de rivier en reflectie op cultuur, filosofie, wetenschap en techniek, toegepast door de mensen die moesten leven met de overstromingen en droogtes, zou een startpunt kunnen zijn voor de toepassing van concepten van integraal waterbeheer in het stroomgebied van de Gele Rivier. Deze reflectie zou gekoppeld moeten worden aan moderne water allocatie methoden in het stroomgebied en ervaringen met integraal waterbeheer vanuit de gehele wereld. Een ethische benadering in het stroomgebied zou (her-) ingevoerd moeten worden als filosofische basis voor integraal waterbeheer. Deze ethische benadering gecombineerd met een wetenschappelijke en technische benadering zouden gezien moeten worden als de belichaming van de filosofische basis. Het combineren van twee benaderingen zal een dieper begrip en nieuw perspectief geven over hoe de concepten van integraal waterbeheer en een rationeel inter-provinciaal oppervlaktewater toewijzingsschema toegepast kan worden om de conflicten tussen de provincies te verminderen en mens en milieu in het stroomgebied te harmoniseren.

De ethische benadering als voorgesteld in dit proefschrift is gebaseerd op de terugkeer van de oorspronkelijk Taoistische filosofie in het stroomgebied. Taoisme staat voor harmonie tussen en mens en natuur en de natuur haar eigen weg te laten volgen. Met name staat Taoisme ook voor rechtvaardigheid en het uitgangspunt van rechtvaardigheid kan als basis dienen om conflicten over de toewijzing van water te vermijden. De Taoistische filosofie zou de andere overheersende Confusciaanse

filosofie, die meer controle gericht is (benutting van de rivier) en wat de feitelijke filosofie voor de management van het stroomgebied van de afgelopen decennia was, moeten vervangen. Beide aanpakken zijn afwisselend dominant geweest in de geschiedenis van het hoogwaterbeheer van de rivier.

Vervolgens onderzoekt het proefschrift de mogelijkheid tot interpretatie van de op het Taoisme gebaseerde ethische benadering voor operationele stappen in de toewijzing van water aan de provincies. De Taoistische benadering staat voor toepassing van rechtvaardigheidsprincipes in integraal waterbeheer, waarbij een hoeveelheid 'gereserveerd water' benodigd voor een vitaal ecosysteem en voor primaire menselijke waterbehoefte buiten de onderhandelingen wordt gelaten. Verschillende inter-provinciale water toewijzingsrichtlijnen zijn uitgezet volgens verschillende rechtvaardigheids-principes (b.v. proportioneel met de provinciale bevolking, het huidige provinciale waterverbruik of de oppervlak van de provinciale) gecombineerd met verschillende samenstellingen van gereserveerd water (zoals alleen voor ‘Environmental flow’, voor ‘Environmental flow’ en drinkwater en voor ‘Environmental flow’, drinkwater en industriewater).

De voorgestelde technisch/wetenschappelijke aanpak bestaat uit de ontwikkeling van een water toedelingsmodel waarmee de verschillende toewijzingschema’s voor het stroomgebied van de Gele Rivier geanalyseerd kunnen worden. In het model van het bestudeerde gebied worden de fysische componenten (reservoirs, onttrekkingspunten, etc.) van het systeem voorgesteld door knooppunten en de verbindingen tussen deze componenten door takken. De aanvoerkant omvat variabele instroom knopen die de natuurlijke toevoer weergeven en grondwater reservoir knopen die de grondwater aquifers weergeven. De vraag naar water is weergegeven in drink en industriële water knopen en voor de landbouw in irrigatie knopen. In de rivierbeschrijving zijn de belangrijkste reservoirs opgenomen evenals de diverse beperkingen en verliezen in het systeem (zoals ijsdammen, minimale ‘environmental flow’, wegzijging, etc). Analyse liet zien dat de beschikbare tijdreeks van klimatologische omstandigheden in het stroomgebied zowel de droge als de natte jaren goed weergeven. Het systeem, inclusief de water beschikbaarheid, de water vraag en gedrag van de belangrijkste reservoirs zijn geanalyseerd en gekalibreerd voor verscheidene historische jaren. In het model zit ook een gedetailleerde beschrijving van de irrigatie (de belangrijkste waterverbruiker) met variabele gewaskalenders en gewaspatronen, irrigatie efficiëntie, regenwater benutting, etc. Het gevalideerde model is daarmee geschikt als analyse instrument om zowel een overzicht als ook gedetailleerde informatie te verkrijgen van de effecten van verschillende toewijzingsschema’s in het stroomgebied.

De bovenbeschreven technisch/wetenschappelijke benadering gecombineerd met de ethische benadering voor inter-provinciale watertoewijzingsrichtlijnen is gebruikt om rechtvaardige inter-provinciale watertoewijzingsschema's te ontwerpen. Het toewijzings-algoritme is eenvoudig en rechttoe-rechtaan en laat flexibiliteit toe voor de beleidsmakers en provincies om de rechtvaardige schema's bij te werken bij veranderende hydrologische, sociaal-economische en demografische omstandigheden.

De resulterende toewijzingen werden gesimuleerd in het water toedelingsmodel, rekening houdende met het huidige en geprojecteerde waterverbruik, de interacties tussen de provincies, het hydrologische regime, de opslag mogelijkheden in reservoirs en de capaciteit van de infrastructuur. Vergeleken met het 1987 Schema en de projecties gebaseerd op het "business-as-usual" scenario (case BAU) blijkt dat de rechtvaardige schema's voor het stroomgebied in zijn totaal economische voordelen opleveren. Aan de andere kant laten de berekeningen ook zien dat een gedeelte van de provinciale oppervlaktewater toewijzingen van deze schema's (en van het 1987 Schema) niet volledig gerealiseerd kunnen worden met de huidige technische voorzieningen (capaciteitsbeperkingen) en geprojecteerd waterverbruik. Alleen kijkend naar de economische voordelen zijn de rechtvaardigheidsschema's veelbelovend om het 1987 Schema te vervangen en tegelijk de conflicten tussen de provincies te verminderen. Hiermee is het succes aangetoond van het combineren van de twee benaderingen in de context van integraal waterbeheer.

Een gedetailleerde analyse van de berekeningsresultaten op stroomgebied niveau laat een aantal kritische tegenstellingen zien in de provinciale baten van de diverse rechtvaardigheidsschema's vergeleken met het 1987 Schema en de BAU case. Op basis daarvan zullen de standpunten tussen YRCC (die het stroomgebied in zijn totaal beschouwd) en die van de individuele provincies duidelijk verschillen. Deze tegenstellingen kunnen geïllustreerd worden middels een diagram waarin de voorkeur voor het stroomgebied als totaal wordt aangegeven met een nummer en de voorkeur van de provincie door hun houding. De voorkeur van het stroomgebied is simpelweg de ordening van de resultaten gebaseerd op het totale economische voordeel van de water toewijzing (van hoog naar laag). De houding van de provincie wordt ingedeeld als: meewerkend, goedkeurend, enigszins tegen, tegen en sterk tegen. Een dergelijk samenwerkingsanalyse diagram kan de YRCC helpen om op een eenvoudige wijze de belangrijkste conflicten te verhelderen en kan de provincies helpen om bewust te worden van het standpunt van de YRCC die naar het hele stroomgebied kijkt.

Helaas, maar nauwelijks verrassend, kan er niet altijd consensus worden bereikt door alle provincies, zelfs niet voor het geprefereerde rechtvaardigheidsschema vanwege het grote verschil tussen water vraag en aanbod. Om coöperatie binnen het stroomgebied te bereiken worden er 3 oppervlaktewater compensatiemechanismen voorgesteld die gebruik maken van de onbenutte oppervlaktewater toewijzingen in de diverse rechtvaardigheidsschema's. Dit is gedaan op basis van een realistische interpretatie van de opstelling van de economisch meest getroffen provincies (ofwel diegenen die minder voordeel hebben dan onder het 1987 Schema). Deze provincies kunnen i) hun provinciale economische voordeel onder het 1987 Schema claimen, ii) hun provinciale oppervlaktewater toewijzing onder het 1987 Schema claimen, of iii) staan op hun provinciale toewijzing volgens het gerealiseerde 1987 Schema. Deze verschillende opstellingen zijn doorgerekend op hun effecten. Voor de eerste twee opstellingen werd de toewijzing van onbenut oppervlaktewater aan de economisch getroffen provincies iteratief bepaald door een optimalisatie algoritme met de rivier stroomgebied simulatie te combineren. Om het derde compensatiemechanisme te testen was er geen optimalisatie routine nodig. Iedere oppervlaktewater compensatie mechanisme wordt aangevuld met directe economische compensatie van de resterende 'schade' van de door het nieuwe schema economisch getroffen provincies. Een dergelijke compensatie zou een overdracht van geld inhouden van de provincies die economisch gezien profiteren (ten opzichte van het 1987 Schema) naar de economisch getroffen provincies.

De combinatie van de ethische benadering met de technisch economische benadering hebben geresulteerd in acceptabele gecompenseerde rechtvaardige inter-provinciale water toewijzingsschema's. De rechtvaardigheidsdoelstellingen kunnen worden verenigd met de economische doelstellingen en de milieudoelstelling wordt niet aangetast. Dergelijke gecompenseerde rechtvaardigheidsschema's kunnen gebruikt worden om te zorgen dat samenwerking binnen het stroomgebied gerealiseerd wordt mits alle provincies het eens kunnen worden over de rechtvaardigheidsrichtlijn (een combinatie van bepaalde rechtvaardigheidscriteria en een samenstelling van gereserveerd water). Vergeleken met het 1987 Schema zullen alle provincies tevreden en gemotiveerd zijn voor samenwerking binnen het stroomgebied. Daarom kan geconcludeerd worden dat het gecompenseerde rechtvaardigheidsschema het 1987 Schema kan vervangen om conflicten tussen provincies in het Gele Rivier stroomgebied, veroorzaakt door watertekorten te verminderen. Verder wordt voorgesteld om een sterke institutionele capaciteit en wetgeving te ontwikkelen die dit proces moet faciliteren en moet stimuleren dat de provincies zich ook aan deze schema's houden.

Tot besluit kan geconcludeerd worden dat een ethische benadering gecombineerd met een technisch/wetenschappelijke benadering kan leiden tot succesvolle geïntegreerde water toewijzingschema’s voor het stroomgebied van de Gele Rivier. Aangetoond is dat een geharmoniseerde relatie tussen mens en natuur mogelijk is door het combineren van de twee benaderingen voor de Gele Rivier.

1 Introduction

1.1 Introduction of the Yellow River

Known as the Cradle of Chinese Nation, the Yellow River (YR) is the second largest river in China next to the Yangtze River. The YR originates in the Yueguzonglie area in western China, winds its way to the east, cuts through the Loess plateau from north to south, bends east across the Huang-Huai-Hai plain, and finally empties into Bohai Sea (see Figure 1.1). The Yellow River Basin (YRB) is located between 96°~ 119° longitude and between 32°~ 42° latitude. The river is 5,464 km in length, has a water level difference of 4,480 m and drains an area of 795,000 km^2 (8.28 % of China). The basin includes a closed inland basin of 42,000 km^2.

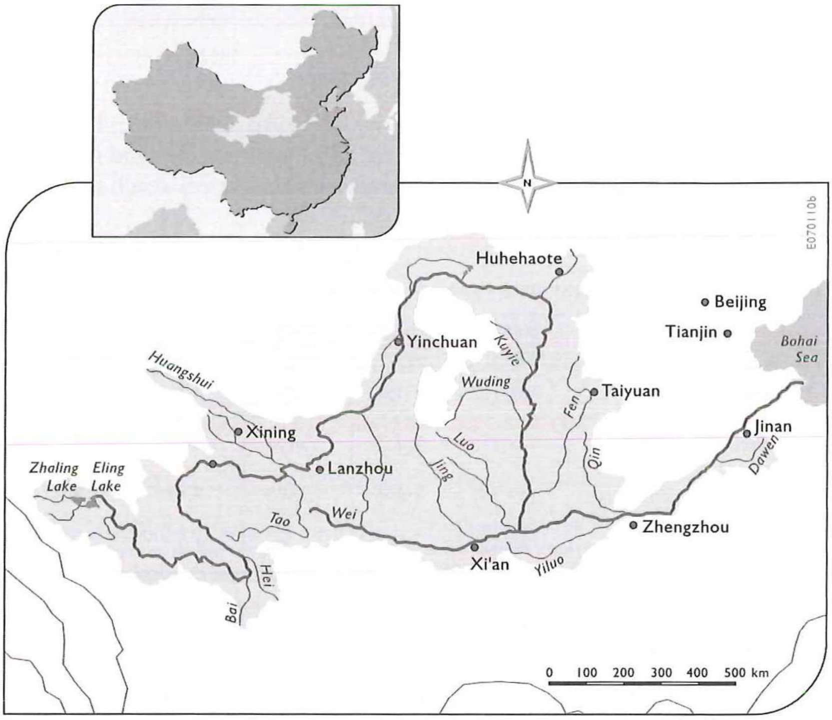


Figure 1.1 Map of the Yellow River Basin

The YRB involves 9 provinces: Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Henan and Shandong (see Figure 1.2). The total population of the YRB in 2001 was 97,8 million (including the interior basin, YR Water Resources Bulletin, 2001) which is 8.5% of the national population. The average population density is 123 per km^2, a bit higher than the national average level. The YRB capita gross domestic product (GDP) is 4533 Yuan RMB (about 580 US $).

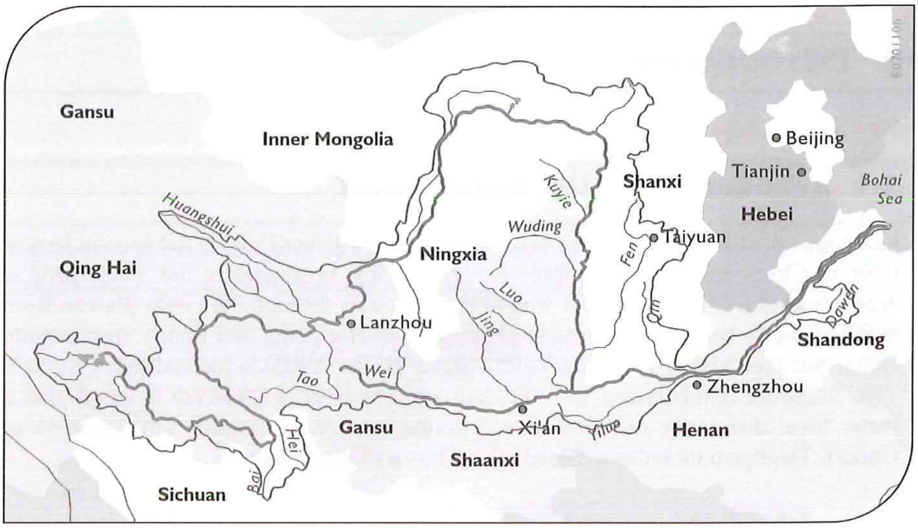


Figure 1.2 Provinces in the Yellow River Basin

According to the geographic, geological and hydrological conditions, the main stream of YR can be divided in the Upper, Middle and Lower reaches and is further divided in 11 sections (see Figure 1.3). The characteristics of every reach are listed in Table 1-1 (Wu et al, 1998).

Table 1-1 Characteristics of different main stream sections of the YR

River reach	Section	Area $(km^2)^1$	Length (km)	Drop $(m)^2$	Gradient $(^{0}/_{000})$	Number of tributaries[3]
Whole river	Source - Estuary	794,712	5,464	4480	8.2	76
Upper reach	Source - Hekouzhen	428,235	3,472	3496	10.1	43
Middle reach	Hekouzhen - Taohuayu	343,751	1,206	890	7.4	30
Lower reach	Taohuayu - Estuary	22,726	785	94	1.2	3

[1] Basin area includes the interior basin.
[2] The drop in water level is calculated based on the upper mouth of the Yueguzonglie basin.
[3] tributaries with a catchment area larger than 1000 km^2

The upper reach of the YR is from the river source to Hekouzheng (Toudaoguai). The upper reach is rich in hydropower resources and some hydropower and conservation projects are constructed. The Qingtongxia and Sanshenggong conservation projects supply YR water to the large scale irrigation districts in Ningxia and Inner Mongolia, jointly indicated as the Ning-Meng Hetao Irrigation District. These irrigation areas are considered in China as important crop 'bases'. The areas have good irrigation conditions and provide abundant land resource.

Figure 1.3 Reaches of the Yellow River

The section from Hekouzhen to Taohuayu (near Huayuankou) is the Middle reach of the YR. Between Hekouzhen and Yumenkou (near Longmen), the YR flows through the Loess Plateau. The severe soil erosion in this plateau (surface area 454,000 km^2) results in an annual sediment loan of 0.9 billion ton, 56% of the entire river sediment load of the river. Between Yumenkou and Tongguan the Weihe River joins the YR. the Weihe is the largest tributary of the YR. The Weihe plain contains the Fen-Wei Irrigation District, one of the highest productive crop areas of the country. The last part of the middle reach, downstream from the Xialongdi dam, is still mainly uncontrolled by reservoirs and is the main cause of the floods in the lower reach.

The YR lower reach, from Taohuayu to the sea outlet, is a rather narrow strip consisting mainly of the river itself and its floodplains, bordered by high dykes. Because of the deposition of huge sediment loads, the river bed has risen gradually between the dykes for centuries. At present, the river bed is already 3~5m higher than the land level behind the dikes, making the YR known in the world as the "suspended" river (see Figure 1.4). As a result of the high sediment load at the estuary each year, an average of 25~30 km^2 additional delta area is created. A sophisticated flood control system has succeeded in preventing major flooding during the last 50 years. The lower reach of the YR also supplies water to another national crop base, the YR Lower Reach Diversion Irrigation District which actually is mainly located outside the basin.

There are totally 36 reservoirs between the section of Longyangxia and Taohuayu with an entire storage of 100.7 billion m^3, a utilized water head of 1930 m, an installed hydropower capacity of 24.93 million kW, and an annual hydropower generation of 86.2 billion kWh. Among them, Longyangxia, Liujiaxia, Luhun, Guxian, Sanmenxia and Xiaolangdi are the main projects, each with a storage capacity of over 1 billion m^3. Their total storage is 56.3 billion m^3, an installed capacity 8.92 million kW and an annual hydropower generation of 33 billion kWh. Through the combined regulation of these reservoirs, tremendous benefits have been realized with respect to flood control (storm flood and ice-jam flood), public water supply, irrigation, hydropower generation, sediment regulation, etc.

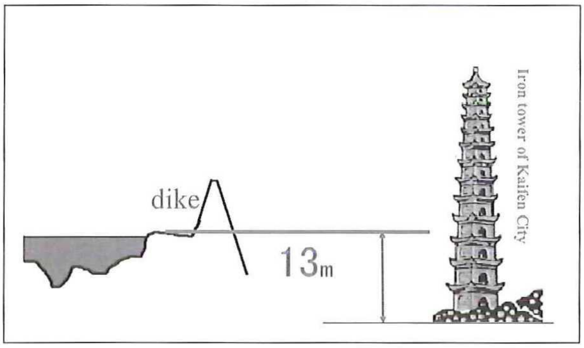


Figure 1.4 Suspended river in the Lower Reach of the YR

As indicated above, the sedimentation in the downstream channel is very high. That sedimentation in the lower reach is a result of an inharmonious water and sediment relationship. Some of the key multipurpose reservoirs on the main stream in the middle reach are designed and constructed to address that issue. They are not only used to meet the needs of farmland irrigation and power generation, but also to enable a 'flushing' release to scour the lower reach of the Yellow River. Among them, the Xiaolangdi reservoir (completed in 2000) is in particular constructed for that purpose. Located at a key position to regulate water and sediment, Xiaolangdi reservoir controls 91% of the runoff and nearly 100% of sediment of the Yellow River. Xiaolongdi is able to adopt various operational modes for water and sediment regulation to increase the sediment carrying capacity of the channels in the YR lower reach, aiming to transport more sediment to the sea. Because the reservoir has a large capacity for sediment interception, its function to regulate water and sediment can be continued for a fairly long period. When its sediment retention capacity is filled up in 30 years, Xiaolongdi will turn into its 'normal' operation and shall still have an effective storage to be used for water and sediment regulation (YRCC, 2001; YRCC, 1998).

1.2 Water shortage in the YR

It is generally recognized that water shortage has become a major bottleneck for the socio-economic development in the YR area and water shortage has become the top issue of water resources management in the basin, in addition to flooding, water quality degradation or environmental deterioration. The major causes of the YR water shortage are described below.

Limited water resources availability

Located mostly in arid and semi-arid areas, the YR gross water availability is 70.7 billion m^3, in which the surface water (SW) availability is 58.0 billion and the net groundwater (GW) availability is 12.7 billion, see Table 1-2. The average water availability per capita in the YRB is 593 m^3 while the availability per hectare is 4860

m^3, only 1/3 and 1/5 of the national values respectively. Obviously, the YR has limited water resources although it is the second largest river in China.

Table 1-2 Gross water quantity in the YR (billion m^3)

River Reach	SW quantity	GW quantity	Overlap quantity[1]	Gross water quantity
Yellow River basin	58.0	39.2	26.5	70.7
Closed internal basin	-	1.2	-	1.2
Entire basin	58.0	40.4	26.5	71.9

[1] The 'overlap quantity' is groundwater that is recharged from surface water.
Source: Chang et al, 1998

The annual natural runoff is 58 billion m^3 in the YRB, see Table 1-3. While this is less than 3% of the national water resources, the YR is accounted to supply water for 11% of the national population and 13% of the irrigation area in China. As the largest water source in the driest part of China (Northwest and North China), the YR does not only supply water to users in the basin but also to some regions and cities outside the basin, such as the YR Lower Reach Diversion Irrigation District in Hebei and to the city of Tianjin. Given such heavy task of water supply, the YR is apparently short of water.

Table 1-3 Annual natural runoff in the YRB (56 years from 1919-1974)

River reach	Catchment area (km^2)	% of basin area	Annual natural runoff (billion m^3)	% of basin annual runoff
Upstream Lanzhou	222,551	29.6	32.3	55.6
Lanzhou-Hekouzhen	163,415	21.7	-1.0	-1.7
Hekouzhen-Longmen	111,591	14.8	7.2	12.5
Longmen-Sanmenxia	190,864	25.4	11.3	19.5
Sanmenxia-Huayuankou	41,615	5.5	6.1	10.5
Huyankou-Lijin	22,407	3.0	2.1	3.6
Yellow river basin	752,443	100.0	58.0	100.0
Interior basin	42,269			
YR basin region	794,712			

Source: Zhu and Zhang, 1999

Uneven spatial and temporal distribution of the YR water resources

The precipitation in the YRB varies between 200 mm and 650 mm with an average of 476 mm. Roughly, the precipitation decreases from the southeast to the northwest of the basin. The open water evaporation is 800~1800 mm, with an average of 1100 mm, see Figure 1.5. Affected by the monsoon climate, the 4 months precipitation from June to September can be 58%~75% of the yearly value. The ratio between the maximum and minimum precipitation in a year ranges from 1.7 to 7.5 in the YRB.

As precipitation is the major source of annual runoff in the YRB, the spatial and temporal runoff distribution in the YRB is also uneven. The spatial distribution is shown in Table 1-3. About 85% annual runoff is generated upstream of Lanzhou and in the section between Longmen and Huanyuankou (i.e. in 60% of total basin area). While, the remaining 15% annual runoff comes from the section between Lanzhou and Longmen and downstream of Huayuankou (i.e. in 40% of total basin area). See also Figure 1.6.

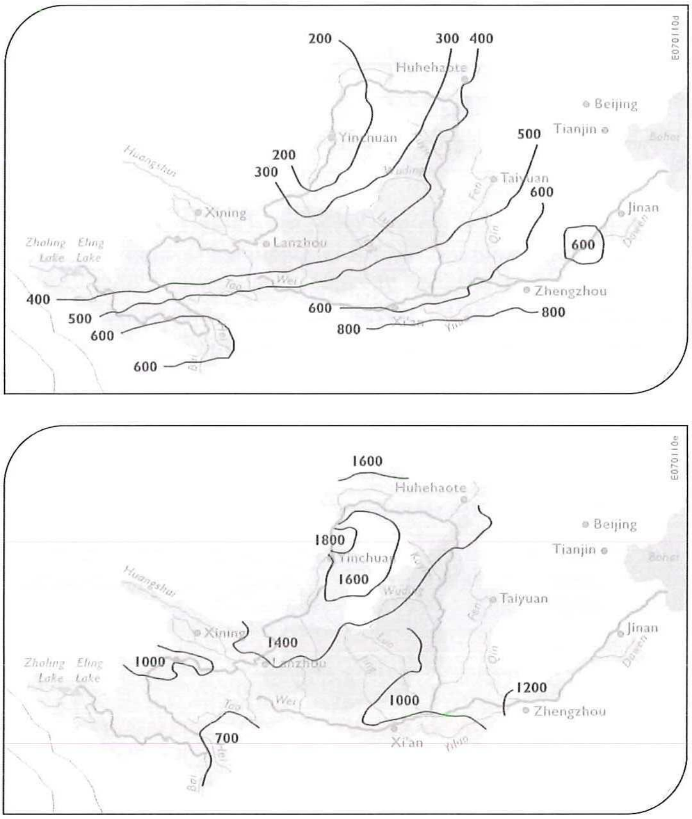


Figure 1.5 Precipitation (upper figure) and open water evaporation (lower figure) in the YRB (in mm/yr)

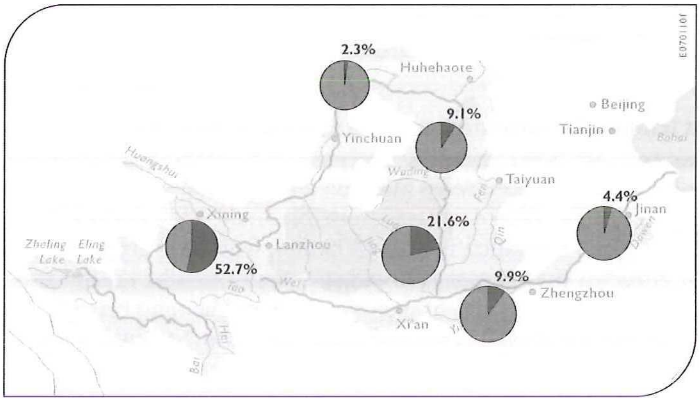


Figure 1.6 Natural runoff contribution to YRB by section

The runoff in the YRB in the 4-month flooding season from July to October is 60% of the total basin runoff. From March to June the runoff reduces to only 10%~20%. The ratio between the maximum and minimum annual runoff is around 3.0 for the mainstream and above 5.0 for the tributaries.

In addition, recorded data since 1919 shows that long term dry periods also occur in the YRB. The 3 main dry periods are the 11 years of 1922~1932, the 6 years of 1969~1974 and the 10 years of 1986~1997. The annual average runoff in those periods was 70% (39.3 billion m^3), 87% (49.0 billion m^3) and 89% (50.1 billion m^3) of the normal annual value respectively.

The overall conclusion with respect to above is that the YR water shortage is mainly a result of the uneven spatial and temporal distribution of the water resources, more than a lack of total resources.

Water quality degradation

Based on monitoring data, 2.1 billion ton of sewage was discharged into the river in the early stage of 1980s. Since 1990s, sewage discharged into the river has sharply increased up to 4.17 billion ton. At present, there are 300 major pollutant sources on the main stream. According to an analysis of the 1997 water quality monitoring data, the river length with which water quality can meet the drinking water standard is only 17% (YR Water Resources Bulletin, 1997). The severe water quality pollution aggravates the shortage of water resources.

High priority of environment and ecosystem water supply

In recent years, more attention has been given to environment and ecosystem water demand. YRCC (see Section 1.4) estimates that about 21 billion m^3 water needs to be reserved for such uses. The main part (15 billion m^3) is for sediment flushing at Lijin station in the flooding season, 5 billion m^3 to maintain channel low flow to sustain ecosystem in non-flooding seasons and 1~2 million m^3 for soil and water reservation in the Loess Plateau in the middle reach aiming to reduce sediment deposition. When these instream uses receive a higher priority, less water will be available for other usages.

Climate change

According to IPPC (Intergovernmental Panel on Climate Change, 2001), the average temperature in the world will increase. The temperature in China shows indeed an increase in the recent 50 years. Much research has been carried out to the impacts of climate change on the YR water resources availability in the coming decades. Among all climatic factors, precipitation will have the most important direct impact on runoff in the YR. As shown in Figure 1.7, the similarities in trends and patterns in natural runoff and precipitation imply that the changes in natural runoff are related to changes in annual precipitation. The decrease of annual precipitation as a result of climate change may be one of the most important factors for the decrease in natural runoff in the YRB.

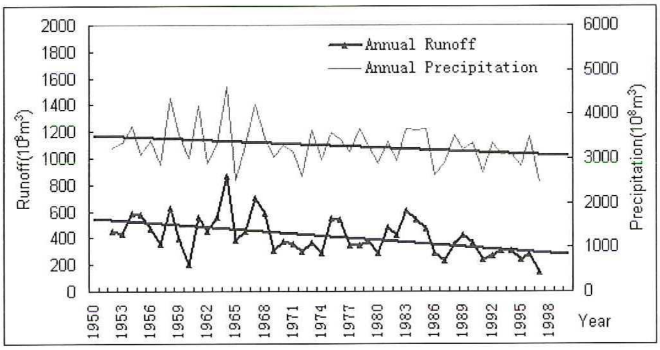


Figure 1.7 Relationship between precipitation and runoff in the YR (Huayuankou station)

Source: Liu and Zheng, 2003

Growing water demand for socio-economic development

Notwithstanding above mentioned climate change, the driving forces of the water shortage in the YRB is the growing water demand related to the socio-economic development of the region. The population in YRB increased from 41 million in 1953 to 107 million in 2000. The effective irrigation area kept expanding from 0.8 million ha in 1949 to 7.51 million ha in 1997 (see Figure 1.8). In total, the water consumption by agriculture and industry increased from 12.2 billion m^3/yr in 1950 to more than 26.8 billion m^3/yr in 1990.

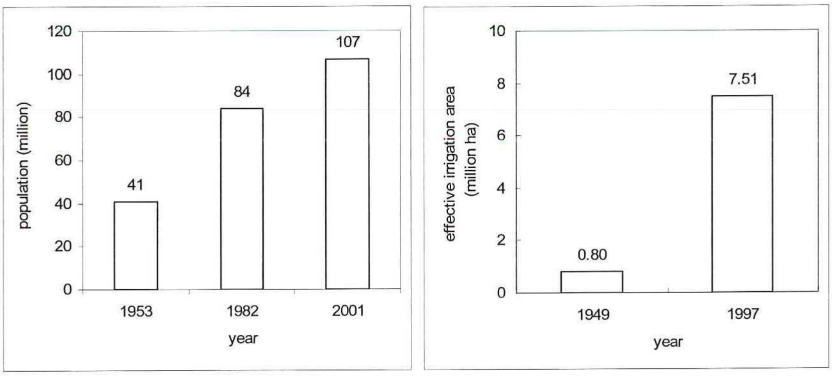


Figure 1.8 Population growth and expansion of effective irrigation area in the YRB

Projected water shortage in the YRB in future

In total, YRCC projects that the gap between water supply and water demand will be 4.0 billion m^3 in 2010 and will reach 16.0 billion m^3 in 2050 (Xiao et al, 2001; Shen et al, 2002; Chen and Zhang, 2001; YRCC, 2003, see Table 1-4).

Table 1-4 Projection of water shortage in the YRB (10^9 m^3)

Projection year	Total water supply			Total consumption volume							Water shortage volume
	SW	GW	Total	Ecological water requirement					Econom. demand	Total	
				(1)	(2)	(3)	(4)	Total	(5)		
2010	58	11	69	13	5	2	1	21	52	73	4
2030	58	11	69	12	5	3	1	21	59	80	11
2050	58	11	69	11	5	4	1	21	64	85	16

(1) sediment transportation in flooding season (2) base flow in non-flooding season
(3) water and soil conservancy (4) river course seepage
(5) water consumption volume in national economy inside and outside the basin

1.3 Conflicts caused by water shortage in the YR

Peter Gleick, in his studies to understand the connections between water resources and (international) conflicts (and security issues), points out that "disputes over control of water resources may reflect either political power disputes, disagreements over approaches to economic development, or both. It is evolving as (international and) regional politics evolves..." (Gleick, 2000). Water disputes typically are erupting in the downstream regions of stressed river basins. Unsurprisingly, this is already a fact in the YRB. Conflicts exist between water use sectors and between provinces in this basin (Li, 2003; Li et al 2003a).

With the expansion of irrigation and continuous progress of urbanisation, it has already happened many times that agricultural water supply was cut down to meet domestic, municipal and industrial (DMI) water demand to ensure human being's livelihood and/or for economic sake. Environmental objectives are at high risk to be reprioritised especially in case of conflicts where economics benefits (irrigation, hydropower generation, etc) are involved in dry seasons.

Above conflicts across water use sectors are interrelated with the conflicts among provinces. Take the conflict between the Ningxia-Inner Mongolia (Ning-Meng in short) and Shandong provinces as an example. The local natural runoff in these provinces is extremely limited, i.e. Ning-Meng has about 2.3% of basin water budget and Shandong has only 4.4% (see Figure 1.6). Both provinces have national irrigation 'bases', i.e. Ning-Meng contains the 'Ning-Meng Hetao Irrigation District' and while Shandong has the 'YR Lower Reach Diversion Irrigation District'. An important difference is their economic conditions. In Ning-Meng agriculture is still dominant while in Shandong advanced industries are developed, including the Shengli Oil Fields.

The water disputes involved in these provinces typically reflect what Peter Gleick is claiming. Located in one of the economic most productive regions in China, Shandong province will endure very high economic losses by water shortage. From a national socio-economic point of view, Shandong is constantly challenging the upstream Ning-Meng provinces with respect to their high water losses as a result of their low irrigation efficiency (40%). The province Shandong argues that Ning-Meng should adopt water saving technologies to reduce their water consumption and which will result in an increased water availability for Shandong.

On the other hand, Ning-Meng is located in an extremely dry region near the Tengeli desert in the west. The average precipitation is only 26 mm with an average open water evaporation of 2000 mm. Without the YR mainstream flow agricultural production would be very difficult and irrigation impossible. To ensure national food security, Ning-Meng has no other choice but to divert water from the YR mainstream for their local irrigation (next to human primary water demand). The gravity irrigation in Ning-Meng provinces has a history of more than 2000 years. The dominant economic activity agriculture is a rather meagre economic activity which can normally provide only very limited budgets to improve the efficiency of their irrigation canals. Due to intensive evaporation, this area needs considerable amount of additional water to control soil salinity. However, how much of this salinity flushing water drains back to the YR mainstream is unclear. This means it remains unknown how much water Ning-Meng exactly consumes. The story is even more complicated as Ning-Meng provinces are autonomous districts in China where many minority ethnic groups live. They have different customs, ethics and understanding of the water resources. The water issues between Ning-Meng and Shandong provinces thus are politically sensitive and they can influence the social stability of China to some degree.

Over the last decades, increasing competition for scarce water resources across the sectors in the YRB, evoked conflicts and tensions among provinces and across water sectors have been intensifying. Domestic water supply in urban and rural areas along the lower YR was not guaranteed and there were often drinking water shortages during dry seasons. Telegrams were sent to China Ministry of Water Resources and the State Council to request for urgent solutions. The growing withdrawals had an extreme consequence - an increase of zero flow in the YR lower reach. Records from 1970s to 1990s show that the frequency, duration and channel length of zero flow increased rapidly. In 1997 the zero flow duration at Lijin station in the YR low reach prolonged to 226 days, see Table 1-5 (Wu et al, 1998; Li, 2005; Qian, 2001; Li et al, 2004). In that year, 2,500 villages and 1.3 million people suffered from serious drinking water shortages.

Table 1-5 Zero flow record at Lijin station in the YRB

Year	Duration (day)	Channel length (km)
1972	19	310
1974	20	316
1975	13	278
1976	8	166
1978	5	104
1979	21	278
1980	8	104
1981	36	662
1982	10	278
1983	5	104
1987	17	216

Year	Duration (day)	Channel length (km)
1988	5	150
1989	24	277
1991	16	131
1992	83	303
1993	60	278
1994	74	308
1995	122	683
1996	136	579
1997	226	704
1998	142	515
1999	42	279

The water shortages in that period caused tremendous economic loss and had considerable social impacts. Being the most productive area in North China, the direct economy loss due to zero flow was estimated at about 456 million US $. Moreover, the low channel flow reduced the bio-diversity in the delta area and adversely affected the water quality by seawater intrusion. Groundwater was overexploited on a large scale, leading to a deterioration of hydro-geological conditions. People regarded zero flow in the YR, the Chinese Mother River, as a loss of Chinese culture. All in all, serious water shortages in the YRB have been recognized as a threat to the social and political stability in China and have resulted in reconsideration of YR water allocation. This will be explained in the next section.

1.4 Current centralised water allocation in the YRB

1987 YR Water Allocation Scheme by YRCC

It has been long realized by the 9 provinces and the two regions outside the basin (Hebei and Tianjin) who need to withdraw water from the YR, that their demands (73.04 billion m^3 at present, see Table 1-4) is much more than the available YR natural runoff (in average 58.0 billion m^3 per year). To deal with this situation, an allocation scheme was sanctioned early in 1987 by the State Council based on the report by the National Plan Commission and the Water Conservation Department (see Table 1-6 and Figure 1.9). This scheme is named the YR 1987 Water Allocation Scheme (1987 Scheme in brief). As shown in the table, the total water allocation quantity is 37 billion m^3/yr. This is calculated based on a 58.0 billion m^3/yr YR available natural runoff minus 21.0 billion m^3/yr water for environment and ecosystem water demand. The provincial water allocation quota of the 1987 scheme is mainly determined based on empirical estimations by experienced YRCC water engineers with the collaboration of the provinces and other institutes and departments, e.g. the National Plan Commission and the Water Conservation Department. The quota to Hebei and Tianjin is based on the projected drinking water demand in future. Even though this 1987 Scheme was officially sanctioned by the State Council it was not implemented until 1999.

Table 1-6 YR 1987 water allocation scheme (total allocation quantity: 37 billion m^3/yr)

Province	**Qinghai**	**Sichuan**	**Gansu**	**Ningxia**	**Inner Mongolia**
Consumption (10^9 m^3/yr)	1.4	0.04	3.0	4.0	5.9
Percentage (%)	3.8	0.1	8.2	10.8	15.8
Province	**Shaanxi**	**Shanxi**	**Henan**	**Shandong**	**Hebei, Tianjin**
Consumption (10^9 m^3/yr)	3.8	4.3	5.5	7.0	2.0
Percentage (%)	10.3	11.7	15.0	19.0	0.5

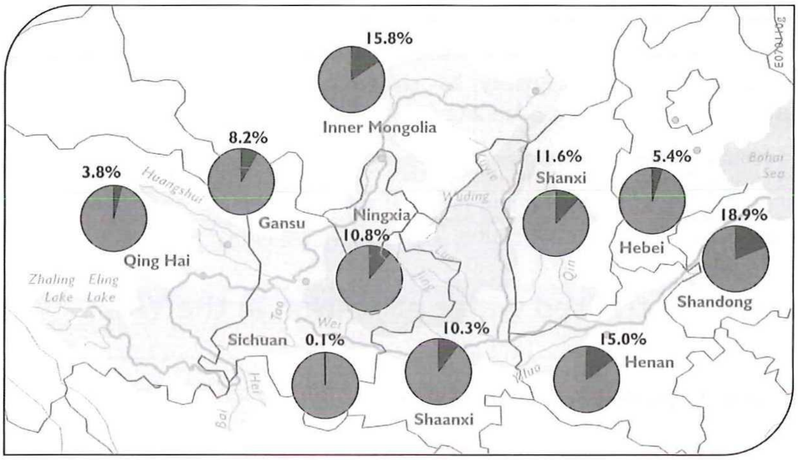


Figure 1.9 Water allocation to the 9 provinces in the YRB according to the 1987 Scheme

Implementation of centralized water allocation by YRCC

At the turn of the 21^{st} century, in order to alleviate the supply-and-demand conflicts on water resources and to prevent the occurrence of zero-flow in the YRB, the State Development Planning Commission (SDPC) and the Ministry of Water Resources (MWR), approved by the State Council, authorized YRCC to perform a central water allocation on the YR in 1999. From 1999 onward, centralized water regulation was performed by YRCC gradually only on the YR mainstream. At beginning it was only in two sections from Liujiaxia Reservoir to Toudaoguai and from Xiaolangdi to Lijin. In 2001 it was extended to from Liujiaxia to Lijin (Figure 1.10).

The centralized water regulation from 1999 actually meant that the 1987 Scheme was finally implemented by YRCC. Tangible successes have been achieved. The drying up of the river at Lijin station did not take place any more. For instance, in year 2000, even when the natural runoff was as low as 47% of a normal year, zero flow was still avoided. There is evidence that the ecological system in the estuary area has begun to recover.

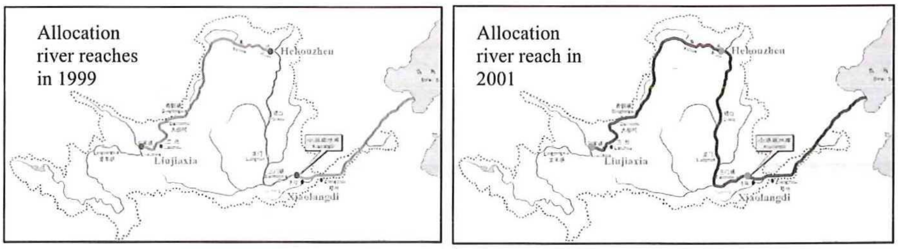


Figure 1.10 Allocation reaches by the DMWA of YRCC in 1999 and 2001

Nevertheless, no drying up at the Lijin station and less ecosystem deterioration does not mean that all water conflicts have been solved. The increase of the instream water flow has taken place at the expense of withdrawals for agriculture and DMI. Although to some extent agreements were reached between the institutes involved on the YR basin wide water allocation, differences of opinions and a huge gap between supply and demand remain and still cause serious conflicts and tensions among upstream and downstream provinces, in particular in dry years and under changing economic and demographic developments. To start solving these issues it is essential to obtain an in-depth understanding of the current centralized YR water allocation procedures and its existing problems.

Working procedure of the centralised water allocation

To gain insight in the centralised water allocation, it is necessary to first understand the water allocation procedures adopted by YRCC. Based on a long-term forecast of the maximum annual YR surface water availability, the monthly water allocation quotas for all provinces are determined as a kind of pre-scheme, with consideration to the water utilization plan submitted by the provinces to YRCC and to the water storage capacity of key reservoirs. Upon approval by the Ministry of Water Resources, this pre-scheme of YR mainstream water regulation will be transmitted to the provinces for reference, followed by implementation for that year. During the implementation, the monthly water allocation quota will be adjusted timely according to medium-term (monthly) and short-term runoff forecasts (e.g. 10 days).

During the year, periodical provincial water diversion and consumption is monitored and controlled by YRCC through key mainstream reservoir operation and mainstream discharge regulation. At peak water consumption periods, in order to guarantee the discharge at important inter-provincial sections (and to guarantee the minimum environmental flow), YRCC sent work teams to important water intakes and key water projects to check and supervise implementation of the water allocation scheme. When necessary, negotiation meetings can be arranged among provinces and across water use sectors to alleviate conflicts.

By the end of each year, a review report is prepared for the examination of the implementation of the water regulation scheme given known runoff. Moreover, the ratio of supply to demand for each province (and each water use sector) will be calculated, and the annual benefit of water allocation will be estimated. This annual review report of the water regulation will be presented during the next year annual meeting which is participated by the provinces and the key water projects management units.

Existing problems of current centralized water allocation in YRB

This centralised water allocation scheme has proven in practise to be successful to some degree. Provincial annual SW withdrawal from the YR mainstream is more or less controlled according to the 1987 Scheme. However, quite some serious problems remain during the implementation of this 1987 Scheme. These problems can be described in three categories: problems related to the water allocation scheme itself, problems related to the institutional capacity of YRCC, and problems related to data transparency.

Problems directly related to the 1987 Scheme itself
The 1987 Scheme itself is a re-distribution of YR average annual runoff among the 9 provinces (and two regions outside). The scheme still lacks a specification on how to

deal with seasonal and annual runoff variations. For the time being, the provincial water consumption quota is just interpreted as a fixed proportional share of the YR surface water. By this, in dry or wet years, the provincial water consumption quota will decrease or increase by the ratio of actual annual runoff versus average annual runoff. Such proportional quota unavoidably causes unequal 'losses or gains' for different provinces in different years considering their different socio-economic conditions. Moreover, the 1987 Scheme has not yet been re-examined or updated to reflect the rapidly changed social- economic conditions in the provinces, especially in the last two decades.

Problems related to the institutional capacity of YRCC

As shown in Figure 1.11, the most closely related agencies to the YR mainstream water allocation are MWR, YRCC, the provinces, and the power groups. The jurisdiction and authorities of related agencies is explained as follows.

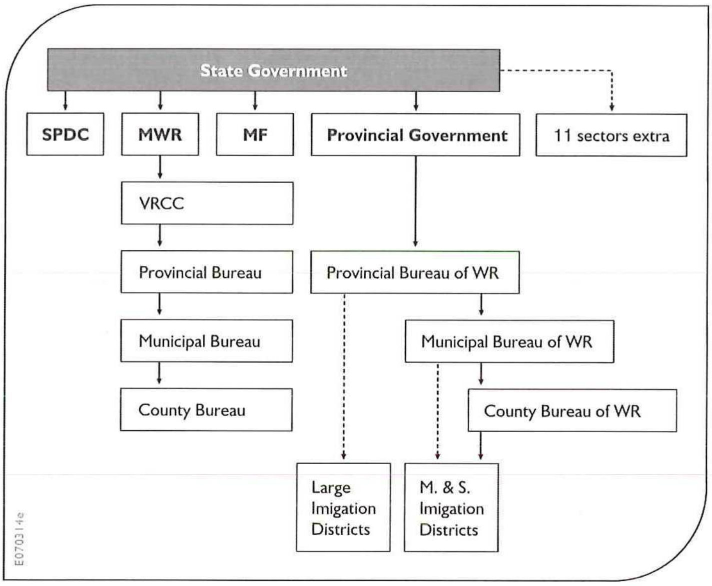


Figure 1.11 Institutions for water allocation in the YRB (after Zhu, 2001)

The **National government** determines the general legislative and policy framework for water management. MWR is responsible for the state water management, and issues the national water legislations and policies. MWR has the authority to determine the annual water allocation plan. Other ministries such as land and agriculture, electricity, etc. are involved in water management as well.

Yellow River Conservancy Commission (YRCC) is a subordination of MWR. Representing MWR, YRCC is responsible for the planning, flood control, water resource allocation, water quantity regulation, water resources protection and soil and water conservation in the whole basin. For historical and political reasons, YRCC has been particularly active in flood protection in the lower reach and in the management of multi-purpose water projects. In relation to water resource allocation, the main tasks of YRCC are as follow: to determine the detailed rules of water allocation under supervision from MWR; to draft and submit the annually water allocation pre-scheme to MWR; to draft and issue monthly (and 10-days) water allocation operational schemes; to regulate the real-time water allocation scheme according to the short-term hydrology forecast and other urgent conditions; and to supervise the implementation of the allocation scheme in the provinces and reservoirs.

The **Provincial government** formulates the water policy for its own province according to the national legislative and policy framework. The province is also responsible for surface water management. Provinces are involved in the preparation of the annual water allocation plan, and implement the plan, i.e. each province has the responsibility to ensure the outflow of its boundary according to the water allocation scheme.

Power groups are also concerned in the water allocation pre-scheme and water allocation plan. Actually, they have the authority to determine the power generation targets of each reservoir, even without coordination with MWR and YRCC. Belonging to the Northwest power group, the power generation of Liujiaxia reservoir is determined by Northwest regional power demand. Belonging to MWR, the power generation of the Xiaolangdi reservoir is determined by the Middle China power group.

Obviously, the responsibilities for water allocation within the YRB are divided along tributary lines and by provincial administrative boundaries. YRCC is only responsible for the main river while others are responsible for the tributaries and the provincial land (including groundwater). Strong coordination links are missing between these different bodies. This is needed as the actions of tributary organisations and provinces directly affect the water in the main river. Such ambiguity in roles and functions has limited YRCC as basin manager. It has to rely on a mandate from the MWR. Under these circumstances, it is difficult to play an effective role in the mediation of water disputes between provinces and resolving other important issues regarding integrated basin management.

The large reservoirs and water diversion projects in the YR mainstream belong to different areas and are managed by different departments (see Figure 1.12). YRCC is lacking effective binding mechanism and authority to implement enforcement measures. Besides, YRCC can not punish provincial violations of agreements of their annual water consumption quota. Also there are no mechanisms yet established that force provinces that exceed their quota to compensate the downstream provinces.

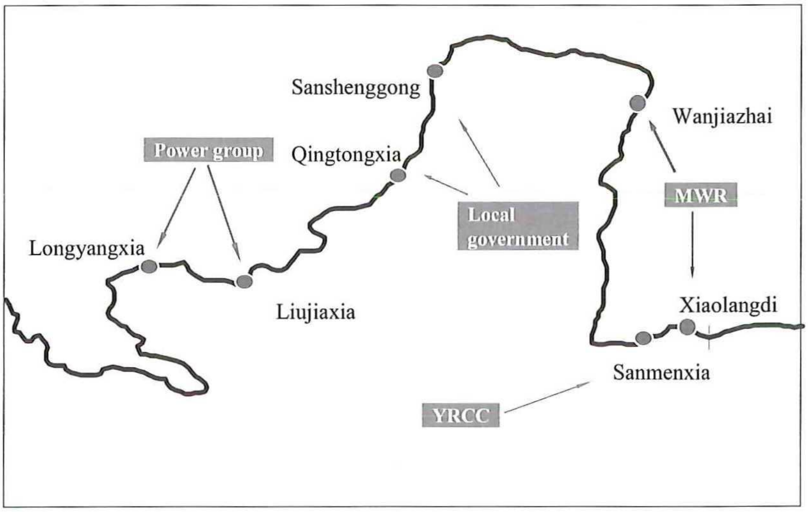


Figure 1.12 Institutions managing the key reservoirs in the YR main stream

Problems related to data transparency
Besides the missing coordination links between the different institutions involved, the lack of 'data transparency' of the water demand of the provinces is an issue. Under the planned economy system when the 1987 Scheme was prepared, the water allocation for the different provinces was based on coordination of the central government in association with the river basin organizations. The state determined the total amount of water allocated to a given province and the provincial government was responsible for the water allocation within its jurisdiction including the water allocation among different sectors and different administrative districts. This led to a situation that the provincial governments planned for high water demands and requested more water allocations from the national government. This uncontrolled maximisation of demand did not only caused implementation difficulties as argued above, it also stimulated the provincial governments to ask for more investments (e.g. for increase in irrigation areas) through state financial appropriation while at the same time there was little incentive to invest in water saving management. This all has widened the gap between the supply and demand in the basin.

These three problem categories make it difficult for YRCC to carry out its 'liaison' position to mitigate the conflicts among provinces and across water use sectors. YRCC can not reasonably determine, control and interfere in the provincial water withdrawals due to lack of institutional capacity, lack of data transparency, lack of conflict prevention mechanisms, etc. As the competition for water will only become more intense in the future, there is a strong need to develop a rational water allocation scheme which can be implemented smoothly to optimise the socio-economic performance of the system, protect the ecosystem and ultimately alleviate water shortage deduced conflicts in the basin. This situation provided the background and reason for the initiative of the research described in this thesis on the development of integrated basin wide water allocation in the YRB to realise a harmonized sustainable development of the basin.

1.5 Research question and methodology

As described above, the water shortage situation in the YRB is imposing a major constraint to the further socio-economic development of the area and improvement of the environmental conditions in the basin. The issues involved typically ask for an Integrated Water Resources Management (IWRM) approach. IWRM is a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP, 2000). IWRM is a rather new (and still evolving) approach. The concepts and techniques behind IWRM might possibly provide opportunities to solve the mentioned issues. With that in mind the main objective of the research has been formulated as follows:

> *To develop a framework for the application of the concepts of IWRM in the Yellow River basin with a particular focus on alleviating the conflicts between provinces on the water allocation.*

To achieve this research objective the following specific questions need to be answered:

1. What is the present situation in the Yellow River basin on water supply and demand and what kind of changes are expected if environmental conditions are taken into account?
2. How can IWRM be applied in the Yellow River basin and are there specific requirements for a successful application?
3. What aspects should be taken into account and how can these aspects be quantified to enable a trading off of the interests involved?
4. What alternative approaches for a more equitable distribution of the water allocation can be developed, including compensation for those users/regions who will receive less water than before?

1.6 Content of the thesis

The thesis is divided into 7 chapters in total. In this first chapter, the research objective and research questions were formulated based on an introduction of the water shortage issues in the YRB.

In Chapter 2 it will be argued that an ethical approach needs to be established first to find a proper philosophical basis for the application of IWRM in the YRB. The combination of this ethical approach with scientific and technical approaches will provide in-depth information to evaluate basin water allocation options. The technical approach is based on the development and application of a RIBASIM model for the YRB, This RIBASIM model setup is described in Chapter 3.

In Chapter 4, the current situation of YR water shortage is illustrated by applying the developed model for the basin. Based on different scenarios, it is predicted that the water shortage among provinces and between human and the environment will increase if no action is taken. The necessity is pointed out to develop strategies to mitigate the water shortage deduced conflicts by applying the combined approaches of IWRM.

Chapter 5, the combination of the two approaches is used to establish solutions to mitigate the water shortage deduced conflicts. Rational inter-provincial water allocation schemes are formulated based on equity principles with consideration of 'reserve water' to guarantee vital ecosystem health and primary human water needs. Basin cooperation contradictions for the implementation of these equitable schemes are explicitly presented by diagrams, reflecting the conflicts from a basin and provincial point of view.

To resolve the remaining conflicts, different feasible compensation mechanisms are derived in Chapter 6. These mechanisms are based on a reasonable interpretation of what provinces perceive. Their implications on institutional arrangements are also addressed, needed to facilitate a smooth basin cooperation to implement compensated equitable schemes in the YRB. In the final Chapter 7, conclusions from the whole thesis are drawn and recommendations for further research are made.

The flowchart of the whole 7 chapters of this thesis is shown in Figure 1.13.

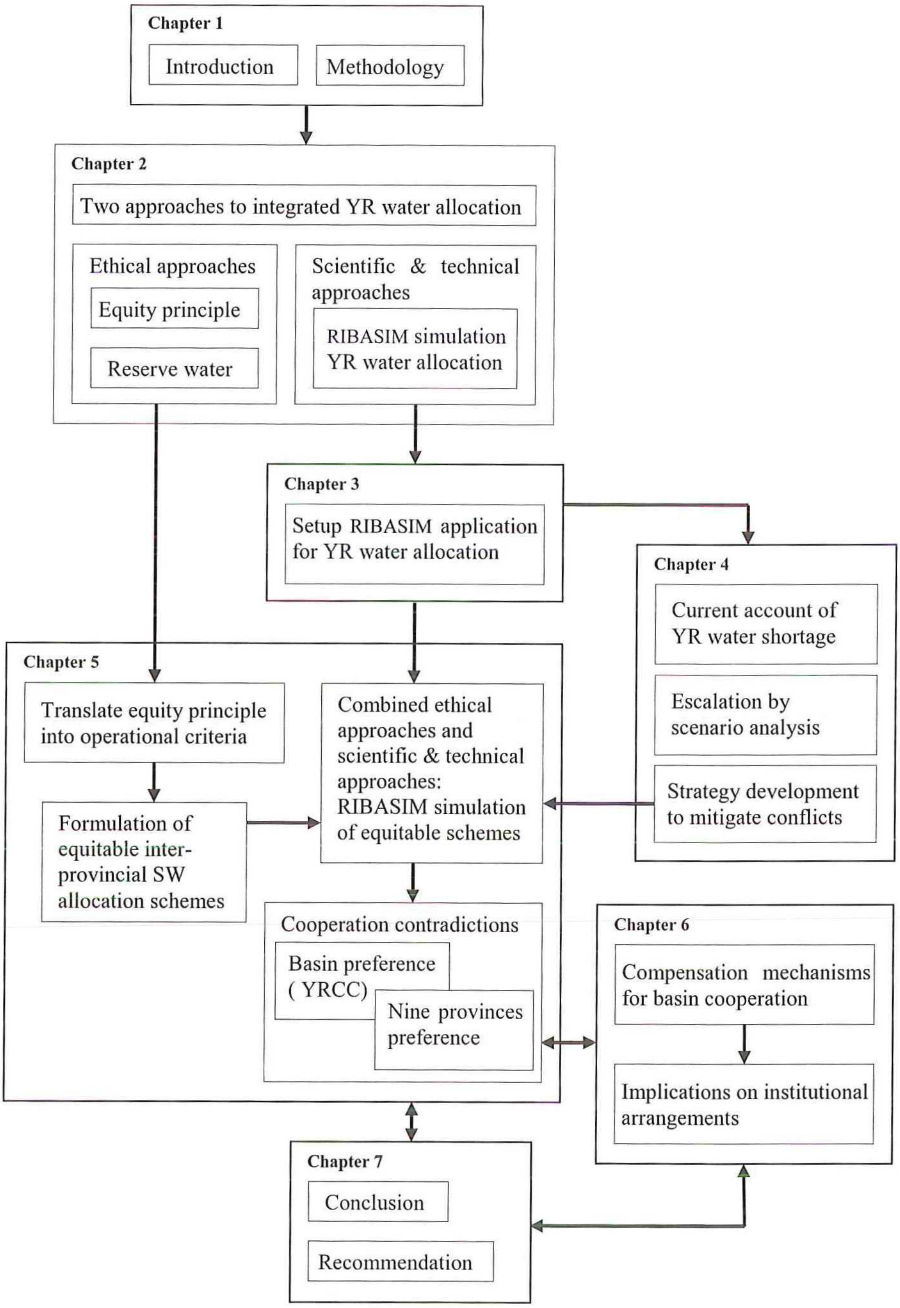


Figure 1.13 Flow chart of the thesis

2 Integrated water allocation for the YRB

Fifteen years of IWRM practice around the world after the Dublin and Rio principles in 1992 indicate that IWRM has gradually gained a world-wide acceptance as a good approach to sustainable development. This is also the case in the YRB. However, the current results of integrated water allocation in the YRB are not very promising, and different understandings of IWRM have led to a bifurcation of targets and actions. Therefore, it is necessary to deepen our understanding of the concept of IWRM and to explore its proper approaches.

In this chapter, based on a deep reflection on the historical and present flood control practices in the YRB, it is argued that a philosophical basis is needed to revitalize the effectiveness of IWRM in the YR and to harmonize human with nature. It is argued that ethical approaches should to be combined with scientific and technical approaches to realise integrated basin water allocation in the YRB with the ultimate aim to prevent and mitigate conflicts among provinces caused by water shortage.

2.1 Introduction of IWRM

2.1.1 Concept

Integrated Water Resources Management (IWRM) introduced in late 1980s and early 1990s, is based on the promotion of the concept of sustainable development given by the Brundtland Report on "Our Common Future" (WCED, 1987). The concept of sustainability was emphasised further more on the Dublin Conference on Water and the Environment in 1992 and the UNCED Rio de Janeiro Conference in the same year. Even though the concept of sustainable development has never been formulated very precisely, some workable definitions exist. The one proposed by ASCE (1998) states that: "Sustainable water systems are designed and managed to fully contribute to the objectives of the society, while maintaining their ecological, environmental and hydrological integrity, and meeting the demands to the system without its degradation, now and in the future".

Recognizing sustainability as its goal, Calder (1998) defines IWRM as the co-coordinated planning and management of land, water and other environmental resources for their equitable, efficient and sustainable use. Equity, efficiency and sustainability should be achieved by a balance of all relevant views and goals of stakeholders at basin, regional and international levels (Crigg, 1999; DWAF, 1998). This balance of interests is proposed by Canter et al (1995) to be struck by a dynamic, interactive, iterative, and multi-sectoral approach, in addition to an economic efficient and socially appropriate approach by full public participation. To date, the best-known definition of IWRM is "a process that promotes the coordinated development and management of water, land and related resources to maximize resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP, 2000).

In practice, IWRM can be contemplated in at least three ways according to Mitchell (1990). First, integrated water management can imply the systematic consideration of the various dimensions of water: surface and groundwater, quantity and quality. The key aspect is the acceptance that water comprises an ecological system formed by a number of interdependent components. At this level, attention for management is directed to joint consideration of such aspects as water supply, waste treatment and disposal and water quality. Second, integrated water management addresses the interaction between water, land and the environment, recognizing that changes in any one may have consequences for the others. At this level, management interest becomes focused upon issues such as floodplain management, erosion control, non-point sources of pollution, preservation of wetlands and fish habitat, agricultural drainage and the recreational use of water. A third and even broader interpretation is to approach integrated water management with reference to the interrelationships between water and social and economic development. The concern is to determine the extent to which water is both an opportunity for and a barrier against, economic development, and to ascertain how to ensure that water is managed and used so that development may be sustained over the long term. At this level, interest turns to the role of water in producing hydroelectricity, in facilitating transportation of goods and in serving as an input of manufacturing or industrial production.

Obviously, "integration" goes against the traditional way of singular thinking and operation. According to the Webster Dictionary the need for integration arises when dealing with the situation of "regular interaction or interdependent groups of items forming a uniform whole". Loucks and van Beek (2000) interprets that IWRM is an "integration" of water related groups of items consisting of natural resource system (NRS), social economic system (SES) and administrative and institutional system (AIS) (see Figure 2.1).

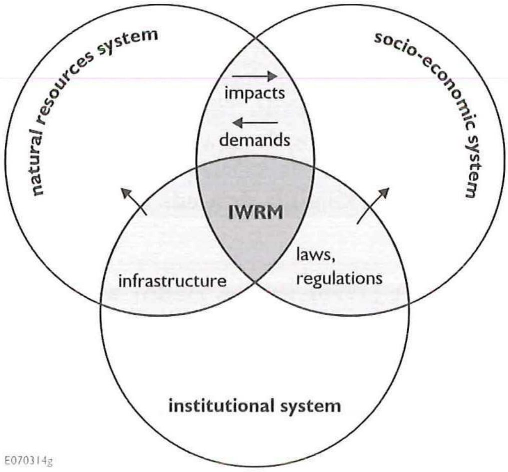


Figure 2.1 IWRM integrating the natural resources, socio-economic and administrative-institutional subsystems

When the interrelationship between NRS, SES and AIS are considered, "integration" thus embraces a number of other "dimensions" (Millington, 2000), for example: sectoral and sub-sectoral integration refers to the planning and management of water resources taking into account the competition and conflicts for water among irrigated agriculture, hydropower, DMI water supply, the environment itself and so on. Economic, social and environmental integration means taking into account not only the financial and economic costs and benefits, but also the social and environmental costs and benefits. Administrative integration refers to the coordination of the water management responsibilities and activities at all levels of government Geographical integration means using the hydrologic boundaries rather than administrative boundaries, as the basic units for water resource management.

That multi-dimension of "integration" includes horizontal integration and vertical integration (Jewitt and Görgens, 2000). Horizontal integration takes place within the same hierarchical level, which can be at macro-scale or micro-scale. For instance, integration could be either between nations sharing a river, or between different water use sectors within the same river basin, such as domestic vs. industrial vs. agricultural vs. environmental, or between upstream vs. downstream users, or between activities of adjacent land uses/users within a catchment. The other type is vertical integration where collaboration/co-ordination crosses a range of political, legislative or management sectors.

2.1.2 Principles

In the 1992 Dublin Conference the so-called key principles for IWRM implementation were formulated. These principles recognize water as a finite and vulnerable resource and the pivotal role played by women in management of water resources. Furthermore, they call for a participatory approach in water management and to treat water as a social and economic good with due consideration of the economic value in its competing potential uses.

IWRM emphasis that those principles need to be applied in a sound manner. Some scholars advocate that the preconditions for successful IWRM include at least four aspects (Farrington and Lobo, 1997; Ashton, 2000; Frost, 2001): first, close involvement of all stakeholders, i.e. planning initiatives are accessible to and should involve all landowners, stakeholders and local community organisations based on trustful and long lasting relationships; second, political support at all levels of government as well as NGOs; third, the will and willingness to implement IWRM by cooperation within and beyond the boundaries of administration or basin; the final aspect is to enable specific institutional arrangements to be adaptable to each basin unique situation.

2.1.3 Constraints and dilemmas

"IWRM is presented as the solution, but, because it is not always well understood, it can also create a sense of hopelessness among professionals", concluded Kuylenstlerna and Rockström at the year 2000 Young Professionals Seminar focused on long term intergenerational challenges. The hopelessness originates from the IWRM practice which is often non-ideal and complicated. The primary difficulty in implementing IWRM relates to interdisciplinary collaboration which requires new methods to integrate the technical, economic, environmental, social and legal aspects into a coherent framework. Further problems in practice are e.g., a narrow interpretation by some stakeholders of what the issue is, the specialized terminology used, a tacit understanding of concepts, problems and solutions within the expert community. Even the combination of organizational culture, personalities and participants attitudes can pose a major obstacle to integration and co-operation. And, "it is a constant source of misunderstanding of concepts, problems and solutions and misinformation in the sense that communication is difficult between disciplines" (Harrenmoës, 2002). Other difficulties and constraints are the lack of funding as well as the quality of the data, information and models upon which a sound knowledge base and policies will be developed, and which inhibits the development of trust and confidence amongst the players.

Above situation exists also in the Yellow River basin and is creating a dilemma (Li et al, 2003b; Li and Van Beek, 2003). IWRM has been presented as the solution for the present problems in the basin. However, the complexity of interdisciplinary and institutional cooperation has made that many stakeholders consider IWRM more as a 'constraint' than as a 'solution'. In their opinion IWRM prevents them from taking action.

As said, it is difficult to involve all social and ethical aspects and to broaden the analysis by involvement of stakeholders in the framing and interpretation of results. This is typically the case when basin wide IWRM is carried out by the responsible basin organization. In most cases, neither the social world of different tribes or ethnic/linguistic groupings are considered, nor the economic world of different levels of development, regional collaboration, trade, industry or capital flows that straddle natural basin boundaries.

Lack of progress in implementing IWRM is also widely attributed to institutional failure and inadequacy. Whether being formal or informal, legal or economic, cultural or political, local or global, institutions are both opportunities for and barriers to implementation of IWRM. Through institutions and only institutions, "humans achieve collective aspirations and resolve individual differences" (Dovers, 2001)". In this sense, institutions provide the basis for the participatory approach to IWRM. Nevertheless, weak institutions with competing mandates and overlapping responsibilities have resulted in a waste of water resources and are impeding the rational and integrated planning and management. The situation could be worse when national water management are carried out in a fragmented way, based on immediate needs and interests, without adequate regard to the finite nature and interdependence of the elements of the natural water cycle.

Another major challenge in IWRM is preserving a balance between the needs of humans and nature. Some state that economic growth is not a threat to environmental sustainability but rather the source of financial resources needed to address environmental problems (WCED, 1987; van den Bergh, 1996). Thus pursuit of sustainable development does not necessarily imply constraints upon economic development (HMSO, 1994). In contrast, others argue that ecosystem carrying capacity has already been exceeded in global terms (Cocks, 1992; Flannery, 1994) and that policies aimed at raising living standards conflict with those designed to increase sustainability (Oearcem, 1993). In general, optimists represent official positions and the pessimists are mainly scientists. Allan (1999) and Schulze (1999) further pointed out that the main concerns are mostly related to political pride and awareness. However, considering the complexity of the formidable task of improving IWRM, just raising the awareness of the utility of comprehensive IWRM will be impressive (Allan et al, 1999). In such circumstances "IWRM is a process that is as yet based on defective assumptions. It can only be as strong as the networks of consensus that the partial participation that is the rule can achieve."

2.1.4 Philosophical basis

Actually, as argued by Des Jardin (1997), environmental issues raise fundamental questions of 'ethics and philosophy.' First, what is the proper ethical relationship between humans and the natural environment? And second, what is the philosophical basis for this relationship? Therefore, besides scientific and technical approaches, an "ethical approach" is also important to address water issues. Without either, our understanding of water crises must remain "very limited and incomplete" (Ip, 1986).

Based on above articulation, we realize that the general understanding of IWRM basically remains a scientific and technological approach. In this or that way, such incomplete understanding causes the dilemmas in IWRM implementation mentioned above. However, IWRM does cover the idea of caring for nature and ecosystems and this implies ethical approaches. In many cases, ethical approaches to IWRM are neither recognized, nor explored. It is very necessary to extend the understanding of IWRM by employing a reasonable philosophical basis. That is, combined with scientific and technological approaches, ethical approaches could revitalize the effectiveness of problem solving by IWRM. The next question is what is a proper philosophical basis of IWRM?

The historian Lynn White (1967) argued that many of our modern scientific and technological approaches to nature started from the Judeo Christian perspective, which is especially anthropocentric. According to White, anthropocentrism or anthropocentric scientific approaches contribute to "our current ecological crisis". In terms of sustainable development, Canter et al (1995) point out that Agenda 21 and most of the international documents on this aspect "use very traditional language from Western science, economics, and law" to describe sustainable development implementation strategies. The emerging water crisis created "a powerful challenge to Western ethical systems" because ethicists were forced "for the first time" to consider and articulate the value of non-human species of plants and animals. Western ethical systems have been accused of failing to value anything other than human happiness or interests and consequentially devalue animals, plants, and ecosystems. For these reasons, traditional or dominant Western philosophical and theological views on the human relationship with nature seem in many cases to have contributed to environmental destruction and degradation.

As the anthropocentric Western philosophy is challenged, we turn to Eastern perspectives. One common element among several Eastern perspectives, particularly when contrasted with the western view, is the de-emphasize on dualism, and the human sense of connection to nature. Eastern conceptions are bio-centric in outlook, and the "primal" peoples of the East subordinated themselves to the integrity of their biotic universe. From this point of view, we may conclude that Eastern philosophy could be an alternative to the Western philosophical basis with respect to the ethical approaches to water issues.

Nevertheless, given the well-documented ecological disasters in Eastern societies, Guha (1989) points out that Eastern knowledge about the natural world was not infallible. Tuan (1968) also argued that "Buddhism and Taoism may have precepts which promote respectful attitudes toward nature, in theory, but that did not prevent the Chinese from engaging in a long history of environmental changes and destruction". Also the present environmental problems in China as a result of the rapid industrial growth is an example of this. However, Hargrove (1989) argues that "environmental values are the ideals indicating how people ought to live, rather than a description of how they necessarily always do behave". He also points out that "the gradual environmental degradation in the East may have resulted from empirical ignorance." Jenkins (2002) further debated that environmental degradation in modern China is explained "in terms of recent increases in the importance of the pragmatic over the ideal". Thus, the environmental problems observed in non-Western society may very well be due to causes other than a lack of wisdom about the proper human relationship to the natural environment.

When the particular case of the YR is considered, its two indigenous philosophies of Confucianism and Taoism are questioned: which one can provide philosophical basis of IWRM in the YRB nowadays? Both originating from the YR, the Cradle of Chinese civilization, Confucianism and Taoism have deeply influenced the Chinese way of thinking for thousands of years. They also influenced the YR people's way to tackle the major water issues, i.e. flooding in the YR. Confucius (551-479 BC) believed that the adaptation of nature to human needs could take place, however by following nature's rules. Humans could cause serious disruptions from ignorance but could also restore harmony by wisdom and learning. For these reasons, Confucius advocated education, self-discipline, and the investigation of natural phenomena and, at the social level, a harmonious social order. The founder of Taoism is believed to be Lao-Tse, a contemporary of Confucius. Unlike Confucianism, Taoism was a philosophy of non-interference. Taoism held the belief that all matters took nature as their law. Tao is characterized by Wu-Wei (literally "no action") and called for spontaneity and for no unnatural action or interference with a given situation, in order to allow matters to take their own course. While Confucius emphasized social order and an active life, Taoists took the view that social conventions were not natural and were destructive to humans. They believed that not to act or interfere with the course of nature was the best way to act and rule.

In the following sections how these two philosophies influenced the water management of flood control in the YRB will be re-examined. Then to answer the question raised above: which philosophy is a proper basis of IWRM in the YRB.

2.2 Reflections from historical flood control in the YRB

YR has a history long back to 21st century B.C. with colourful but also very painful periods of human's survival from frequently occurring natural disasters, especially flooding. Records show that during 602 B.C. to 1985 A.D., there were 543 years when YR downstream banks were breached by flooding; And 5 times the lower reach re-located itself (changed course) (Wu, et al, 1998). As introduced in section 1.1, sedimentation in the YR downstream has 'built' a 'spectacular' suspended river (also see Figure 1.4). Enormous losses of lives and property gained YR the name of Chinese Sorrow. For thousands years flooding is the most vital task in the long history of water management in the YRB. Re-examination of its flood control history in the YRB is believed as the starting point to look for a proper philosophical basis of IWRM in this basin.

2.2.1 Flood control history

According to Chinese legends Yu The Great, the first 'manager' of Chinese waters, (Century 21 B.C.) built the first dikes along the lower reaches of the YR. For his achievements he was appointed emperor. These dikes were built after the failures of his ancestors who built barriers to block or store the water in large holding areas for long period of time. Yu The Great's innovation was to direct the flow to the sea. The first actual recorded construction of levees started in the Warring State periods (770-221 B.C.) when the YR was not 'suspended' yet.

The construction of dikes reduced the flood frequency at first but increased the flood risk (risk = frequency x damage) due to dike failures. During the Han Dynasty (206 B.C. – 220 A.D.) disasters by flood breaches and resulting shifting of the river course were more overwhelming than ever before along with sediment deposition in the lower reach. Erosion increased in the basin by more intensive human activities in the Loess Plateau and the YR lower reach gradually became a suspended river. Because the heavy silt load of the river restricted the effectiveness of flood control, constant efforts were needed to try to maintain sediment equilibrium in the river. To tackle the flooding in the YR, the prominent water manager Jia Rang stated around 7 B.C. his "three measures on river treatment (flood management)". The first measure, the best option according to Jia Rang, was to return the river to an abandoned course. However, this idea proved to be impossible at that time with the limited technological capacities, as the abandoned channel was seriously silted. The second measure was to dissipate the power of the river by draining off water for irrigation in the lower reach and diverting relatively silt-free streams into the YR to increase the silt-carrying capacity. The last measure was to strengthen the dikes to encapsulate the river. This measure was his last choice. He believed that the endless need to increase dike levels was a waste of time, labour and sources.

After Jia Rang, Wang Jing proposed and carried out river channel stabilization around 69 A.D. so effectively that no major dike breach occurred during the next thousand years. His methods included dredging, strengthening the levees at dangerous points, digging new channels for tributaries in rough terrain, and building numerous sluice gates. Thousand years later in the Ming Dynasty (1368-1644 A.D.), Pan Jixun (1521-1595 A.D.) was remarkable because he advocated building strong dikes to contain the river close together so that it would scour its own narrow channel. This was the first forceful statement against the ancient principle of dividing the flow to dissipate the river's power. This strategy to stabilize the river in this way was also followed by Jin Fu (1633-1692) in the early Qing Dynasty (1644-1922 A.D).

Though Chinese recognized for centuries that sediment was the main cause of the floods in the lower YR, Li Yizhi (1882-1938) was the first to argue in the early 1920s to focus attention on the upstream part of the basin and to attack the silt problem at its source. He believed that the most important long-range method of control was to reduce the silt load of the river through conservation measures on the Loess Plateau. Since such measures would require decades to become effective, Li also proposed that detention reservoirs be built upstream to control the maximum flood discharge. Li's approach is still the base for the present flood management in the YRB.

The above described flood control history in the YRB is illustrated in Figure 2.2.

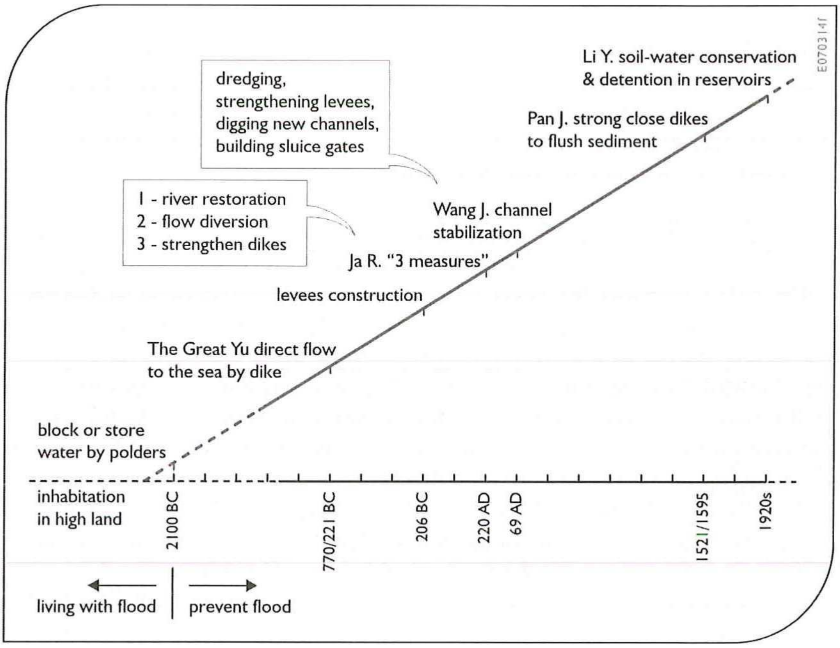


Figure 2.2 Flood control history of the YR

2.2.2 Control by "controlling" or "not controlling"

From former section, it is noticed that two main strategies were alternatively dominated in the long history of flood management in the YR. The first strategy is to confine the YR in a narrow channel by high levees (1-3 km apart). The advantage of this strategy is that the narrow channel has a high sediment transport capacity and a slow silting rate of the riverbed. It might even cause a lowering of the riverbed. However, it has limited capacity to absorb major flood crests and induces fast erosion of dikes. The alternative strategy is to give the river a broad channel between widely spaced lower levees (5-6 km apart). Between these dikes small diversion dams (groins) may be built to keep the river in the centre of the channel. The advantage of this strategy is that widely spaced levees enable the discharge of extreme flood flows. A disadvantage is the fast rise of the bed level due to increased sediment deposition, especially when the river is not forced in a small bed during low flows. Furthermore, peasants moving in the riverbed to cultivate the rich silted lands between the widely spaced levees are in constant jeopardy from high floodwaters.

These two strategies represent more than two different technical approaches to controlling the river. Their roots lie in different philosophical outlooks. Construction of narrowly spaced strong dikes is associated with the Confucianist tendency to curb nature, or "control by controlling". Construction of widely spaced low levees is associated with the Taoist approach of letting nature follow its own course, or "control by not controlling". In Chinese thought, Taoism has long complemented the dominating Confucianism by promoting greater understanding of the harmonious natural world and downplaying the importance of invasive human interventions.

The ancestors that lived with floods before and during the time of Jia Rang (221 BC) represent the 'Taoist' school, while Wang Jing (1st century A.D.) and Pan Jixun (15th century) were famous representatives of the 'Confucianist' approach. Li Yizhi (beginning 20th century) returned to the 'Taoist' approach. Jia Rang advocated to leave room for flood and to use alternative flood control measures such as population resettlement out of the silted abandoned course. These measures are considered Taoism. After Jia Rang a long period of focusing on dike construction started. Wang Jing could be called a Confucianist because he advocated strong dikes that confine the river to a narrow channel. Being more positively to controlling flood, Pan Jixun gave the first forceful statement against the ancient principle of dividing the flow to dissipate the river's power. Pan Jixun's strategy was followed until the beginning of P.R. China by strengthening and raising the levees. The flood risk management views that are being studied for the YR at this moment show again more respect for nature and look for alternatives to dike raising. Therefore, these present ideas are more in accordance with the Way (Tao) of water, or "control by not controlling". This reflects that Taoism is the heading direction of flood control for the YR as long-term strategy.

In brief, philosophies of Confucianism and Taoism guided the historical flood control as the two dominant ethical approaches alternatively conducted in the basin. This is also partially caused by the fact that scientific approaches were not much developed or weighed by the government till recent decades. Not surprisingly, without proper scientific and technical approaches, the YR remained a Chinese Sorrow for a long time.

2.2.3 Modern flood control: a way towards Taoism

Nowadays scientific and technological approaches in diverse fields are being applied in modern YR flood management. Both structural measures and non-structural measures are adopted. Structural measures include reservoirs, diversion structures, detention basins, embankment, dredging, channel modifications, etc. Non-structural measures include flood warning systems, telecommunication technology, land use zoning, etc. Also, short-term flood control measures (e.g. flood control system operation and sediment trapping systems) are combined with long-term flood management measures (e.g. soil and water conservation projects). Most of the flooding problems of the YRB are now controlled (or harnessed as the Chinese call it) by the construction of major reservoirs. Only the lower YR downstream of Xiaolangdi is still free flowing. The flood control system of this section (see Figure 2.3) is based on the operation principle of "retaining water at the upper stream, discharging at the downstream and retarding at detention basins on both banks". This approach is comparable with the IWRM oriented approach to flooding as implemented in many western countries.

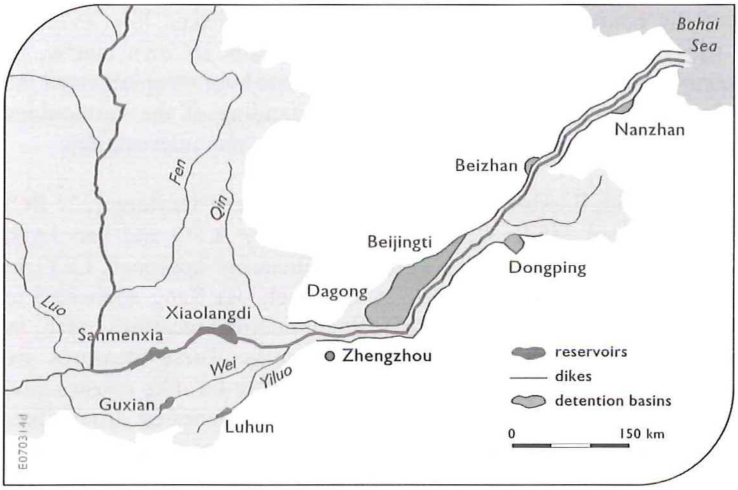


Figure 2.3 Flood control system in the Lower Reach of the YR

However, the first results indeed indicate that modern scientific and technical approaches to IWRM do not necessarily result in a promising and acceptable solution. The threats of flooding still exist and become more complicated as water scarcity and increasingly fragile environment interrelate among each other in the YRB. By providing a solution with IWRM to one problem, other and sometimes even more problems emerge.

At the turn of the 21st Century, YR flood management started to looking for alternatives to dike rising (Li and De Bruijn, 2003). These present ideas suggest a harmony attitude with nature instead of trying to control ("harness") it. This suggestion is more in accordance with the Way (Tao) of water, or "control by not controlling". This actually recalls the old philosophical debate on flood control in the YR. It reminds us people of the 21^{st} century that the historical ethical approaches should no longer be neglected. And, more important, this change of attitude indicates that Taoism becomes again the heading direction of flood control at the long-term strategy.

2.2.4 Taoism as philosophical basis

The recent tendency of flood control in the YRB returns to Taoism. Compared with Confucianism, Taoism gives more emphasis to nature and to harmonization of humans with nature. It seems time to reinforce Taoism in China to promote a strong concern the human's relationship with nature and to provoke people at all level to care for nature (Li et al 2004). As a strong vehicle towards awareness building, Taoism can be accounted to provide the proper philosophical basis to IWRM in the YRB. Actually, the Taoism philosophy of co-operating with nature is not very specific for China. The same approach, without a reference to Taoism, is practised in other river systems in the world, e.g. in Bangladesh (Islam, 2001), the lower Missouri (Criss and Shock, 2001), the Napa River in California (Wheeler, 1998) and the Netherlands (Klijn et al, 2001; Li and De Bruijn, 2003). It is not the approach as such that is advocated but the ethical basis that influences the people's awareness and co-operation. Without such strong ethical basis a new approach to river management cannot successfully be implemented.

2.3 Two approaches to integrated allocation in the YRB

It has been argued that both approaches are important for successful IWRM implementation, i.e. ethical approaches and scientific and technological approaches. Then the indigenous Chinese philosophy of Taoism is debated to be able to provide proper basis of IWRM for the YR. The following question is how Taoism can be interpreted as ethical approaches to deal with water allocation issues in the YRB. This will be answered in this section.

2.3.1 Ethical approaches

All major environmental conferences of the last three decades (Mar del Plata, Dublin, Rio, Johannesburg, etc.) called for an improved water management, with an emphasis on sustainability and a more equitable distribution of water. Sustainability asks for a harmonization of human activities with nature.

2.3.1.1 The equity principle

Selborne (2000) mentions that if ethics are to be the basis for resolving intricate questions involving a multiplicity of often conflicting perceptions, a foundation of agreed upon principles must underpin public policy. The following Guiding Principles thus address the need to contribute to the water debate by identifying a number of fundamental concerns that go beyond science and to find ways of putting people at the heart of an increasingly complex, fragmented and impersonal vision of the world. The emphasis is on the notions of solidarity, social justice, equity, water as a common good and ecological stewardship that have emerged as the principle issues of our time. They are in no way exhaustive but should be viewed as opening, rather than concluding, the (international) dialogue on the ethical dimension of freshwater resources that is so vital for human development.

'Equity' in availability and applicability of water is an important ethical issue at all levels, from local community to the global scale. Indeed, at the heart of all water conflict management is the question of equity. 'The art and practice of equitable distribution of and access to fresh water for all people in the 21st century, as a fundamental human right and international obligation, is the mother of all ethical questions of all transboundary natural resources of a finite nature.' (Odhiambo, 1999). Some argue that 'application of an equitable water-sharing agreement is a prerequisite… to hydropolitical stability, which finally could help propel political forces away from conflict in favour of cooperation (Wolf, 1996; Wolf and Dinar, 1994).

The principle of equity is key to water allocation (Wouters, 1997; Wolf, 1999), which was also the premise of the 1966 Helsinki Rules (McCaffrey, 1993). The equity principle is described as 'all people have basic rights of access to resources for their survival and development; no groups in society should be put at a serious disadvantage in this respect (Savenije and Van der Zaag, 1998)'. The equity principle is related to transboundary principles, water-as-an-economic-good principle, and eventually precautionary principles. Equity needs to be applied between water users, between existing and potential users and between consumers of water and the environment.

However, 'the distribution of rights and duties is problematic and no easy solutions are in sight, but attention and awareness are essential. The ethical community has been expanded from a human dimension to include an ecological dimension, which aggravates the dilemma (Harremoës, 2002). Fortunately, in the light of ethics by promoting Taoism approaches, such 'dilemma' might be tackled and the 'attention and awareness' can be strengthened.

As argued above, Taoism is more preferable to be chosen as proper philosophical basis of IWRM. According to the Taoism's cornerstone document *Tao Te Ching*, "The Tao of Heaven is to take from those who have too much and give to those who do not have enough (Chapter 77)." That is to say, the rich should feel obligated to help the poor. This also means that everyone is provided with proper chances to make a living. People from different groups or different class are not differentiated between the superior and the inferior, or between the noble and the base. So it is completely possible for them to live in harmony and equity, to exist and develop corporately, to communicate with one another, and to promote appreciation of each other (Zhou, 2006). Influenced by Taoism, the major objective of 'basic social services for all' is to be pursued and applying equity principles can provide a kind of base to avoid conflicts from the very beginning.

2.3.1.2 Reserve water

Taoism, the root of Chinese culture, pursues harmony between human and nature. Taoist believe that every thing in universe is a reasonable being, and that nature is not inferior to man, but has the same equal status and value as man. The Taoist ethical idea of "I am One with all things" promotes to establish the concept of man and nature having equity. In the Taoist opinion, all things in the universe vary in their appearances, but have the same origin. As it is said that "The universe and I came into being together; I and everything therein are One," (Chuang Tzu, Chapter 2.) man is equal to nature just like everything being equal to each other in their value. Man therefore should confer equal respect on all things living and non-living, and vindicate the right of all things for existence. People must transcend the misbelieve of blinkered anthropocentrism, and counter that it is too aggressive to collect material wealth or even employ natural resources in the same way as to 'kill the hen to get the eggs'. They should use natural resources in a reasonable and abstemious way, by which not only they keep their healthy life, but also nature takes its course.

Taoist ethical ideas of 'the harmonious oneness of the universe' and 'man Tao follows what is natural' are in favour of the harmoniousness of human and nature. This Taoism doctrine lays a proper philosophical basis to imply the concept of 'reserve water' in water allocation. Reserve water is defined as the amount of water required to meet basic human needs and to maintain environmental sustainability (DWAF, 1998). Designated as the *Reserve*, it is considered as a right. This reserve may be used for primary water requirements of the population and for the water requirements of riverine ecosystems. This is grounded from the facts that (in many places of the world) the unfairness of the situation in the water sector can be so enormous that certain constitution itself starts to guarantees access to water and a healthy environment for every citizen (Lévite and Sally, 2002; Zaag et al, 2002). With ethical approaches based on Taoism, reserving water out of negotiation for basic human needs and for nature should be appreciated in water allocation practice in the YR.

In conclusion, the ethical approaches based on Taoism philosophy can motivate people from all levels to accept and implement the equity principle and promote the 'reserve water' concept for integrated water allocation for the YR. This ethical approach is supposed to be combined with scientific and technical approaches to prevent and mitigate the conflicts among provinces caused by limited water availability in the YR.

2.3.2 Scientific and technological approaches

2.3.2.1 Application of systems analysis

Planning, designing and managing water resources systems today requires a structural analysis approach in which the positive effects (e.g. additional crop production) of proposed developments and management is balanced against the negative effects (e.g. costs and environmental impacts. To deal with the complexity of the system a systems analysis approach is often used. A systems analysis approach basically divides the full system into sub-systems and analyses those individual sub-systems in relation to the other sub-systems. Once the sub-systems and their interrelations are understood they are integrated back into the overall system and a comprehensive analysis is carried out.

Basically a systems analysis approach requires two frameworks. The first framework is an explicit description of the various stages involved in planning. This framework is often referred to as the *analytical* (or conceptual) framework. An example of such framework is described in Loucks and Van Beek (2005). An analytical framework requires the definition of subsystems. For IWRM the following subsystems can be identified; the natural resource system (NRS), the socio-economic system (SES) and the administrative and institutional system (AIS) as described in section 2.2.1 and illustrated in Figure 2.1. Within this analytical framework a set of coherent models for the quantitative analysis of measures and strategies is used. This set of models and related databases is often referred to as the *computational* framework. The next section deals with the computational framework as used in this study. The analytical framework will be followed in the analysis steps as described in the next chapters.

2.3.2.2 Use of computer models in Systems Analysis

The starting point of scientific and technological approaches to integrated YR water allocation is proper model application in order to gain a clear picture of water allocation problems. In this study, the software package RIBASIM (RIver BAsin SImulation Model) is applied to simulate different water allocation alternatives.

RIBASIM is designed for any analysis which requires the water balance of a basin to be simulated. To perform simulations with RIBASIM, a model schematization of the study area (i.e. the YRB) is set up, in which all the necessary features of the basin are represented by nodes connected by links. There are four main groups of elements to be schematized in the model:

i) infrastructure (surface and groundwater reservoirs, rivers, lakes, canals, pumping stations, pipelines), both natural and man-made;
ii) water users (public water supply, agriculture, industry, hydropower, aquaculture, navigation, nature, recreation), or in more general terms: water related activities;
iii) management of the water resources system (reservoir operation rules, allocation methods); and
iv) hydrology (river flows, runoff, precipitation, evaporation) and geo-hydrology (groundwater flows, seepage).

Such a network schematization can represent all basin features which are significant for its water balance analysis.

Major hydrologic relations/processes included in RIBASIM are flow transport and balance from river outlets/ reservoirs to crop fields or DMI demand sites. Moreover, RIBASIM can include hydrologic process of return flows from irrigated and urban areas, interaction between surface and groundwater, evapotranspiration in irrigated areas, as well as physical bounds on storage, flows, and diversions. Given long term series of natural runoff (surface water income from sub-catchment) and groundwater inflow, the influence of catchment water utilisation on the YR mainstream water availability (mainstream discharge) can be analyzed.

Basically, the water balance calculation is carried out in two phases:

i) Target setting phase (demand phase). In this phase, it is important to determine all the water demands, targets of discharge from surface water reservoirs, aquifers and targets of diversion flows at weirs and pumping stations.
ii) Water allocation phase (supply phase). In this phase, allocation of water to the users will be realized according to the targets, water availability and allocation rules.

RIBASIM can realise water allocation in several ways. "First come, first served" along the natural flow direction is the basis for its water allocation. This allocation pattern can be amended by rules which, for example, allocate water according to priority to certain particular users, or allocate water proportionally to demand. By tracing and accumulating upstream analyses, the water availability at a certain site (both nodes and links) can be assessed if the given demand will be met under the chosen runoff conditions. By tracing and accumulating downstream analyses, water discharges at certain (river) section can be quantified if all downstream demands should be satisfied.

By water allocation priority simulation, different water demand satisfying degrees among different water use sectors and provinces can be illustrated. Moreover, the water allocation priority setting can be adjusted not only among water sectors or among provinces, but also within one use sector or one user (e.g. within an irrigation district). By such, it is possible to see how and whether some specific water allocation requirements can be met. Besides priority simulation, scenarios of water re-allocation especially under drought conditions can be modelled by changes of the node or link attributes.

Another feature of RIBASIM is its capability to determine irrigation water demand, the major YR water user in the YR in details. When advanced irrigation nodes are included in basin schematization, RIBASIM can activate its module of AGWAT (the AGricultural WATer demand model) to analyze water consumption at a rather detailed level. Basically, AGWAT is used for the calculation of crop water requirements determined by the following factors, related to soils and hydro-meteorological conditions or to agricultural and irrigation practice, i.e.:

- potential evapotranspiration and crop factors;
- expected and actual rainfall;
- seepage and readily available soil moisture;
- cropping patterns and cropping intensities;
- cropping calendars;
- instantaneous water supplies related to specific farming operations;
- irrigation efficiency and re-use of drainage water for irrigation;
- acreage of irrigated areas; and
- staggering periods and starting dates for land preparation.

The calculation of water demands in irrigated agriculture is divided into 2 phases. First, the calculation of net water demands and drainage losses will be carried out, then is the calculation of total gross water demands and drainage losses. Another advantage of AGWAT is that it can also take water shortage into account.

Through RIBASIM water allocation simulation, the performance of the basin can be evaluated in terms of water allocation, water shortages, firm and secondary hydropower production, overall river basin water balance, crop production, water supply reliability, groundwater use, etc. Basin performance evaluation by such explicit indexes is beneficial for comparison and choice making of alternative water allocation schemes.

In addition, the main functions of loading data, calculating and reviewing results, are handled through an interactive screen structure in RIBASIM. Such easy use of the model and its user-friendly interface gives it the added capability of facilitating dialogue among the various stakeholders with an interest in water allocation and management in the basin.

For above reasons, RIBASIM has been chosen as an ideal tool to analyze possible water allocation strategies under severe water shortage conditions and under changed social economic conditions in the YRB. Flexible water allocation schemes among or within different water users can be simulated and rapidly assessed by explicit indexes under alternative scenarios. RIBASIM enables stakeholders to understand the linkages between water utilization activities in some regions or water use sectors and their consequences in some other regions or sectors, to gain transparent pictures of allocation alternatives. The most acceptable or most satisfying water allocation schemes can be explored to formulate promising strategies that aim to alleviate water shortage deduced conflicts subsequently.

2.3.3 Combination of the two approaches

To recap, the ethical approaches in the context of integrated water allocation for the YRB are based on Chinese indigenous philosophy of Taoism. Taoism can motivate and stimulate the application of equity principle and promote the concept of reserve water to harmonise human and nature. Scientific and technical approaches are establishment of advanced model application of RIBASIM to provide insight of the YR water allocation problems and to function as a platform for provinces to participate, negotiate and cooperate with each other.

The combination of the two approaches is by translation of equity principle in scheme design outlines where the concept of reserve is also considered. Following these design outlines, different equitable inter-provincial water allocation schemes can be formulated. Afterwards, by RIBASIM simulation, the evaluation of these equitable schemes can be carried out to illustrate their advantages/shortcomings over the 1987 Scheme. Feedbacks to institutional arrangements and legislation will also be derived for improvement of integrated water allocation in the YRB.

In the next chapter, the RIBASIM model application for YR water allocation will be established and calibrated. In Chapter 4, facilitated by RIBASIM simulation, water allocation problems in the YRB at present and in future will be analyzed in depth. Then, in Chapter 5 and 6, concrete methods to combine ethical approaches with scientific and technical approaches will be introduced and analysed.

The combined two approaches is a step by step process aiming to give higher priority of nature, to balance economic and environmental development without compromising future generations' benefits. In fact, this study is one of the few tempts if not the first tempt to explore YR basin sustainable development based on combined ethical and technical and scientific approaches in the context of IWRM in its water management history.

3 Developing a water allocation model for the YRB

To enable an analysis of possible YR basin wide water allocation strategies across sectors and provinces it is needed to develop water balance and allocation model for the basin. Generally, a water allocation analysis follows four steps: 1) problem definition, including system and analysis conditions; 2) establishment of 'current accounts', which provides a snapshot of the actual water demand, resources availability and resources supply for the system; 3) scenario building based on different sets of future trends caused by policies, technological development, and other external factors that affect demand, supply and hydrology; and finally 4) evaluation of alternatives with regard to criteria such as adequacy of water resources, costs, benefits, environmental impacts, etc. This Chapter 3 deals only with the first two steps, in particular the basin schematisation, arranging the input data, base case calibration and validation. The remaining steps of the analysis will be described in Chapter 4 and Chapter 5.

3.1 Setup of model application for the YRB

3.1.1 System boundaries

For water resources management the river basin is the most appropriate unit of analysis because it is at the basin level that hydrological, economic and ecologic relationships can be integrated into a comprehensive analysis framework. The competition for water across sectors and among provinces increases the importance of the river basin as the appropriate unit of analysis. Modelling at this scale can provide essential information for policymakers in their resource allocation decisions. In this research, water allocation is set according to the hydrology boundary of the YRB but with due consideration to the administration boundaries of the provinces. The upper-boundary of the river system schematization will be the Longyangxia reservoir upstream while the lower-boundary will be the Lijin monitoring station (see also Figure 1.3).

The YRB is an open system in the sense that some administrative units outside the actual hydrological boundaries of the basin heavily rely on water diverted from the YR to meet their agriculture and domestic, municipal and industrial (DMI) water demands. These units include Hebei and Tianjin (to the North of Shandong province) and the national crop 'base' YR Lower Reach Diversion Irrigation District.

Accordingly, the natural resource boundaries in this study are based on the hydrological boundaries for the upper and middle YR reaches. For the lower reach the boundary is drawn beyond the hydrological boundaries till where there is supposed to be no water use from the YR anymore. This includes Hebei and Tianjin.

3.1.2 Water utilisation division

Considering the variation in hydrology and water related activities from region to region, it is necessary to divide the YR basin into smaller parts. The general China national water resources planning divides the YRB up into 8 regions, 20 sub-regions and 45 sub-sub-regions. This division is based firstly on the hydrological boundaries and secondly on the administrative boundaries and has been used in most research for water resource planning for the YRB.

However, in order to clarify the causes and effects of water related conflicts among provinces, more transparent information is needed on the provincial water allocation and utilization. In this research more emphasis is laid on the administrative boundaries within the hydrological boundaries. This required that modifications are made compared to the above described division. Some sub-sub-regions within certain catchment boundaries are merged in case they are within the same provincial boundary. On the other hand some sub-sub-region within certain catchment boundaries that is located in more than one province is divided into smaller units. In this way, the linkages between provincial water users and river sections or catchments are more clearly indicated. The name of the divisions as 'province_main-river-section: catchment' tells from which province, in which section of the YR mainstream and within which catchment or tributary the division is located. Sometimes when the tributaries are not very important, the last part of the name is used as YR in general (see Table 3-1). In total, 30 water utilization divisions (29 inside the basin + Tianjin/Hebei) are defined whose hydrological and administrative relationships can easily be recognized, presented in Figure 3.1.

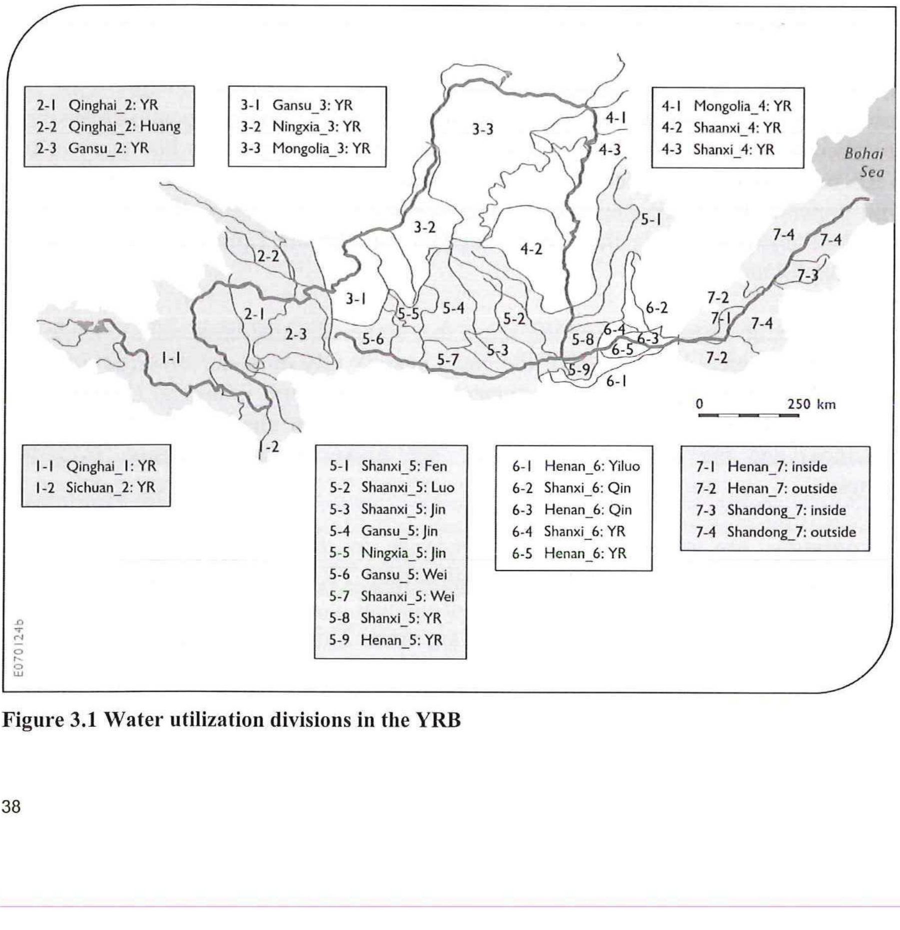


Figure 3.1 Water utilization divisions in the YRB

As indicated in the table, some water use regions are neglected for two factors. The first factor is the scarce population and limited economic activity in the region, often very upstream of a tributary. The other factor is an internal drainage condition where the water supply and utilization process is taking place in a closed system and does not have sensible impact on the water availability or on water users outside. In total, the neglected area to the whole basin is about 7.75%, in which 5.28% is the internal drainage basin. Apparently those neglected regions will neither have much influence on the performance of the whole basin, nor will they have accounted impacts on the provincial water allocation.

Table 3-1 Water utilization divisions in the YRB

River section	Hydrological boundaries	Administrative provincial boundaries	Division name[1]
1	Above Longyangxia	Qinghai Sichuan *Gansu (neglected)*	Qinghai_1: YR Sichuan _1: YR
2	Longyangxia – Lanzhou	Qinghai: Longyangxia – Provincial Boundary Qinghai:Huangshui[2], Datong *Gansu : Huangshui (neglected)* Gansu: Taohe, Daxiahe, Zhuanglanghe, mainstream	Qinghai_2 : YR Qinghai_2: Huang Gansu_2: YR
3	Lanzhou – Hekouzhen	Gansu: Longzhong high land Ningxia *(its internal drainage area: neglected)* Inner Mongolia *Shanxi: internal area: neglected*	Gansu_3: YR Ningxia_3: YR Mongolia _3: YR
4	Hekouzhen – Longmen	Inner Mongolia Shaanxi Shanxi	Mongolia_4: YR Shaanxi_4: YR Shanxi_4: YR
5	Longmen – Sanmenxia	Shanxi: Fenhe Shaanxi: Luohe Gansu:Luohe (neglected) Shaanxi:Jinhe Gansu:Jinhe Ningxia:Jinhe Ningxia:Weihe (neglected) Gansu:Weihe Shaanxi:Weihe Shanxi:Longmen-Sanmenxia mainstream Henan: Longmen-Sanmenxia mainstream	Shanxi_5: Fenhe Shaanxi_5: Luohe Shaanxi_5: Jinhe Gansu_5: Jinhe Ningxia_5: Jinhe Gansu_5: Weihe Shaanxi_5: Weihe Shanxi_5: YR Henan_5: YR
6	Sanmenxia – Huayuankou	Henan:Yiluohe Shaanxi:Yiluohe (neglected) Shanxi:Qinhe Henan:Qinhe Shanxi:Sanmenxia-Huayuankou mainstream Henan:Sanmenxia-Huayuankou mainstream	Henan_6: Yiluohe Shanxi_6: Qinhe Henan_6: Qinhe Shanxi_6: YR Henan_6: YR
7	Huayuankou – Bohai	Henan diversion irrigation district, inside basin Henan diversion irrigation district, outside basin Shandong diversion irrig. district, inside basin Shandong diversion irrig. district, outside basin Tianjing, Hebei (transfer PWS)	Henan_7: inside Henan_7: outside Shandong_7: inside Shandong_7:outside Tianjin-Hebei
Total neglected region area's percentage to YRB		61,578 km^2 / 794,712 km^2 = 7.75%, in which the internal drainage area is 42,000 km^2, 5.28% of total basin area	

[1] Division name describes 'province_main-river-section_catchment'.

[2] 'shui' or 'he' stands for 'river' in Chinese

3.1.3 Basin schematization

To perform simulations a model schematization of the study area is set up, in which nodes represent physical entities and links represent the connection between them. The basin water utilisation division itself provides the very basis for such schematisation. Each water utilisation division consists of two categories of nodes: 1) water supply nodes: variable inflow nodes presenting natural runoff and groundwater reservoir nodes presenting groundwater aquifers; and 2) water demand nodes: PWS (Public Water Supply) nodes and irrigation nodes. Along the main channel, key mainstream reservoirs are included as well as their regulation rules. Flow constraints and losses are also accounted, i.e. ice-jam flood control, low flow requirement, channel seepage, etc. The nodes and links in the YRB schematization are summarized in Table 3-2 and Table 3-3. Detailed information of the basin schematization is to be further explained in the following paragraphs.

Table 3-2 Schematization of the YRB - summary of the nodes

Category	Node type	Physical entity	Represents	Nr
Water supply	Variable inflow	Natural runoff	Natural runoff of each water utilisation division	29
	Fixed inflow	GW aquifer recharge and channel storage flow	GW recharge for each GW aquifer in every water utilization division, channel storage flow release by ice melting	30
	GW reservoir	GW aquifer	GW aquifer in every water utilization division	23
Water demand	Irrigation	Irrigation agriculture	Demand of large scale irrigated agriculture of each water utilisation division. In total, 75% of all irrigation area in the basin.	29
	PWS	Water utilisation of domestic, municipal and industry	Public water supply for each water utilisation division	30
	Loss flow	Water loss other than water utilisation	Seepage in channels, irrigation districts, uncontrolled water withdraw, special 'balance_loss nodes' for segmental inflow correction	23
	Low flow	Minimum flow requirements	Environmental minimum flow including sediment flushing flow, ecosystem base flow, and soil and water conservation flow; and ice jam flood prevention*	4
Control nodes	SW Reservoir	SW reservoir and operation	YR backbone reservoirs which control 92% of YR inflow	6
	Diversion	water diversion from a river or canal to downstream demands	Water diversion to PWS and irrigation in each water utilisation division	34
Other nodes	Bifurcation	Incoming flow distribution over various downstream links	Only at natural gravity irrigation at Hetao irrigation district	2
	Confluence	Confluence of tributaries or canals	All over the basin where flows return from tributaries, PWS, irrigation, etc, or inflows are lumped	50
	Terminal	Downstream boundary of the river system	Outlet of the YRB	31

Table 3-3 Schematization of the YRB - summary of the links

Link type	Physical entity	Represents	Nr
Diverted flow link	Intake structure (gate) and canal	When flow is diverted from the main channel to the canal for outstream water uses in each water utilisation division	63
SW flow link	Connection between two nodes for SW flow	When necessary all over the basin schematisation	220
Bifurcated flow link	Flow from a bifurcation in the main river and the flow is a function of the upstream flow	Only at natural gravity irrigation at Hetao irrigation district	2
GW recharge link	Connection fixed inflow node and GW aquifers	For every GW reservoir nodes in most water utilization division	23
GW outflow link	GW outflow above GW storage capacity	For every GW reservoir nodes in most water utilization division	23
GW abstraction link	GW abstraction from aquifer by water users	For every GW reservoir nodes in most water utilization division	46

3.1.4 YRSIM model

YRSIM is an existing water resources simulation model for YR long term water resources planning developed by YRCC in early 1990s. The model is rather outdated but still in use and especially contains useful hydrological data. It describes the performance of the YR water system over time at a given demand and at a prescribed operation policy. Just like RIBASIM, YRSIM uses node and links to schematize the basin, and the flow in the links is generated on the basis of supply and demand described in the nodes. For this thesis, only two relevant documents were obtained from YRCC about this YRSIM model: general background introduction of YRSIM project and the primary analysis of YR water supply and utilization. These documents were analysed in relation to available hydrological and social economic data. While the model itself was not accessed thus no further details on the YRSIM will be given here.

3.2 Water supply

As described, each water utilisation division has one variable inflow node (SW) and one GW reservoir node which is recharged by fixed inflow nodes. The exceptions are the water utilisation divisions of Hebei and Tianjin which are outside the basin. Thus, 29 sets of variable inflow nodes and GW reservoir nodes are schematized, as shown in Table 3-4 below. It is important to point out that in some water utilization divisions, variable inflow nodes and/or GW reservoir nodes will be omitted if the water availability is too small to take this into account.

Table 3-4 Relation of variable inflow nodes to water utilization divisions in the YRB

Basin division	Variable inflow node	Fixed inflow node	GW reservoir node
1-1	Qinghai_1: YR_SW	Qinghai_2:Huang_GW	Qinghai_1:YR_GW RSW
1-2	Sichuan_1: YR_SW	Sichuan_1:YR_GW	Sichuan_1:YR_GW RSW
2-1	Qinghai_2: YR_SW	Qinghai_2:YR_GW	
2-2	Qinghai _2: Huang_SW	Qinghai_1:YR_GW	Qinghai_2:Huang_GW RSW
2-3	Gansu_2: YR_SW	Gansu_2:YR_GW	Gansu_2:YR_GW RSW
3-1	Gansu_3: YR_SW	Gansu_3:YR_GW	Gansu_3:YR_GW RSW
3-2	Ningxia_3: YR_SW	Ningxia_3:YR_GW	Ningxia_3:YR_GW RSW
3-3	Mongolia_3: YR_SW	Mongolia_3:YR_GW	Mongolia_3:YR_GW RSW
4 -1	Mongolia_4: YR_SW	Mongolia_4:YR_GW	Shaanxi_4:YR_GW RSW
4 -2	Shaanxi_4: YR_SW	Shaanxi_5:Jinhe_GW	
4 -3	Shanxi_4: YR_SW	Shanxi_4:YR_GW	
5-1	Shanxi_5: Fenhe_SW	Shanxi_5:Fenhe_GW	Shanxi_5:Fenhe_GW RSW
5-2	Shaanxi_5: Luohe_SW	Shaanxi_5:Weihe_GW	Shaanxi_5:Luohe_GW RSW
5-3	Shaanxi_5: Jinhe_SW	Shaanxi_5:Luohe_GW	Shaanxi_5:Jinhe_GW RSW
5-4	Gansu_5 : Jinhe_SW	Gansu_5:Jinhe_GW	Gansu_5:Jinhe_GW RSW
5-5	Ningxia_5: Jinhe_SW	Ningxia_5:Jinhe_GW	Ningxia_5:Jinhe_GW RSW
5-6	Gansu_5: Weihe_SW	Gansu_5:Weihe_GW	Gansu_5:Weihe_GW RSW
5-7	Shaanxi _5:Weihe_SW	Shaanxi_4:YR_GW	Shaanxi_5:Weihe_GW RSW
5-8	Shanxi_5: YR_SW	Shanxi_5:YR_GW	Shanxi_5:YR_GW RSW
5-9	Henan_5: YR_SW	Henan_5:YR_GW	Henan_5:YR_GW RSW
6-1	Henan_6: Yiluo Lushi_SW Henan_6: Yiluo Luhun_SW Henan_6:Yiluo down_SW	Henan_6:Yiluohe_GW	Henan_6:Yiluohe_GW RSW
6-2	Shanxi_6:Qinhe_SW	Shanxi_6:YR_GW	Henan_6:Qinhe_GW RSW
6-3	Henan_6: Qinhe_SW	Henan_6:Qinhe_GW	
6-4	Shanxi_6: YR_SW	Shanxi_6:Qinhe_GW	
6-5	Henan_6: YR_SW	Henan_6:YR_GW	
7-1	Henan_7: Jintihe_SW	Henan_7:InYR_GW	Henan_7:InYR_GW RSW
7-2		Henan_7:OutYR_GW	Henan_7:OutYR_GW RSW
7-3	Shandong_7: Dawenhe_SW	Shandong_7:InYR_GW	Shandong_7:InYR_GW RSW
7-4		Shandong_7:OutYR_GW	Shandong_7:OutYR_GW RSW

3.2.1 Variable inflow nodes

The determination of spatial differentiated natural water availability is an essential prerequisite to understand and to mitigate the economic and social impacts of droughts at provincial and basin level. A major difficulty in river basin modelling is to estimate such naturalized runoff from the watershed areas. Often, the available data allows only for crude approximations, either because of sparse and incomplete data sets from the gauging station network, or the gauged records do not represent virgin flow conditions. Two commonly used approaches are i) the application of rainfall-runoff models (monthly time series) or ii) station to station transposition techniques. Sometimes a combination of both methods is used. In this research, the YRSIM hydrological input data of natural runoff is mostly refereed to obtain the input of naturalized monthly flows at each variable inflow node. Below is a brief description of how YRSIM hydrological inflow data is referred and further treated in this thesis.

Data series choice

Two sets of hydrological data were available from YRCC: set A is a time series of the period 1965-1974 in corresponding to 48 sub-regions from YRSIM. Set B is a time series for the period 1952-1990 for many mainstream hydrology stations. Set A is based on the long time series of 1919-1979 which has been collected and developed by the YRCC Planning, Design and Survey Bureau (YRCC PDSB in short). Set B is collected and developed by the YRCC Hydrology Bureau. The YRSIM project (see Section 3.1.4) has made a comparative analysis of these two hydrological time series data and concluded that the two sets of data are consistent. The average annual natural flow comparison of the two sets of data is shown in Table 3-5.

Table 3-5 Comparison of two series of average annual natural runoff in the YRB ($10^9 m^3$)

Department of YRCC	Time period	Lanzhou	Hekouzhen	Huayuankou
A. Planning, Design and Survey Bureau	1919-1979	32.61	31.78	56.34
B. Hydrology Bureau	1952-1990	32.61	31.90	56.30

From the 1919-1979 time series of the YRCC PDSB, the ten year series of 1965-1974 is chosen in YRSIM model to represent the long term hydrology process including dry and wet years. The annual flow characteristics of series 1965-1974 and its comparison to the long time series of 1919-1979 by YRSIM are quoted in Table 3-6. Annual water yield in different river sections in representative years from 1965-1974 are shown in Table 3-7. Table 3-8 and corresponding Figure 3.3 can illustrate that the chosen 1965-1974 time series does present P=50%, P=75% and P=95% in a good way. The locations of the associated main gauge stations are given in Figure 3.2.

Table 3-6 Characteristics of annual runoff series 1965-1974 and its comparison to series 1919-1979, runoff in 10^9 m^3 - the stations below the line are on tributaries

Station	1965-1974				1965-1974 compared to 1919-1979			
	Average annual natural runoff	Coefficient of variation Cv	P=50% annual natural runoff	P=75% annual natural runoff	Average annual natural runoff difference	Cv ratio	P=50% annual natural runoff difference	P=75% annual natural runoff difference
Guide	21.3	0.26	19.9	17.1	-0.1	1.18	-0.4	0.4
Lanzhou	32.9	0.27	32.9	26.8	0.1	1.23	-1.2	0.0
Hekouzhen	32.8	0.29	27.8	26.5	0.3	1.26	-1.0	0.1
Longmen	39.0	0.29	33.6	31.7	0.0	1.32	-1.3	0.0
Sanmenxia	50.6	0.25	45.6	41.9	0.1	1.09	-0.6	0.0
Huayuankou	55.1	0.25	49.3	44.6	-0.2	1.04	-0.9	-0.4
Zhuangtou	0.8	0.35	0.8	0.6	0.4	0.81	0.7	2.3
Huaxian	9.0	0.32	7.3	6.7	0.3	0.82	-1.4	0.7
Hejin	2.5	0.30	2.5	1.8	2.3	0.73	2.9	2.8
Heishiguan	2.8	0.23	2.6	2.5	-2.0	0.55	-2.3	0.2
Xiaodong	1.1	0.44	1.0	0.6	-2.8	0.92	-2.6	-3.8

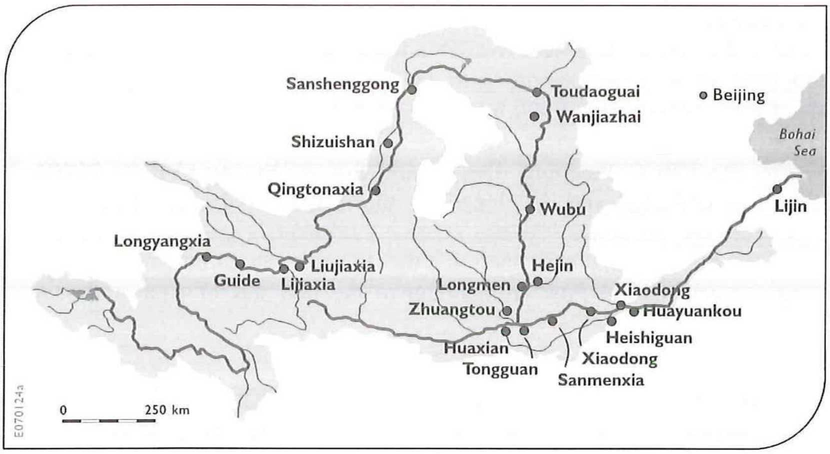


Figure 3.2 Main gauge stations in the YRB

Table 3-7 Annual water yield in representative years in the YRB, data series 1965-1974 from YRSIM ($10^9 m^3$)

Section	1	2	3	4	5	6	7
	Above Guide	Guide – Lanzhou[1]	Lanzhou – Hekouzhen[2]	Hekouzhen - Longmen	Longmen - Sanmenxia	Sanmenxia - Huayuankou	Huayuankou - sea
P=50%	19.9	11.4	0.9	5.9	12.6	5.1	2.3
P=75%	17.1	10.8	0.7	4.0	10.9	4.5	1.4
P=95%	14.8	9.3	0.5	3.3	8.2	3.3	1.0
Average	21.3	13.5	0.9	5.8	13.8	5.3	2.4

[1] Lanzhou is close to Liujiaxia

[2] Hekouzhen is close to Toudaoguai

Table 3-8 Average annual water yield at main river sections, data series 1965-1974 from YRSIM ($10^9 m^3$)

Hydrology year	Above Guide	Guide - Lanzhou	Longmen - Sanmenxia	Sanmenxia - Huayuankou
1965-1966	17.4	8.7	9.7	4.1
1966-1967	28.1	16.5	17.7	4.6
1967-1968	33.2	21.0	13.1	6.6
1968-1969	23.6	13.8	16.6	7.5
1969-1970	16.6	10.0	10.9	3.8
1970-1971	15.1	11.1	13.4	3.7
1971-1972	22.9	11.9	9.9	5.3
1972-1973	20.2	8.7	7.1	3.0
1973-1974	18.7	11.7	12.6	5.2
1974-1975	21.1	9.9	9.3	3.6

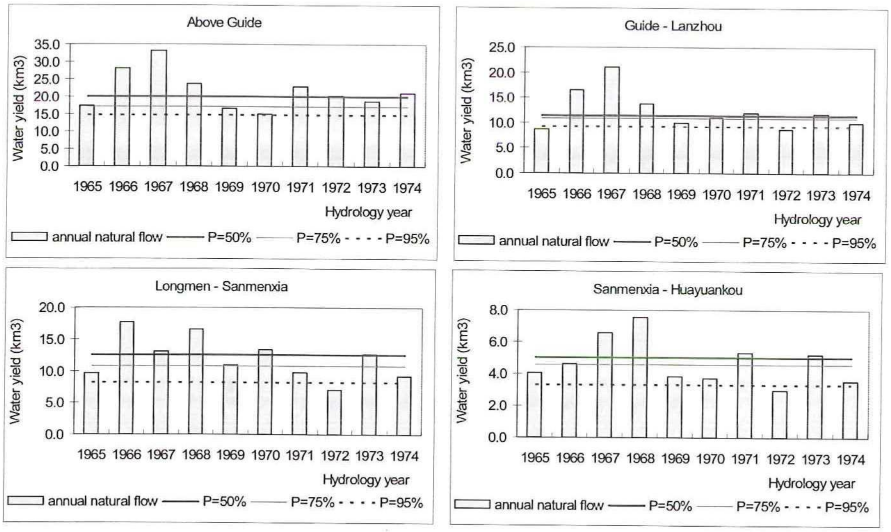


Figure 3.3 Representatives of annual natural runoff at main stations in the YR (from YRSIM)

This time series of 1965-1974 is referred in this thesis to represent the long term hydrology series of 1919-1979 in terms of the average annual natural flow, P=50% natural flow, P=75% natural flow, and Cv (coefficient of variation). Preferably a longer time series should be used (e.g. 40 years) but for computational reasons only 10 years was possible. Such short time series is considered acceptable as long as the variability in the process is sufficiently included.

As the original data sets of the two departments from YRCC are consistent, it is possible to use both 1965-1974 natural flow series as input for variable inflow nodes. For the 29 variable inflow nodes in relation to the 30 water utilization divisions, the data series of 33 hydrology stations from above mentioned 2 data sets A and B were used. Their data consistency was carefully checked with reference to the most reliable hydrology stations. To limit the length of the thesis, it is not described here in details.

Balance_loss nodes

While applying these series in water balance calculations it appears that for some sections (see Figure 3.4, upper), negative inflow occurs. This can be due to errors in the measurement of streamflow, estimation of water usage, GW recharge, etc. Such negative inflow values are difficult to accommodate in water balance models as inflow input. A 'work-around' has been applied by artificially increasing these negative inflows by specifying a flow rate of zero in the inflow nodes, while applying a flow reduction at a so-called 'balance_loss' node immediately after the inflow node. In this way, the system boundary inflow is actually not increased and negative inflow values are avoided. The basic information on balance_loss nodes is shown in Table 3-9 where possible causes of negative inflow are pointed out by YRSIM. The total adjusted inflow by these balance nodes is 22,990 m^3/s, or 10.64% of the total inflow at the Lijin station.

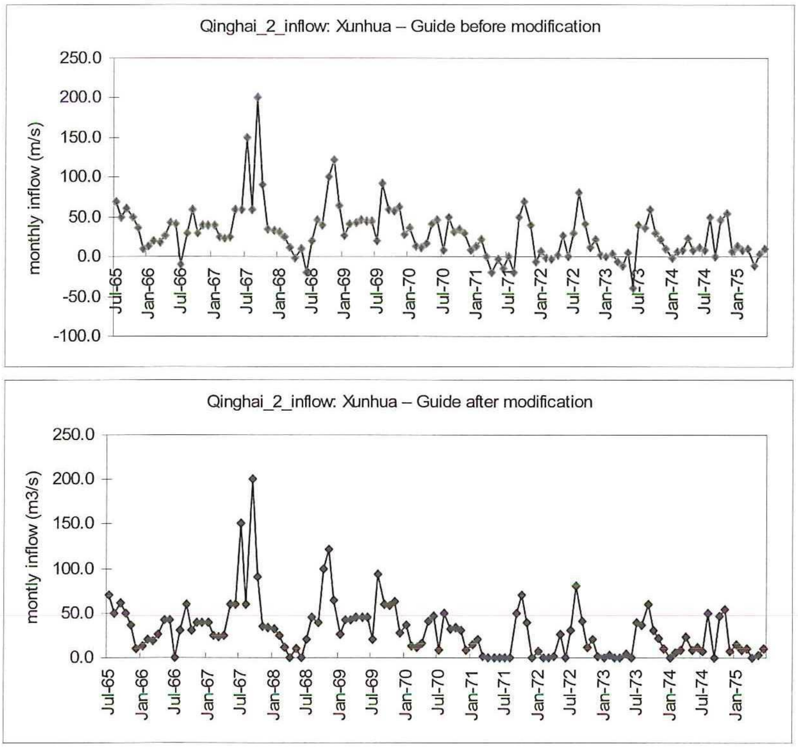


Figure 3.4 Example of modification of natural runoff at Guide station in the YR

Table 3-9 Basic information on balance_loss nodes in the YRB (m^3/s)

Index	Node	Adjusted inflow	Main causes of negative inflow
1	Lijiaxia_Balance_loss	168.0	Error on hydrology data measurement due to large catchment area
2	Liujiaxia_Balance_loss	106.0	Error on evaporation, seepage
3	Lanzhou_Balance_loss	965.0	Error on estimation of water abstract for some small scale irrigation districts, on data measurement in large catchment
4	Qingtongxia_Balance_loss	3114.0	Error on estimation of evaporation and irrigation return flow
5	Hekouzhen_Balance_loss	3518.2	Error on estimation of irrigation, GW recharge, return flow, evaporation
6	Longmen_Balance_loss	6879.1	Error on data measurement where GW seepage is significant in the Loess Plateau
7	Sanmenxia_Balance_loss	1712.0	Error on estimation of irrigation, GW recharge
8	Huayuankou_Balance_loss	5181.1	Error on hydrology data measurement
9	Lijin_Balance_loss	1346.0	Error on estimation of irrigation, GW recharge

3.2.2 Groundwater Reservoir nodes

In general GW availability does not change much over the years and it is assumed in this research that the GW availability is equal to the annual GW utilization in the YRB also due to limited available information. In RIBASIM, it is further assumed that the GW supply is constant throughout a year. That is, the sum of annual GW utilization in each water utilisation division is averaged as monthly input to the fixed inflow nodes. This means that the decrease of the GW level (depletion) will not be considered and its possible impact on the total water balance is not represented.

3.3 Water demand

In each water utilization division one irrigation node and one PWS node present the local agricultural and DMI water utilisation. The relations of the irrigation nodes and the PWS nodes to the water utilization divisions are given in Table 3-10. The agriculture and DMI demand in the internal drainage basin is neglected considering its separate closed water supply and utilization system.

Table 3-10 Irrigation and PWS nodes: relation to water utilisation division in the YRB

Index	Water utilization district	Advanced irrigation node	PWS node
1-1	Qinghai_1: YR	Qinghai_1: YR_AdvIRRI	Qinghai_1: YR_PWS
1-2	Sichuan _1: YR	Sichuan _1: YR_AdvIRRI	Sichuan _1: YR_PWS
2-1	Qinghai_2 : YR	Qinghai_2 : YR_AdvIRRI	Qinghai_2 : YR_PWS
2-2	Qinghai_2:Huang	Qinghai_2:Huang_AdvIRRI	Qinghai_2:Huang_PWS
2-3	Gansu_2: YR	Gansu_2: YR_AdvIRRI	Gansu_2: YR_PWS
3-1	Gansu_3: YR	Gansu_3: YR_AdvIRRI	Gansu_3: YR_PWS
3-2	Ningxia_3: YR	Ningxia_3: YR_AdvIRRI	Ningxia_3: YR_PWS
3-3	Mongolia _3: YR	Mongolia _3: YR_AdvIRRI	Mongolia _3: YR_PWS
4-1	Mongolia_4: YR	Mongolia_4: YR_AdvIRRI	Mongolia_4: YR_PWS
4-2	Shaanxi_4: YR	Shaanxi_4: YR_AdvIRRI	Shaanxi_4: YR_PWS
4-3	Shanxi_4: YR	Shanxi_4: YR_AdvIRRI	Shanxi_4: YR_PWS
5-1	Shanxi_5 : Fenhe	Shanxi_5 : Fenhe_AdvIRRI	Shanxi_5 : Fenhe_PWS
5-2	Shaanxi_5:Luohe	Shaanxi_5:Luohe_AdvIRRI	Shaanxi_5:Luohe_PWS
5-3	Shaanxi_5: Jinhe	Shaanxi_5: Jinhe_AdvIRRI	Shaanxi_5: Jinhe_PWS
5-4	Gansu_5 : Jinhe	Gansu_5 : Jinhe_AdvIRRI	Gansu_5 : Jinhe_PWS
5-5	Ningxia_5: Jinhe	Ningxia_5: Jinhe_AdvIRRI	Ningxia_5: Jinhe_PWS
5-6	Gansu_5 : Weihe	Gansu_5 : Weihe_AdvIRRI	Gansu_5 : Weihe_PWS
5-7	Shaanxi_5:Weihe	Shaanxi_5:Weihe_AdvIRRI	Shaanxi_5:Weihe_PWS
5-8	Shanxi_5: YR	Shanxi_5: YR_AdvIRRI	Shanxi_5: YR_PWS
5-9	Henan_5: YR	Henan_5: YR_AdvIRRI	Henan_5: YR_PWS
6-1	Henan_6:Yiluohe	Henan_6:Yiluohe_AdvIRRI	Henan_6:Yiluohe_PWS
6-2	Shanxi_6: Qinhe	Shanxi_6: Qinhe_AdvIRRI	Shanxi_6: Qinhe_PWS
6-3	Henan_6: Qinhe	Henan_6: Qinhe_AdvIRRI	Henan_6: Qinhe_PWS
6-4	Shanxi_6: YR	Shanxi_6: YR_AdvIRRI	Shanxi_6: YR_PWS
6-5	Henan_6: YR	Henan_6: YR_AdvIRRI	Henan_6: YR_PWS
7-1	Henan_7:inside	Henan_7:inside_AdvIRRI	Henan_7:inside_PWS
7-2	Henan_7 : outside	Henan_7 : outside_AdvIRRI	Henan_7 : outside_PWS
7-3	Shandong_7:inside	Shandong_7:inside_AdvIRRI	Shandong_7:inside_PWS
7-4	Shandong_7: outside	Shandong_7: outside_AdvIRRI	Shandong_7: outside_PWS
			Hebei-Tianjin_PWS
Total	29	29	30

3.3.1 PWS nodes

In this research, it is assumed that the monthly PWS is constant throughout the year and that unconsumed PWS (the difference between the withdrawal and the consumption) will return to the network. The monthly provincial PWS (m^3/s) and return flow percentages are calculated as the average values from the annual provincial PWS withdrawal and consumption rates according to YRCC Water Resource bulletin on 1999. Furthermore, the proportion of monthly PWS demands in each sub-sub-region within a province from YRSIM data on 1990 is used to determined the quantities of monthly PWS in different water utilization divisions within a province (where the latest concerned data is available).

3.3.2 Advanced irrigation nodes

As introduced in section 2.6.1.1, the AGWAT module in RIBASIM is used to calculate irrigation water demand in so-called 'Advanced irrigation nodes' which requires a much more elaborate approach. This demand varies substantially in time and space depending on:

- type of crops;
- crop coefficients, depending on the type and growing stage of a crop;
- dates when farmers start land preparation;
- cropping calendars including occasional water supplies for land preparation, weeding, fertilize applications, etc;
- status of the irrigation system and related irrigation efficiency; and
- soil types and agro-climatic factors.

In this research the main steps to calculate the agricultural water demand are:

1) calculation of actual effective rainfall,
2) specification of soil features of seepage and soil moisture capacity,
3) computation of net crop water requirement,
4) determination of cropping calendar and cropping pattern, and
5) specification of irrigation efficiency

The actual effective rainfall that is stored in the crop root zone needs to be calculated to determine the irrigation water demand. An empirical way to estimate the effective rainfall is to multiply the actual monthly rainfall by an effectiveness rainfall factor (% of actual monthly rainfall) that is obtained from YRSIM data. This effectiveness varies between 0.55 and 0.75 when monthly actual rainfall changes from 100mm to 200mm.

The soil texture and structure influences the drainage characteristics and permeability of the soil. For paddy rice fields the permeability is decisive, while, for dry land crops the soil moisture content between field capacity and wilting point is important. To determine those associated parameters for paddy rice fields and dry land crops, a literature review has been carried out on irrigation practices related to the YRB, i.e. Chen and Guo et al (1995), Irrigation Handbook (Xiong et al, 1994), Chen and Kang (1995), Li (1999), Zhang et al (1998), Li et al (2000), Peng and Li (2000, 2001a, 2001b), Peng et al (2002a, 2002b). FAO technical report 56 by Allen et al, 1998, was also taken into account. These documents were also used to determine other parameters that will be explained in the following sections, such as the net crop water requirement, cropping patterns, irrigation efficiency, etc.

3.3.2.1 Computation of net crop water requirement

The net crop water requirement (*W*) for a given crop is given by Eq. 3.1:

$$W = \sum_{i=0}^{T} (K_{c,i} \cdot ET_{0,i} - P_{eff,i}) \qquad \text{Eq. 3.1}$$

where

$K_{c,i}$	the crop coefficient of the given crop during the growth stage i;
T	the final growth stage;
$ET_{0,i}$	reference crop evapotranspiration during the growth stage i [mm];
$P_{eff,i}$	effective rainfall during the growth stage i [mm].

For this equation it is important to determine the reference crop evapotranspiration ET_0 and the crop coefficient K_c. $K_c{\cdot}ET_0$ is the actual crop evapotranspiration (ET_c).

To calculate the monthly ET_0, FAO Penman-Monteith method (FAO irrigation and drainage technical report 56, Allen et al, 1998) is widely used, see Eq. 3.2:

$$ET_0 = \frac{0.408(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \qquad \text{Eq. 3.2}$$

where

ET_0	reference evapotranspiration [mm day^{-1}];
R_n	net radiation at the crop surface [MJ m^{-2} day^{-1}];
G	soil heat flux density [MJ m^{-2} day^{-1}];
T	mean daily air temperature at 2 m height [°C];
u_2	wind speed at 2 m height [m s^{-1}];
e_s	saturation vapour pressure [kPa];
e_a	actual vapour pressure [kPa];
$e_s - e_a$	saturation vapour pressure deficit [kPa];
Δ	saturation vapour pressure curve at air temperature T [kPa °C^{-1}];
γ	psychometric constant [kPa °C^{-1}].

This Penman-Monteith equation has been incorporated in CROPWAT (FAO, 1993) which has been the most widely used for estimation of evapotranspiration and crop water requirement. Its CLIMWAT database includes ET_0 data of many stations in China. Those monthly ET_0 values from the YRB are used as input to the advanced irrigation nodes in RIBASIM.

3.3.2.2 Determination of cropping calendar and cropping pattern

The major crops grown in the YRB are spring wheat, spring maize, summer maize, paddy rice, winter wheat and cotton. When climatic and cultivation conditions are considered, they can be further classified into 20 crop types, each with different cropping growing stages, crop coefficient K_c for different growth stages. In total 33 cropping patterns are defined for the YRB are defined for each irrigation node. Some examples are shown in Table 3-11.

Table 3-11 Examples of cropping calendars in the Yellow River Basin

Cropping calendar for cropping Pattern 1: Jiexiu SprMaize

Stage	Main crop	J	F	M	A	M	J	J	A	S	O	N	D	days	Kci	A*
1	Jiexiu SprMaize				P									54	0.870	
2	Jiexiu SprMaize													32	0.870	
3	Jiexiu SprMaize													24	0.870	
4	Jiexiu SprMaize									H				30	0.870	
5	Jiexiu SprMaize									N				20		
6	Jiexiu SprMaize										IR			30		100

Cropping calendar for cropping Pattern 4 : Lanzhou SprWheat

Stage	Main crop	J	F	M	A	M	J	J	A	S	O	N	D	days	Kci	A*
1	Lanzhou SprWheat			P										63	0.695	
2	Lanzhou SprWheat													21	1.067	
3	Lanzhou SprWheat													17	1.054	
4	Lanzhou SprWheat													18	1.049	
5	Lanzhou SprWheat							H						28	0.975	
6	Lanzhou SprWheat							N	N	N	N			95		
7	Lanzhou SprWheat											IR		30		50

Cropping calendar for cropping Pattern 5: Yinchuan Rice Salinity

Stage	Main crop	J	F	M	A	M	J	J	A	S	O	N	D	days	Kci	A*
1	Yinchuan Rice					P								60	1.141	150
2	Yinchuan Rice													17	1.298	
3	Yinchuan Rice							SF						18	1.308	100
4	Yinchuan Rice													17	1.344	
5	Yinchuan Rice									SF	H			45	1.218	100

Cropping calendar for cropping Pattern 7: Linfen WinWheat, Kaifeng SumMaize

Stage	Main crop	J	F	M	A	M	J	J	A	S	O	N	D	days	K_{ci}	A*
1	Linfen WinWheat									P				24	1.485	50
2	Linfen WinWheat													142	1.087	
3	Linfen WinWheat													42	0.848	
4	Linfen WinWheat													22	1.104	
5	Linfen WinWheat													32	1.207	
6	Linfen WinWheat						H							7	1.263	
7	*Transition stage*						T							1		
8	Kaifeng SumMaize						P							27	0.909	
9	Kaifeng SumMaize													19	1.063	
10	Kaifeng SumMaize													20	1.29	
11	Kaifeng SumMaize									H				28	1.226	

Cropping calendar for cropping Pattern 16 : Kaifeng Cotton

Stage	Main crop	J	F	M	A	M	J	J	A	S	O	N	D	days	K_{ci}	A*
1	Kaifeng Cotton				P									63	0.62	
2	Kaifeng Cotton													29	0.853	
3	Kaifeng Cotton													62	1.353	
4	Kaifeng Cotton										H			42	0.981	
5	Kaifeng Cotton											IR		30		50

Cropping calendar for cropping Pattern 18 : Yuncheng WinWheat

Stage	Main crop	J	F	M	A	M	J	J	A	S	O	N	D	days	K_{ci}	A*
1	Yuncheng WinWheat										P			45	1.553	120
2	Yuncheng WinWheat													74	1.585	
3	Yuncheng WinWheat													53	1.182	
4	Yuncheng WinWheat													32	1.172	
5	Yuncheng WinWheat													14	1.049	
6	Yuncheng WinWheat						H							22	1.018	

Note: A*: instantaneous application, mm; H: harvest, P: plant; T: transition period;
N: no activity; IR: irrigation to store water for next crop; F: salinity flushing

Water logging is serious in Ningxia and Inner Mongolia and the salinity flushing water requirement plays an important role in the irrigation schedule, as shown in calendar Nr.4 and Nr.5. After the harvest of spring wheat, spring maize and cotton (in autumn), a considerable amount of water is also irrigated in early winter. This amount of water is stored in the soil for the crops of next year when limited rainfall and river discharge is available. In addition, the water storage does affect the soil temperature in winter. This amount of water is considered as an instantaneous irrigation application in certain cropping patterns. As shown in the tables for two-crop cropping patterns (calendar Nr.7), a transition period (*T*) is introduced during which farmers can harvest the first crop and, in the meantime, prepare the cultivation of the second crop. The transition period *T* actually stands for the starting dates of the cultivation of the second crop, and it can last as long as one staggering period, i.e. a month in this study, till the last farmer finishes the harvest and cultivation.

3.3.2.3 Investigation of irrigation efficiency

Investigation conducted on SW irrigation efficiency on some major irrigation districts in the YRB (YRSIM, Fu et al, 2001; Chang et. al., 2001) show that SW irrigation efficiency in the YRB is not high. It is often between 0.30-0.45 in individual irrigation districts. The canal distribution water use efficiency is about 0.45 - 0.50 and the field water use efficiency is between 0.80 and 0.90.

Table 3-12 Irrigation efficiency in the YRB (%)

Index	Advanced irrigation node	Irrigation efficiency
1-1	Qinghai_1: YR_AdvIRRI	75
1-2	Sichuan _1: YR_AdvIRRI	75
2-1	Qinghai_2 : YR_AdvIRRI	66
2-2	Qinghai_2:Huang_AdvIRRI	65
2-3	Gansu_2: YR_AdvIRRI	65
3-1	Gansu_3: YR_AdvIRRI	58
3-2	Ningxia_3: YR_AdvIRRI	41
3-3	Mongolia _3: YR_AdvIRRI	47
4-1	Mongolia_4: YR_AdvIRRI	45
4-2	Shaanxi_4: YR_AdvIRRI	62
4-3	Shanxi_4: YR_AdvIRRI	50
5-1	Shanxi_5 : Fenhe_AdvIRRI	50
5-2	Shaanxi_5:Luohe_AdvIRRI	58
5-3	Shaanxi_5: Jinhe_AdvIRRI	61
5-4	Gansu_5 : Jinhe_AdvIRRI	43
5-5	Ningxia_5: Jinhe_AdvIRRI	77
5-6	Gansu_5 : Weihe_AdvIRRI	49
5-7	Shaanxi_5:Weihe_AdvIRRI	75
5-8	Shanxi_5: YR_AdvIRRI	50
5-9	Henan_5: YR_AdvIRRI	56
6-1	Henan_6:Yiluohe_AdvIRRI	54
6-2	Shanxi_6: Qinhe_AdvIRRI	50
6-3	Henan_6: Qinhe_AdvIRRI	51
6-4	Shanxi_6: YR_AdvIRRI	50
6-5	Henan_6: YR_AdvIRRI	48
7-1	Henan_7:inside_AdvIRRI	47
7-2	Henan_7 : outside_AdvIRRI	43
7-3	Shandong_7:inside_AdvIRRI	43
7-4	Shandong_7: outside_AdvIRRI	54

Note however that many individual irrigation areas are lumped into one large gross irrigation district (or one irrigation node) within a water utilization district. The *regional* irrigation efficiency therefore can be much higher than *district* irrigation efficiency. This sometimes can be explained by (intensive) re-use of drainage water, for instance in Ningxia or Shandong. Without further investigation, this study simply uses the available highest district irrigation efficiency within a water utilization division as input of regional irrigation efficiency to its irrigation notes, see Table 3-12. The error caused by this method is not further discussed due to limited information availability.

3.3.2.4 Crop yield response to water

In RIBASIM, the inbuilt module WADIS is used to assess the yield reduction due to water shortage based on research of Doorenbos et al (1979), represented by Eq. 3.3:

$$1-\frac{Y_a}{Y_m}=k_{yi}\cdot\left(1-\frac{ET_{ai}}{ET_{ci}}\right) \qquad \text{Eq. 3.3}$$

where

Y_a actual harvested yield;
Y_m maximum crop yield when water is not limiting;
k_{yi} yield response factor during the growth stage *i*;
ET_{ai} actual evapotranspiration during the growth stage *i*;
ET_{ci} evapotranspiration for non-limiting water conditions during the growth stage *i*.

Yield response factors can be empirically derived for individual growth stages (*i*) and over the total growing period of crops. And this equation is valid for most crops for water deficits in the range ($1-ET_{ai}/ET_{ci} \leq 0.5$).

Unfortunately, k_{yi} data is not available in this study. What available is Jensen's sensitivity index λ_i (Jensen, 1968) from YRSIM input data which can also be used to reflect the relationship between crop yield and evapotranspiration, as shown in Eq. 3.4.

$$\frac{Y_a}{Y_m}=\prod_{i=1}^{N}\left(\frac{ET_{ai}}{ET_{ci}}\right)^{\lambda_i} \qquad \text{Eq. 3.4}$$

where

N number of growth stages;
λ_I sensitivity index of crop to water stress during the growth stage *i*.

This method assumes that the water stress effects in each crop growth period are independent and it can integrate the effect of all the water stress throughout the growing season.

For RIBASIM application, it is necessary to transform the Jensen's sensitivity index λ_i into yield response factor k_{yi}. If evapotranspiration is suppressed only during a particular growth stage *i* where λ_i is known, then (ET_{ai}/ET_{ci}) can be rewritten as Eq. 3.5.

$$\frac{Y_a}{Y_m}=\left(\frac{ET_{ai}}{ET_{ci}}\right)^{\lambda_i} \qquad \text{Eq. 3.5}$$

Thus combine above equation with Eq. 3.3, we get Eq. 3.6.

$$1-\frac{Y_a}{Y_m}=1-(\frac{ET_{ai}}{ET_{ci}})^{\lambda_i}=k_{yi}\cdot\left(1-\frac{ET_{ai}}{ET_{ci}}\right) \qquad \text{Eq.3.6}$$

Then by regression analysis the yield response factor k_{yi} for a specific sensitivity index λ_i can be obtained with (ET_a/ET_c) in the range of (0.50-0.99). The incremental interval of (ET_a/ET_c) used in above equation is 0.01 resulting in 50 data points when $1-\frac{Y_a}{Y_m}$ (expressed by $(1-(\frac{ET_{ai}}{ET_{ci}})^{\lambda_i})$) is plotted against $(1-\frac{ET_{ai}}{ET_{ci}})$. The slope of the resulting graph is the k_{yi} value. Here, one numerical example is given in Figure 3-5 for two growing stages of Yuncheng Winter wheat (Yuncheng Winwheat). The k_{yi} value for every growing stage of Yuncheng Winwheat is in Table 3-13.

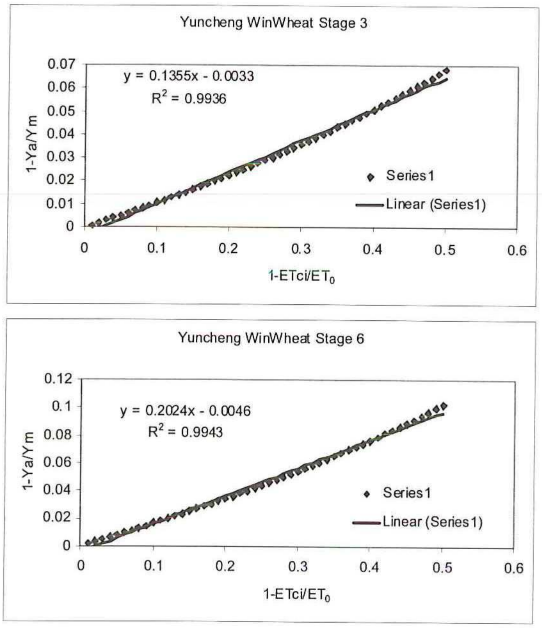


Figure 3-5 Correlation between crop yield response factor and Jensen sensitivity for Yuncheng Winter wheat (example of growth stage 3 and stage 6)

Table 3-13 Transformation of Jensen sensitivity index into yield response factor (Example of Yuncheng Winwheat)

Growing stage	**Stage 1: establishment (planting) to frozening**	**Stage 2: frozening to vegetative**	**Stage 3: vegetative to tillering**	**Stage 4: tillering to ear sprouting**	**Stage 5: ear sprouting to yield formation**	**Stage 6: yield formation to ripening**
λ_i	0.098	0.093	0.102	0.170	0.171	0.155
k_{yi}	0.130	0.124	0.136	0.221	0.222	0.202
Coefficient	0.9935	0.9935	0.9936	0.9945	0.9945	0.9943

And the transformed yield response index for every growing stage of all the crops in the YRB is included in Table 3-14. And potential crop yield for irrigated and rainfed agriculture from YRSIM is listed in Table 3-15.

Table 3-14 Yield response factor for 20 crops in the YRB

Index	Crop type	Yield response factor					
		Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
1	Kaifeng Cotton	0.194	0.595	0.521	0.430		
2	Yuncheng Cotton	0.265	0.538	0.586	0.293		
3	Changyuan Cotton	0.148	0.352	0.390	0.189		
4	Jiexiu SprMaize	0.141	0.217	0.329	0.312		
5	Tianshui SprMaize	0.066	0.195	0.225	0.137		
6	Fufeng SumMaize	0.102	0.365	0.525	0.303		
7	Linfen SumMaize	0.141	0.217	0.329	0.312		
8	Kaifeng SumMaize	0.048	0.205	0.322	0.185		
9	Tongguan SumMaize	0.145	0.181	0.628	0.564		
10	Changyuan SumMaize	0.022	0.199	0.226	0.119		
11	Xinxiang Rice	0.572	0.630	0.409	0.774		
12	Yinchuan Rice	0.423	0.285	0.141	0.021		
13	Lanzhou SprWheat	0.025	0.142	0.142	0.150	0.090	
14	Yinchuan SprWheat	0.397	0.430	0.552	0.610	0.261	
15	Wuyuan SprWheat	0.085	0.290	0.424	0.344	0.267	
16	Xian WinWheat	0.133	0.118	0.162	0.186	0.248	0.230
17	Kaifeng WinWheat	0.169	0.050	0.217	0.311	0.429	0.227
18	Luoyang WinWheat	0.099	0.080	0.115	0.137	0.189	0.189
19	Linfen WinWheat	0.128	0.112	0.141	0.269	0.344	0.286
20	Yuncheng WinWheat	0.130	0.124	0.136	0.221	0.222	0.202

Table 3-15 Potential crop yield for irrigated and rainfed agriculture (kg/ha)

Index	Crop type	Irrigated agriculture	Rainfed agriculture
1	Kaifeng Cotton	962	566
2	Yuncheng Cotton	975	624
3	Changyuan Cotton	968	605
4	Jiexiu SprMaize	6750	1993
5	Tianshui SprMaize	7200	1494
6	Fufeng SumMaize	6975	2093
7	Linfen SumMaize	7338	3141
8	Kaifeng SumMaize	6750	3294
9	Tongguan SumMaize	7200	2494
10	Changyuan SumMaize	6750	3386
11	Xinxiang Rice	8354	0
12	Yinchuan Rice	9640	0
13	Lanzhou SprWheat	7559	1513
14	Yinchuan SprWheat	6496	2599
15	Wuyuan SprWheat	6496	1143
16	Xian WinWheat	5922	1981
17	Kaifeng WinWheat	6696	3699
18	Luoyang WinWheat	6742	2649
19	Linfen WinWheat	5325	2816
20	Yuncheng WinWheat	6029	3015

3.4 SW reservoir nodes

The hydraulic characteristics for the six backbone reservoirs in the YR, Longyangxia, Liujiaxia, Luhun, Guxian, Sanmenxia and Xiaolangdi are listed in Table 3-16 (after Chen, 1997; Liu et al, 2002; Li et al, 1998; Handbook of YR Water Information, 1991 and 1998; Handbook of YR Downstream Flood Control, 1988; YR Flood Prevention Pre-scheme of 1999; YR Large Reservoirs YRCC, 1982). Locations of those reservoirs can be found in Figure 1.3 except that Huxian and Luhun are on upper reach of Yiluo River.

Table 3-16 SW reservoir nodes in the YRB

Reservoir	**Longyangxia**	**Liujiaxia**	**Luhun**	**Guxian**	**Sanmenxia**	**Xiaolangdi**
Main function	Hydropower generation	Hydropower generation	Flood control	Flood control	Flood control	Flood control, sediment trap
Secondary function	Flood control, irrigation, ice-jam flood prevention	Irrigation, ice-jam flood prevention, flood control	Irrigation, water supply, hydropower generation	Irrigation, water supply, hydropower generation	Ice jam flood prevention, irrigation, hydropower generation	Water supply, irrigation, hydropower generation
Hydropower installed capacity (10^4 kw)	128	116	6 (neglected)	18 (neglected)	40	180*[5]
Dead storage water level *[1] (m)	2512	1694	290	475	280	175*[6]
Initial water level (m)	2600	1735	298	534	310	275
Flood control level *[2] (m)	2594	1720	298	535	305	246
Full reservoir level (m)	2605	1738	332	551	340	280
Main gate level*[3] (m)	2512	1694	290	475	280	175
Turbine gate level*[4] (m)	2512	1694	----	----	287	195
Dead storage (Mcm)	2764.4	677.2	28.27	37.51	0*[7]	194.5
Full reservoir storage (Mcm)	26663	6400	1246	1135	8158	12650

1. Dead storage level is determined by the lowest gate level. 2. Flood control level: June-October
3. Main gate level: lowest gate level. 4. Turbine gate level: lowest turbine gate level.
5. Xiaolangdi hydropower generation fully started from 2002, the first 3 years total power generation is 180(10^4kw).
6. Xiaolangdi dead storage level in long term operation is 230m. During the strategy design it will be adjusted to 230m.
7. The dead storage of Sanmenxia is already fully silted.

For each reservoir, the specific operation purpose is defined: flood control, energy generation and downstream water supply. Their operation is presented by flood control and (firm) storage curves in the RIBASIM reservoir nodes. Actually, the operation of those reservoirs also includes sediment flushing (Sanmenxia and Xiaolangdi), ice jam flood prevention (Liujiaxia and Sanmenxia) and combined reservoir regulation (Longyangxia and Liujiaxia for combined regulation of hydropower generation, combined regulation of Guxian, Luhun, Sanmenxia and Xiaolangdi for storm flood prevention in the down stream) based on long term reservoir regulation practices.

3.5 Low flow nodes

Constraints by low flow nodes are applied to ensure minimum flow requirements. One of these requirements is to control ice-jam flood which takes place at two sections in the YRB. One is from Shuizuishan to Toudaoguai and the other is downstream of Sanmenxia. In winter ice is stored in the channel thus it can be regarded as "abstracted" from the surface water system. In summer this amount of water is released again as a "source" of water. Channel ice storage is estimated 1.0-1.2 billion m^3 in average at Shuizuishan-Toudaoguai section and less than 100 million m^3 downstream of Sanmenxia (Wang, 2003), where the latter quantity has been neglected. In RIBASIM, the winter ice water abstraction is presented by a diversion node, a diverted flow link, a low flow node and a terminal node. The summer ice water source is presented by a fixed inflow with a confluence node.

The environmental low flow requirements are presented by low flow node in RIBASIM. It only includes flow requirements for sediment flushing, soil and water conservation and river base flow at Lijin and Wubu stations. In addition to environmental low flow, a low flow node is also set above Lijin station to transfer water to the outside basin cities (i.e. Hebei and Tianjin). All low flow nodes for ice-jam flood prevention, environmental low flow and water transfer to cities outside the basin are summarized in Table 3-17.

Table 3-17 Summary of the low flow nodes in the YRB (billion m^3)

Node name	Function	Quantity
Ning-Mong-ice_Low	Ice-flood control	1.2
Lijin_Low	Sediment flushing and base flow	18
Hebei-Tianjin_Low	Water transfer	2.0 (maximum in normal year)
Wubu_Low	Soil and water conservation	2.0

3.6 Loss flow nodes

In the YRB, the water allocation section is analysed from Longyangxia till Lijin at the length of 3802 km. Flow loss is considerable over such river length due to main channel seepage and open channel evaporation. The total estimated loss flow is 230.2 m^3/s or 7.26 billion m^3 (Wang et al 2003). This is about 13.01% of average year YR inflow, 55.78 billion m^3.

In this study, only the major water users and main infrastructures are accounted in basin schematisation due to lack of detailed information. The final basin schematization is shown in Figure 3.6.

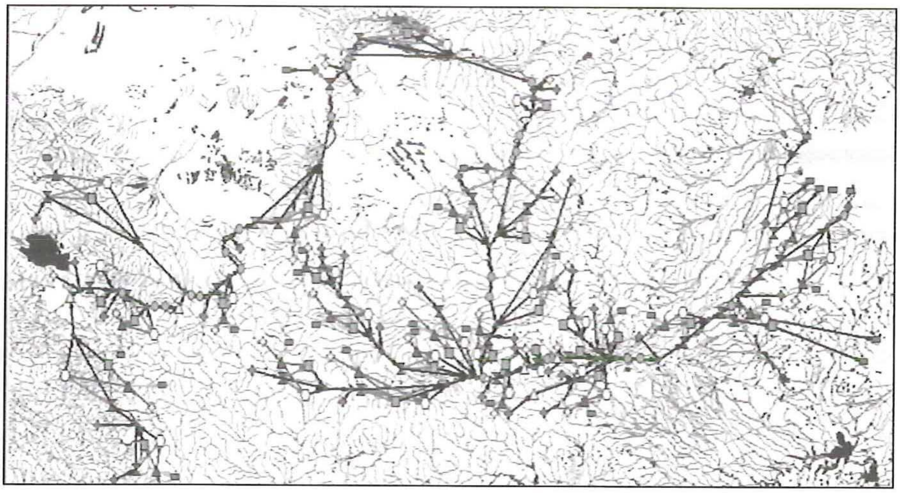


Figure 3.6 YR basin schematization in RIBASIM

3.7 Calibration and validation

Before the Yellow River simulation model can be used for the development of alternative allocation schemes, the model needs to be calibrated and validated. Calibration is the tuning of the parameters of the model and if needed and allowed also the input data to have the outcome of the model fit the real situation. This is done by a comparison of the simulation outcome with measured values. This gives also an indication of the accuracy of the model. The next step is that the calibrated model is validated by using another set of monitoring data to check whether the simulation outcome matches the measured values in an acceptable degree.

As explained in Section 3.2.1, data series of 1965-1974 is used for calibration and the data set on 1999 is chosen for validation. It is acknowledged that the calibration data may not be very accurate and therefore the accuracy of the calibration is relatively low. For the same reason the outcome of validation can not fit the measured values perfectly, either. However, this is considered acceptable for the type of analysis carried out in this research where it is more important to obtain tendencies or relative values of the system response than to determine accurate values.

3.7.1 Calibration

In this aspect, the calibration is done by looking at three aspects: the operation of the infrastructures, the water utilization and the channel discharge. In early 1960s and 1970s, Besides, in that period the 'first come, first serve' rule still dominated the practice of water allocation. Hence, all the demands in the YRB (i.e. PWS, irrigation, environmental flow, etc.) had the same water allocation priority of 1 and there was little strategic operation involved.

For the calibration of the operation of the infrastructure only the Luhun reservoir can be considered in the period 1965-1974. The other reservoirs were either under (re-) construction (i.e. Sanmenxia) or were not yet constructed. Due to its limited water allocation capacity (see Table 3-16, less than 2.1% of total basin SW), the calibration of the operation of Luhun was skipped.

Considering that DMI is not the major usage in the basin (less than 9.6% of total DMI plus irrigation withdrawal and less than 8.6% of total DMI plus irrigation consumption - YR water resources bulletin 1998), the focus of the water utilization calibration was put on the calibration of the irrigation SW withdrawal and consumption. When combined with the calibration of the channel discharge calibration, the DMI water utilization can be indirectly calibrated. The details of irrigation water utilization and channel discharge calibration are described in the next two sections respectively.

3.7.1.1 Calibration of water utilization

Unfortunately no full data set is available on irrigation demand, irrigation withdrawal or irrigation consumption for 1965-1974 for all the irrigation districts. Therefore calibration of agricultural water utilization is only done for the three major irrigation regions in the YRB: the Ning-Mong Hetao Plain, the Fen-Wei Plain and the Lower Reach Irrigation District (see section 1.1). According to statistic data from YRCC, irrigation area of these three major regions is above 70% of total irrigated area in the YRB, and their irrigation demand is about 80% of the total.

Here, the reference values of irrigation consumption of 1965-1974 are deduced from a project by YRCC Hydrology Bureau on determination of natural runoff in the YRB. The irrigation consumption is estimated as the discharge difference between two adjacent hydrology stations. This means, besides irrigation consumption, the discharge difference also covers DMI consumption, channel seepage, evaporation, small or middle scale reservoir storage change, etc.

Then, irrigation calibration is to 'compare' the simulated irrigation consumption to the measured data investigated by YRCC Hydrology Bureau for 1965-1975. Here, the comparison is mainly on the variation tendency of irrigation consumption over time (i.e. month) and on instantaneous irrigation application for salinity flushing or for soil water storage for next crop in following growing season.

Ning-Meng Hetao irrigation district (node Ningxia_3:YR_AdvIRRI) is taken as an example. Figure 3.7 shows simulated irrigation consumption series compared with reference series. The first impression is that the variation tendencies from both series are similar. The time and quantities of the peak and low irrigation consumption are close to or comparable to each other.

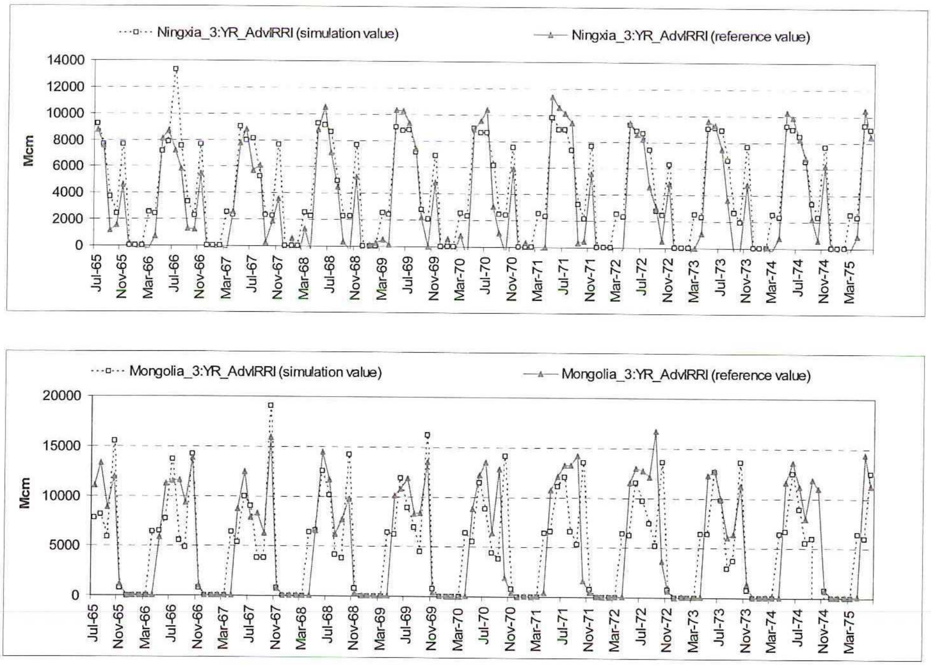


Figure 3.7 Calibration of irrigation water consumption in Ning-Meng Hetao Plain

To get better impression of above comparison on irrigation consumption, the correlation coefficient r^2 is illustrated in Table 3-18. From that table, the values of correlation coefficient r^2 are mostly above 0.9 in Ningxia and close to 0.8 in Inner Mongolia, indicating that the simulated series matches reference series in more or less acceptable degrees.

Table 3-18 Correlation coefficient r^2 of irrigation consumption for the Hetao Plain

Year	Ningxia_3: YR_AdvIRRI	Mongoli_3:YR_AdvIRRI
1965-1966	0.94	0.80
1966-1967	0.91	0.82
1967-1968	0.92	0.90
1968-1969	0.95	0.77
1969-1970	0.96	0.85
1970-1971	0.94	0.51
1971-1972	0.95	0.58
1972-1973	0.96	0.60
1973-1974	0.94	0.81
1974-1975	0.97	0.71

3.7.1.2 Calibration of river discharge

The comparison of the simulated river discharge with measured discharge is plotted for the most reliable gauging stations in the YRB, see Figure 3.8 and Figure 3.9. From these figures, the tendency of simulated river discharge matches reasonably to that of the measured data, except during the low flow period in Lijin station. A major reason to the substantial difference is the imprecise measurement of the low flow in that channel. Sometimes flows were not measured at all, since flood control drew most attention in 1960s and 1970s.

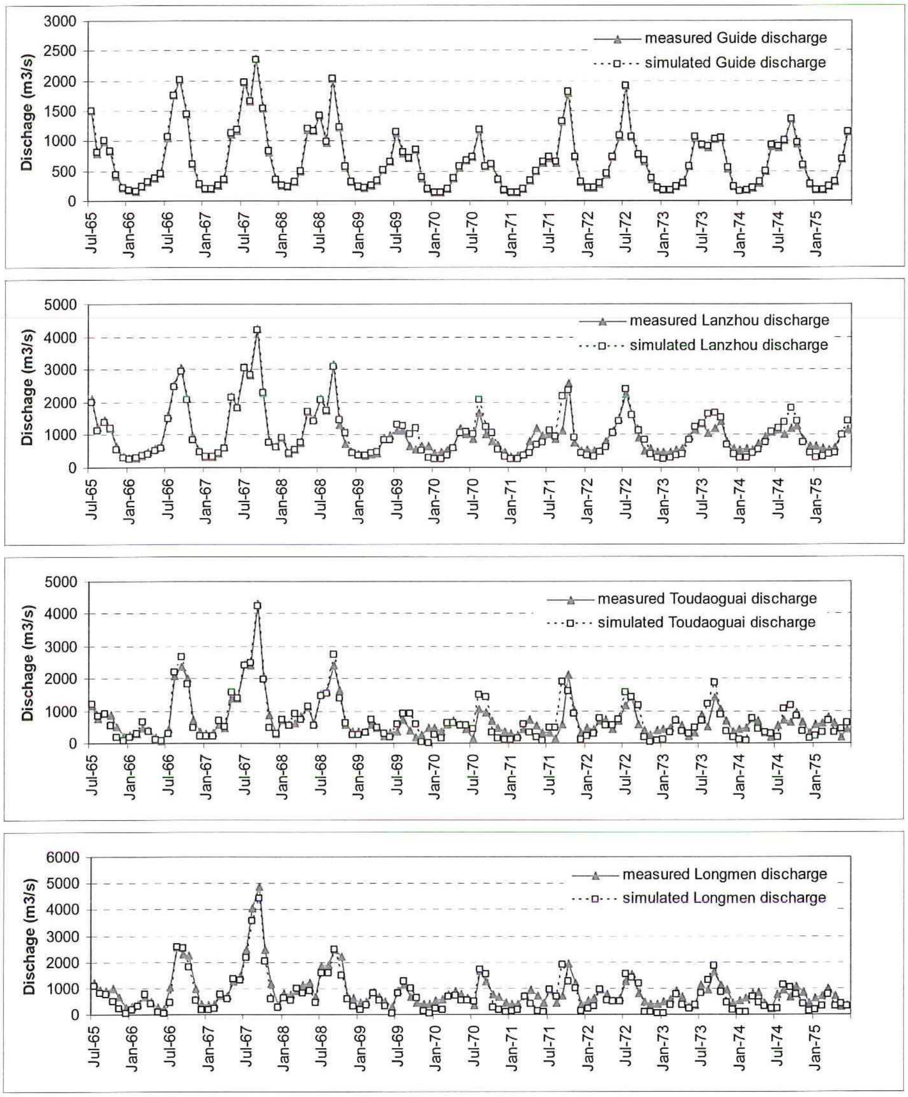


Figure 3.8 Comparison of simulated and measured river discharge at main gauge stations of Guide, Lanzhou, Toudaoguai and Longmen in the YRB

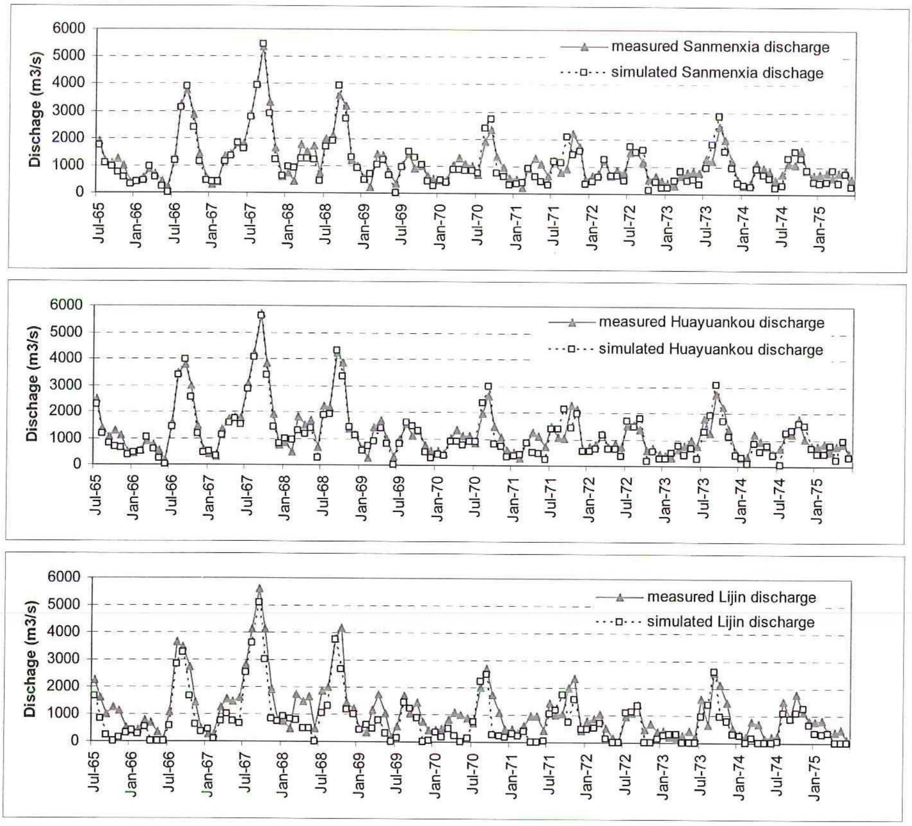


Figure 3.9 Comparison of simulated and measured river discharge at main gauge stations of Sanmenxia, Huayuankou and Lijin station in the YRB

Certainly, improvement of calibration is always possible, but it needs better data input and takes more time. Since the main concern is on relative values for further analysis on water allocation, has been concluded here that the current calibration of river discharge is acceptable.

3.7.1.3 Calibrated basin water balance

To complete the calibration a basin water balance is created (Table 3-19) to check if all water has been accounted for. It has been concluded that the formulated RIBASIM model can be accepted for further validation.

Table 3-19 Basin water balance in the YRB (1965-1974)

	Item	Volume (Mcm)	Percentage (%)
In	Fixed boundary inflow	11,462	13.0
	Variable boundary inflow	57,902	65.9
	SW reservoir rainfall	5	0.0
	SW reservoir storage change (-)	8	0.0
	GW reservoir storage change (-)	1	0.0
	PWS return flow	3,485	4.0
	Adv.irrigation return flow	15,057	17.1
	Sum	87,921	100

Out	Adv.irrigation.extraction	47,680	54.2
	DMI extraction	10,800	12.3
	Reservoir evaporation	18	0.0
	SW reservoir storage change (+)	0	0.0
	GW reservoir storage change (+)	0	0.0
	Boundary outflow	28,830	32.8
	Loss flow	592	0.7
	Sum	87,921	100.0

3.7.2 Validation

Validation is conducted to check whether the calibrated YR model can be trusted to represent water allocation results in different (i.e. other than 1965-1974) hydrological and socio-economical conditions. The main purpose is to get insight of water demand and water supply as well as channel discharge. For this purpose, data set on year 1999 from YRCC and Institute of Water Hydraulics Research (IWHR) is collected with a lot of efforts. The obtained data sets include annual natural runoff at main stations, monthly rainfall, annual GW utilization quantity, monthly river discharge at main stations, reservoir annual storage change, reservoir monthly inflow and outflow, reservoir monthly water level and storage, annual provincial agricultural and PWS water withdrawal and consumption, etc. Also it is assumed that crop patterns and irrigation efficiency do not change much between 1970s and 1990s in the YR. Considering YRCC water allocation practices started on 1999 to avoid zero flow in the downstream, water allocation priority of environmental flow is set as 2, equal to irrigation. And allocation priority to PWS is still set as 1.

In this validation step, the operation of the 6 backbone reservoirs is included for the year 1999. Unfortunately, reservoir operation curves (flood control, hydropower generation curve or target curve, firm storage curve) are not available for this year. Therefore only average year reservoir operation curves are used. Obviously, such application can lead to simulated reservoir outflow that differs from measured flows for the year 1999. To remove the influence from this application, two sub-steps are adapted for validation in order to compare simulated and measured channel discharge and water utilisation.

Sub-step 1: **validation of channel discharge section by section** for sections that are not influenced by reservoir operation. For river sections between two reservoirs, the upstream boundary inflow is forced to equal to the measured outflow of the upstream reservoir. The simulated inflow to the adjacent downstream reservoir is then compared to the measured value to evaluate the validity of the water utilization for this section. This test is conducted section by section from upstream to downstream along the YR.

Sub-step 2: **validation of overall basin water utilisation**. In this process, reservoir annual storage change is made comparable to the measured data. Then, the rest available water volume in the basin (total basin inflow minus total reservoir storage change) should be equal to the measured value of water utilization. This is done by comparison of each provincial water withdrawal and consumption to the statistic data.

3.7.2.1 Validation of channel discharge section by section

To avoid the influence of reservoir operation, YR mainstream is divided into sub-sections mainly by the mainstream reservoirs and important gauge stations, as shown in Table 3-20. Figure 3.10 and Figure 3.11 show the comparison of simulated and measured sectional downstream channel discharge. The correlation coefficient and detailed analysis are included in Table 3-20. The comparison results of the water utilization pattern are considered acceptable in this study.

It is necessary to mention that by the end of 1999, Xiaolangdi reservoir was not constructed completely. It started to be filled by 1770 Mcm water from Oct till Dec. So, when Xiaolangdi reservoir is included in 1999, its water level is set as 160m (empty reservoir) from Jan till Sept. And from Oct. till Dec during its dead storage filling up period, Xialongdi did not function to supply water for downstream users or to prevent flooding, therefore, its gate is set not online adjustable.

Table 3-20 Division of the YR main channel and validation of sectional water utilization

Index	River section	Upper boundary inflow	Down-stream discharge	Correlation coefficient r^2	Comparison and analysis
1	Above Longyangxia	Upper-boundary natural runoff	Inflow to Longyangxia	0.95	Well validated.
2	Downward of Longyangxia – upward of Liujiaxia	Longyangxia reservoir outflow	Inflow to Liujiaxia	0.63	Not ideal. Monthly difference is large only during flooding seasons, which partially caused by inaccurate input data of hydrology series and Lijiaxia reservoir operation which is omitted in the schematization.
3	Downward of Liujiaxia – Shizuishan	Liujiaxia reservoir outflow	Lanzhou	0.97	Well validated. Monthly difference is not ideal only from Mar. till May, probably due to inaccurate input of natural runoff from tributary Huangshui.
			Shizuishan	0.70	Not ideal. Monthly difference is obvious during April till August, probably partially also due to accumulative error of upstream (above Lanzhou) and Qingtongxia reservoir operation which is omitted in the schematization.
4	Downward of Shizuishan – Toudaoguai	Shizuishan	Toudaoguai	0.90	Acceptably validated. Monthly difference is not ideal during April till August, probably due to inaccurate input of loss flow in the section, irrigation return flow and Sanshenggong reservoir operation which is omitted in the schematization.
5	Downward of Toudaoguai – upward of Sanmenxia	Toudaoguai	Longmen	0.93	Well validated.
			Tongguan	0.74	Acceptably validated considering accumulative error of upstream, inaccurate input of hydrology series of the largest tributaries of the YRB: Weihe and Fenhe, and many small and middle scale reservoirs' operation which are omitted in the schematization.
			Sanmenxia reservoir inflow	0.74	Acceptably validated considering accumulative error of upstream.
6	Downward of Sanmenxia – upward of Xiaolongdi	Sanmenxia reservoir outflow	Inflow to Xiaolangdi	0.99	Well validated.
			Xiaolangdi reservoir outflow	1.0	Operation of Xiaolangdi reservoir can reflect reality which is not guided by operation curves yet during its first filling up stages.
7	Downward of Xiaolangdi – Huayuankou	Xiaolangdi reservoir outflow	Huayuankou	0.98	Very well validated.
8	Downward of Huayuankou – Lijin	Huayuankou	Lijin	--	Inaccurate measure of low flow in the channel, uncontrolled flow diversion between widely distanced embankment (1-3km), meandering and braided flow.

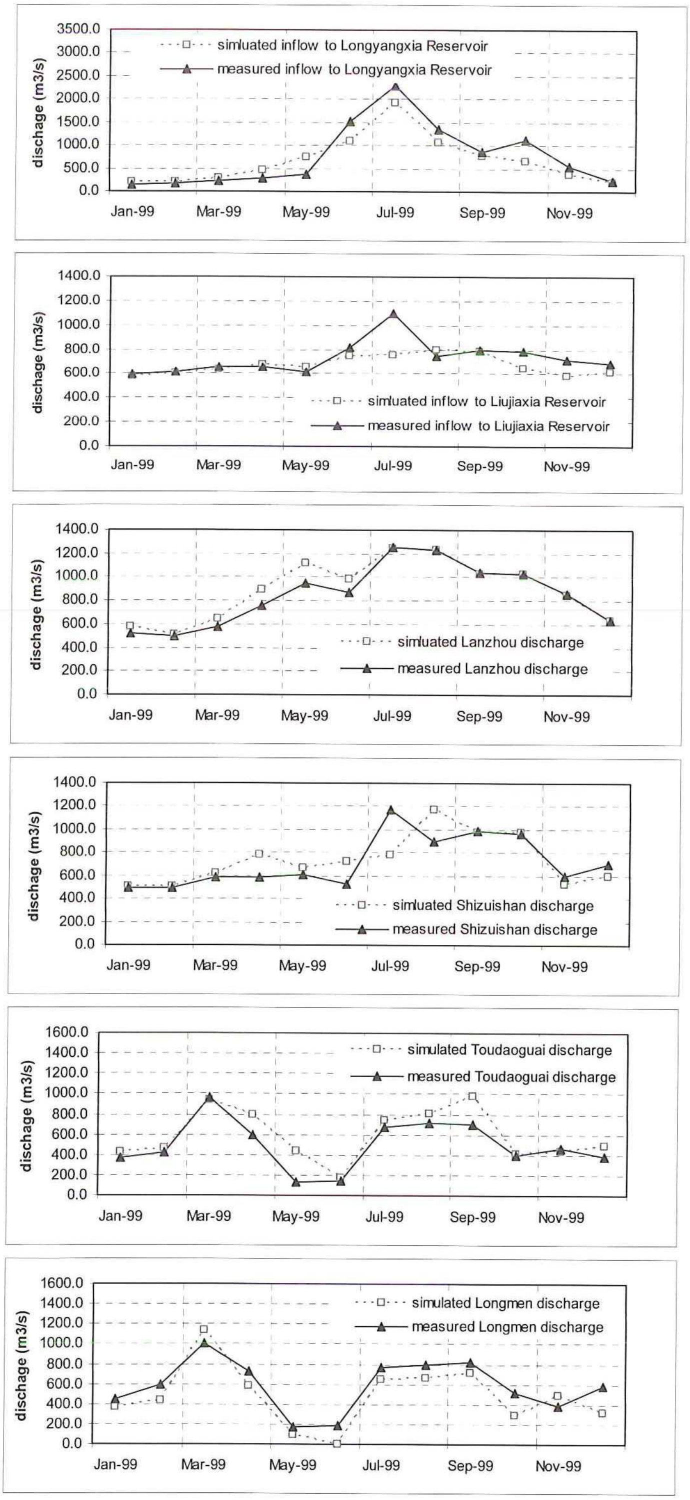


Figure 3.10 Comparison of river discharge section by section from Longyangxia to Longmen

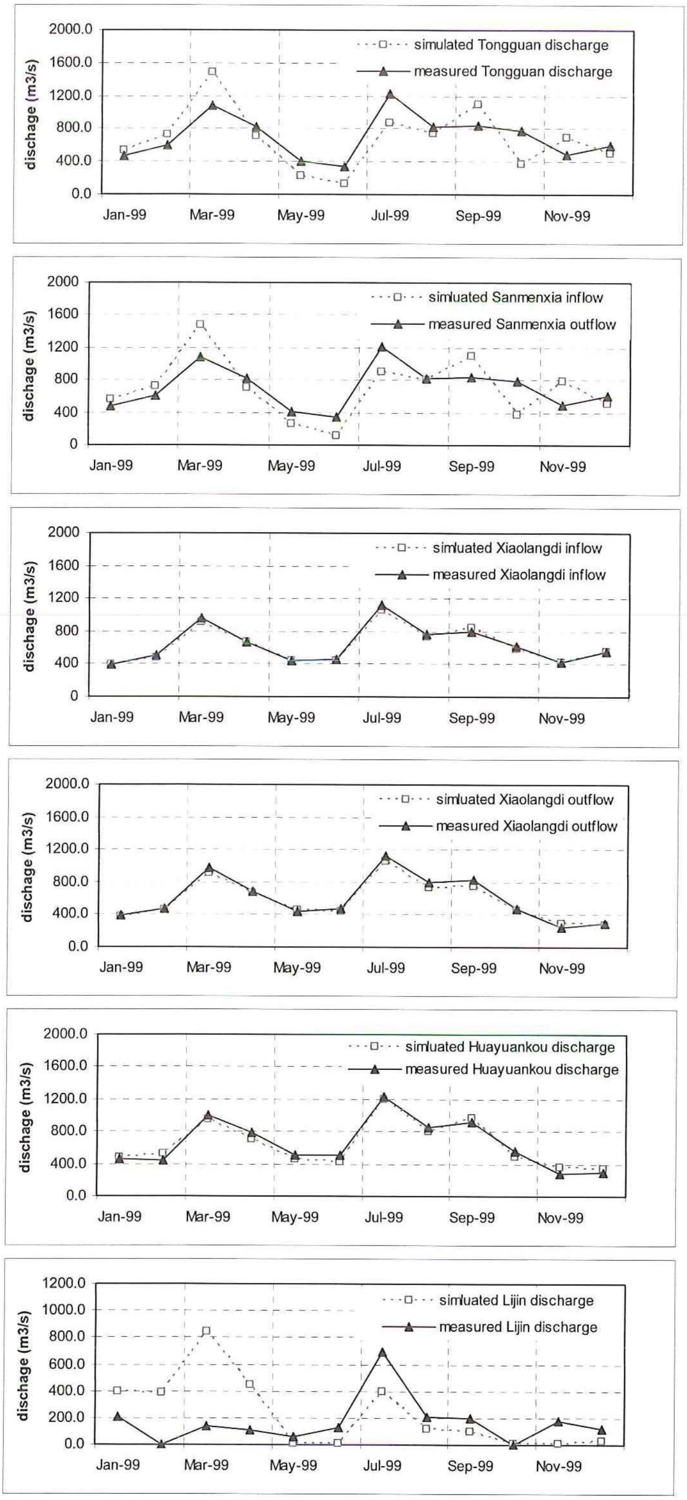


Figure 3.11 Comparison of river discharge section by section from Tongguan to Lijin

3.7.2.2 Validation of overall basin water utilization

As explained above, total storage change of the 6 backbone reservoirs over the year 1999 should be adjusted as close as possible to the measured quantity. The initial water levels of those reservoirs are from YRCC Water Resources Bulletin 1998. The measured reservoir water levels from 1999 are referred to determine their target curve and firm storage curve. Considering that Longyangxia is in the charge of West Power Group, the water allocation downstream of Longyangxia is set not online adjustable in RIBASIM model as its operation will not respond to downstream demands. All the parameters of Xiaolangdi are kept as the same from calibration stage functioning as water storage node. In total, annual storage change of the 6 backbone reservoirs is 627 Mcm or 10.4% less than measured actual quantities of 6039 Mcm on 1999.

Next, the comparison of simulated and measured data of provincial DMI and irrigation water utilization is included in Table 3-21 and Table 3-22 respectively. The comparison shows that the validation of provincial DMI withdrawal and consumption is acceptable with maximum 7.9% difference from statistic data (i.e. Inner Mongolia). In terms of total basin irrigation, the simulated withdrawal and consumption values differ between 1.2% and -7.5% from the statistics data. For provincial irrigation, the difference figures are much larger. While neglecting Sichuan (whose irrigation is less than 0.1% of basin amount), the highest difference occur in Qinghai and Shanxi, with deviations of more than 40% from statistic values. Fortunately, their provincial agricultural water utilization is only 4.0% and 6.0% of overall basin water utilization. Regarding the accuracy of model calibration, such validation results on irrigation are not ideal but are accepted for the purpose of this study.

Table 3-21 YR provincial DMI withdrawal and consumption on 1999 (Mcm)

Province	DMI withdrawal				DMI consumption			
	ref.	% of total	sim.	dif. (%)	ref.	% of total	sim.	dif. (%)
Gansu	1792	9.9	1797	0.3	1110	10.1	1114	0.4
Henan	1417	7.8	1416	-0.04	851	7.8	850	-0.1
In. Mongo.	717	3.9	711	-0.8	473	4.3	469	-0.8
Ningxia	670	3.7	672	0.3	193	1.8	208	7.9
Qinghai	487	2.7	488	0.3	230	2.1	229	-0.2
Shaanxi	1829	10.1	1834	0.3	1183	10.8	1192	0.8
Shandong	902	5.0	878	-2.6	609	5.6	597	-1.9
Shanxi	1263	6.9	1266	0.3	815	7.4	823	1
Sichuan	10	0.1	10	0.2	10	0.1	10	0.2
Total	9087	50.0	9073	-0.2	5474	50.0	5494	0.4

Table 3-22 YR provincial irrigation withdrawal and consumption on 1999 (Mcm)

Province	Irrigation withdrawal				Irrigation consumption			
	ref.	% of total	sim.	dif. (%)	ref.	% of total	sim.	dif. (%)
Gansu	2502	5.9	2958	18.2	1948	5.8	2148	10.3
Henan	4991	11.8	6228	24.8	4423	13.2	4941	11.7
In.Mongo.	9031	21.4	7041	-22.0	7941	23.7	6012	-24.3
Ningxia	9131	21.6	9508	4.1	4198	12.5	4421	5.3
Qinghai	1517	3.6	753	-50.4	1064	3.2	382	-64.1
Shaanxi	3795	9.0	3754	-1.1	3149	9.4	3211	2.0
Shandong	8969	21.2	9103	1.5	8738	26.1	7055	-19.2
Shanxi	2327	5.5	3419	46.9	2008	6.0	2819	40.4
Sichuan	15	0.04	1		15	0.04	0.7	
Total	42278	100	42765	1.2	33484	100	30990	-7.5

Another validation test conducted is the comparison of GW and SW allocation to DMI and irrigation. Table 3-23 and Table 3-24 illustrate the comparison results. In general, simulated GW allocation to provincial DMI and irrigation differs slightly from the statistic data. It is only -7.8% in terms of GW allocation to basin DMI, 0.5% in terms of basin irrigation and -3.0% in terms of total budget. When provincial level is checked, the difference is a bit more noticeable but still considered acceptable. For instance, the only large difference occurs in Henan and Shanxi, where the GW allocation to DMI is less than the statistic data, 27.4% and 16.0% lower. This may be caused by neglected SW recharge to GW.

Table 3-23 Comparison of GW allocation to YR provincial water utilization on 1999 (Mcm)

Province	GW allocation to DMI			GW allocation to IRRI			GW allocation to DMI and IRRI		
	ref.	sim.	dif. (%)	ref.	sim.	dif. (%)	ref.	sim.	dif. (%)
Gansu	395	395	0.0	254	243	-4.3	649	638	-1.7
Henan	918	667	-27.4	17650	1873	6.1	2683	2540	-5.3
In. Mongo.	533	533	0.0	1619	1523	-5.9	2152	2056	-4.5
Ningxia	415	401	-3.4	136	146	7.1	551	547	-0.8
Qinghai	308	308	0.0	20	20	-1.4	328	328	-0.1
Shaanxi	1357	1357	0.0	1735	1640	-5.5	3092	2997	-3.1
Shandong	591	591	0.0	732	727	-0.7	1323	1318	-0.4
Shanxi	1079	906	-16.0	1428	1557	9.1	2507	2464	-1.7
Sichuan	0	0	0	0	0	0	0	0	0
Total	5596	5158	-7.8	7689	7729	0.5	13285	12887	-3.0

Table 3-24 Comparison of SW allocation to YR provincial water utilization on 1999 (Mcm)

Province	SW allocation to DMI			SW allocation to IRRI			SW allocation to DMI and IRRI		
	ref.	sim.	dif. (%)	ref.	sim.	dif. (%)	ref.	sim.	dif.(%)
Gansu	1097	1397	27.4	2548	2703	6.1	3645	4100	12.5
Henan	499	746	49.4	3226	4337	34.4	3725	5083	36.5
In.Mongo.	185	176	-4.7	7412	5467	-26.2	7597	5644	-25.7
Ningxia	255	269	5.5	8995	9301	3.4	9250	9570	3.5
Qinghai	179	179	-0.1	1497	726	-51.5	1676	905	-46
Shaanxi	472	472	0.0	2060	2097	1.8	2532	2569	1.5
Shandong	311	284	-8.5	8237	8314	0.9	8548	8598	0.6
Shanxi	184	357	93.8	899	1848	105.5	1083	2204	103.5
Sichuan	10	10	0.0	15	1	-92.8	25	11	-55.7
Total	3192	3890	21.9	34889	34794	-0.3	38081	38684	1.6

Unfortunately, SW allocation to provincial water utilization is less ideal, see Table 3-24. The difference between simulated SW allocation to basin DMI, to basin irrigation and to total basin DMI and irrigation, is 21.9%, -0.3% and 1.6% respectively. Looking at provincial level, the worst cases are in Henan, Qinghai and Shanxi (leave Sichuan out). For example, in Henan province, the simulated SW allocation to DMI is 49.4% larger than reference data, its SW allocation to irrigation is 34.4% higher, and to total DMI and irrigation is 36.5% more. Such mismatches can be caused by many factors. One of them is because SW inflow itself is affected largely by the natural runoff assessment. Besides, allocation of SW data itself is also quite inaccurate. For Qinghai and Shanxi whose SW utilization is a small proportion from basin (see Table 3-23), their validation is less critical and therefore not further analyzed. Again, with regard to the accuracy of model calibration, such validation results on irrigation are accepted and no further efforts are made to improve it.

3.7.2.3 Whole basin water balance

The final simulated basin water balance is shown in Table 3-25 below.

Table 3-25 Basin water balance in the YRB on 1999

	Item	Volume (Mcm)	Percentage (%)
In	Fixed boundary inflow	14,545	18.2
	Variable boundary inflow	48,276	60.3
	SW reservoir rainfall	166	0.2
	SW reservoir storage change (-)	1,784	2.2
	GW reservoir storage change (-)	0	0.0
	PWS return flow	3,580	4.5
	Adv.irri. return flow	11,775	14.7
	Sum	80,125	100.0
Out	Adv.irri.extraction	42,765	53.4
	DMI extraction	11,037	13.8
	Reservoir evaporation	903	1.1
	SW reservoir storage change (+)	7,196	9.0
	GW reservoir storage change (+)	404	0.5
	Boundary outflow	17,228	21.5
	Loss flow	591	0.7
	Sum	80,124	100.0

In this chapter, the set up of RIBASIM application of YR basin wide water allocation is completed. Through calibration the model has been set up to reflect the major characteristics in reality. Validation has proven that the characterisation is not precise, but it is considered acceptable for the purpose of this study. In next chapter, current accounts on water shortage causing conflicts in the YRB will be analysed and clarified. Also the scenario definition will be established to embody different sets of future trends based on policies, technological development, and other factors that affect demand, supply and hydrology externally.

4 Primary analysis of water allocation in the YRB

After calibration and validation, the RIBASIM model can be used for preliminary analysis of the 'current account' of water allocation in the whole basin. Here, the base case refers to water allocation practices on 1999 as validated in Chapter 3 (as the 1987 Scheme was actually implemented from 2001 onwards). Later on, the analysis is focused on clarification of water shortage problems in the present situations and in future. Unless it is specifically described, the values in this chapter are average ones.

4.1 Current account of basin water allocation

By use of RIBASIM outputs, the water shortage degree (ratio of shortage to demand, %) is chosen to clarify the current water allocation problems for the Yellow River.

1. water shortage degree for PWS,
2. water shortage degree for irrigation, and
3. water shortage degree for environment low flow.

The calculated values for above indicators are listed in Table 4-1. Accordingly, the implied meaning of the current water allocation account is addressed below.

Table 4-1 Water shortages in the YRB in the base case on 1999 (%)

Province	PWS	Irrigation	PWS + irrigation
Sichuan	0.0	0.0	0.0
Qinghai	0.9	3.2	2.7
Gansu	0.0	1.1	0.7
Ningxia	0.6	4.2	3.9
Inner Mongolia	0.0	1.0	0.9
Shaanxi	0.0	11.3	8.1
Shanxi	0.0	20.4	16.2
Henan	0.0	3.4	2.8
Shandong	0.0	0.4	0.4
Basin	0.1	4.7	4.0
Environment low flow	---	---	15.9

1) Water stress for irrigation: mainly in tributaries

By assigning the highest water allocation priority (1) to water supply for DMI, its allocation is ensured in the YRB. But water supply to irrigation is not sufficient. The highest water shortage degree for irrigation is in Shaanxi and Shanxi, i.e. 11.3% and 20.4% respectively. As irrigation is the major water usage in the YR, highest water shortage degree values for total irrigation and PWS also take place in those two provinces.

It is necessary to point out that the irrigation area implied in the base case is based on the actual irrigation area of year 1999. The actual irrigation area is only 72% of the designed irrigation area for 1999. This explains why the water shortage degree in irrigation is not that disappointing in the base case.

To gain insight of the irrigation water stress in those two provinces, irrigation node Shannnxi_5:Fenhe_AdvI and Shaanxi_5:Weihe_AdvI are further examined. When upstream available inflow (SW and GW), irrigation demand and simulated irrigation supply are plot in one chart (see Figure 4.1 and Figure 4.2), it becomes evident that the causes of irrigation stress is lack of local water availability.

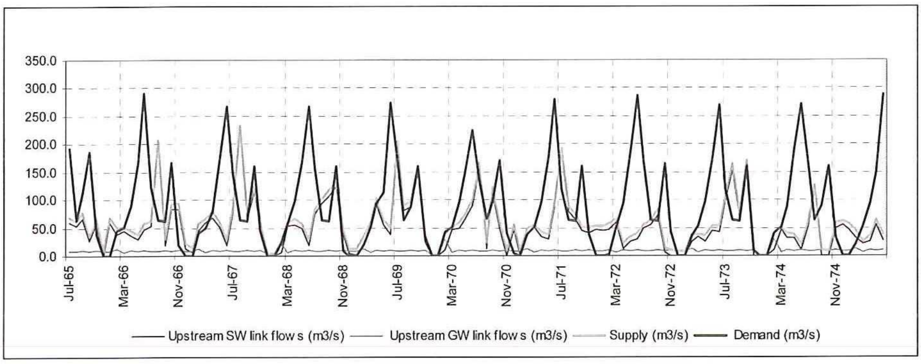


Figure 4.1 Irrigation water supply to Shanxi_5:Fenhe_AdvI in the base case

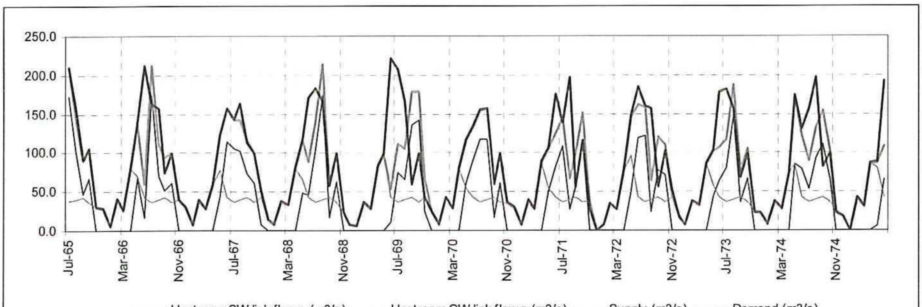
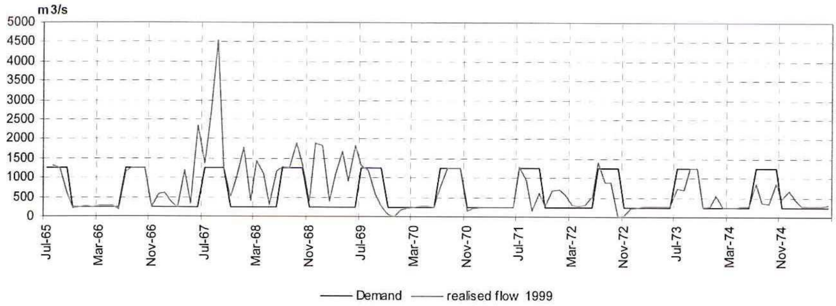


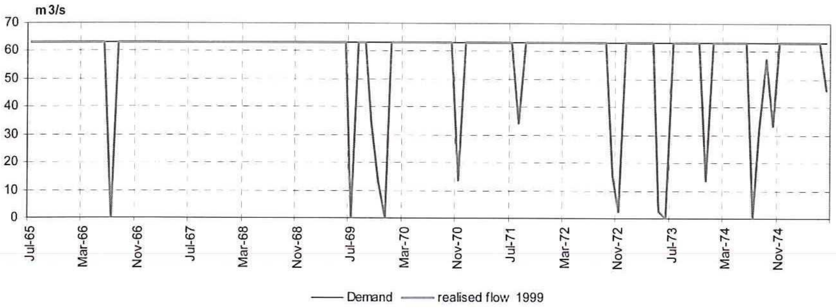
Figure 4.2 Irrigation water supply to Shaanxi_5:Weihe_AdvI in the base case

2) Water shortage for environmental low flow

As shown in Table 4-1, the water shortage degree for environment low flow is 15.9%. As explained previously, environmental low flow at Lijin station is mainly for sediment flushing to the YR delta and to maintain river base flow. And environmental low flow at Wubu station is for soil and water conservation to reduce sediment yield in the Loess Plateau in long term. Unfortunately, neither of these requirements can be ensured in the base case, see Figure 4.3.



(a) Lijin station



(b) Wubu station

Figure 4.3 Demand and realized discharge at Lijin and Wubu stations in the base case

In brief, there is no sufficient water to meet water demands either for human society (DMI and irrigation) or for the ecosystem. The tension among different water usages is already depressing. The logical expectation that increasing water demand would exacerbate the water allocation conflicts in the YR in future, will be discussed in the next section.

4.2 Problems to be expected in future

This section focuses on assessing how serious water shortage would come up in the YR in future. Different scenarios are designed to predict the impact of increased water demand and climate change on YRB water allocation.

4.2.1 Scenario assumptions

In this part, a set of scenarios of population growth, industrialization and climate change are established. When these scenarios are combined, more transparent information would be presented to examine basin water supply conditions by RIBASIM simulation.

4.2.1.1 Water demand projection

Many prior studies used the period until 2030 or 2050 for water demand projections in DMI and irrigation water utilization. This study uses the year 2010, 2030 and 2050 for projections. As water supply and demand issues have already truly become bottlenecks to economic growth in the YR, those impacts would continue in such a long time frame if no proper strategies are developed to address the problems.

There are two macro-economic factors that will largely determine future demand for water resources: population growth (rural and urban population growth) and economic growth (regional GDP). Besides, food supply also plays an important role on irrigation water demand determination.

Population growth

Facts show that China's compulsory birth-control policies are effective in holding down population growth. As projected by China central government, by year 2010, the total Chinese population would be controlled as high as 1.396 billion, by year 2050 it would be 1.602 billion. Accordingly, China population growth rate is estimated 7.15‰ during the year 2000-2010, 4.69‰ during the year 2010-2030 and 2.204‰ during the year 2030-2050 (Liu et al, 1996).

However, future population in the YRB would probably more or less differ from that of overall China. To consider the spatial difference of population growth among different regions in the YR, the actual population growth rate from 1982-1990 in the YRB are referred to (after YRSIM data), i.e.

Growth rate in region R over time period T
= (national growth rate over time T) ×
(past actual growth rate in region R)/ (past actual national growth rate)

Obviously, it is a very rough assumption, for example, it does not consider the migration/resettlement of people among provinces. The inaccuracy of above assumptions should be kept in mind for later analysis.

Urbanisation

More and more people live in urban areas, drawing their food and natural resources from the surrounding rural areas. According to the census on year 2000, urban population accounts for 22.9% of the overall population figures in the YR. With social and economic development, urbanisation tends to continue to increase gradually. For the YRB over the year 2010, 2030 and 2050, projected ratios of urbanisation are used from the project 'Rational distribution and optimal regulation of the water resources in the YR' (Chang, 1998). The combined projections for urban and total YR populations are listed in Table 4-2 for year 2010, 2030 and 2050.

Table 4-2 Population projection in the YRB (10^6 persons)

Province	1999		2010		2030		2050	
	Total	Urban	Total	Urban	Total	Urban	Total	Urban
Gansu	15.9	2.9	17.4	4.4	19.3	5.8	20.3	6.9
Henan	15.6	2.4	17.1	4.8	19.1	6.5	20.1	7.9
In. Mongo.	6.6	2.7	7.1	3.2	7.7	3.7	8.1	4.1
Ningxia	4.8	1.2	5.4	1.6	6.1	2.3	6.5	2.9
Qinghai	3.9	1.0	4.3	1.4	4.8	1.7	5.1	2.0
Shaanxi	24.6	5.6	26.8	7.4	29.8	10.2	31.2	13.2
Shandong	40.0	9.9	43.5	14.6	48.0	18.9	50.3	22.8
Shanxi	19.2	4.2	20.9	6.3	23.2	8.6	24.3	10.7
Sichuan	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0
Basin	130.6	29.9	142.5	43.5	158.1	57.8	166.0	70.6

Domestic water use

The gap in the living standards between urban and rural areas in China is large. In the cities, municipal water supply systems are in place and the use of baths, showers and flush toilets is spreading. Most rural villages still depend on village wells and basic water supply facilities. A growing number of big cities have attained a high rate level of over 150 l/d/capita in domestic water withdrawal per capita, while rural villages can use only 50 to 60 l/d/capita in average.

Therefore, difference is made between urban and rural water use per capita for demand projection. In addition, water withdrawal for livestock in rural areas is included in rural domestic water use. Based on statistical data and with reference to the YRCC water resources bulletin of 1990's, present domestic water use is 70-160 l/d/capita in urban areas and 41-66 l/d/capita in rural areas, and both values are assumed to increase about 10-15 l/d/capita every 10 to 20 years. In this way, the projected domestic water demand in the YR is listed in Table 4-3.

Table 4-3 Scenario of domestic water demand in the YRB

Item	1999	2010	2030	2050
Urban domestic water usage (l/d/capita)	154	169	184	198
Rural domestic water usage (l/d/capita)	60	72	85	98
Total population (10^6 persons)	130.6	142.5	158.1	166.0
Urban population ratio (%)	23	30	36	42
Urban population (10^6 persons)	29.9	43.5	57.8	70.6
Rural population (10^6 persons)	100.7	98.9	100.3	95.4
Urban domestic water demand (10^9 m^3)	1.7	2.7	3.9	5.1
Rural domestic water demand (10^9 m^3)	2.2	2.6	3.1	3.4
Domestic water demand (10^9 m^3)	3.9	5.3	7.0	8.5
Hebei Tianjin demand (10^9 m^3)	2.0	2.0	2.0	2.0

Industrialisation

Industry water demand has been computed as a water withdrawal per unit industrial production ($m^3/10^4$ Yuan) multiplied by the industrial production (in units of 10^4 Yuan). Both unit industrial water withdrawal (per unit industry production) and industrial production growth change with economic development.

According to China national economic development strategy, industrial production growth rate would be 6.4% between 2000 and 2010, 5.6% between 2010 and 2030 and 5.0% between 2030 and 2050 (see Liu et al, 1996). To account for the regional development difference, it is assumed that the industrial development in Shandong is 15% higher than national industrial growth rate; in Gansu, Qinghai, Sichuan and Ningxia it is 15% slower; and Henan, Shaanxi, Shanxi and Inner Mongolia would catch up the same tendency of the national industrial development figures.

At present, the average unit industrial water withdrawal in the provinces along the YR is 176 m^3/unit. Reuse of industry water is only 40% to 60% (Lin, 2003). In general, technology advances along with economic development. Thus, unit industrial water withdrawal value will probably decline while the reuse percentage will probably increase. Some studies predict that the decrease of unit industrial water withdrawal would be 4.0% between 2000 and 2010, 3.0% between 2010 and 2030 and 2.0% between 2030 and 2050 (Liu et al, 1996). Also, it is assumed that faster regional economic developments will results in lower unit industrial water withdrawal rates. Or, the rate of unit industry water withdrawal is 15% lower in the coastal area (Shandong), and 15% higher in the upstream provinces (Gansu, Qinghai, Sichuan and Ningxia). By such, the final projected industry water demand is projected and listed in Table 4-4.

Table 4-4 Scenario of industrial water utilization in the YRB

Item	1999	2010	2030	2050
Industry production (10^9 Yuan)	326	609	1,842	4,999
Unit industry water withdrawal ($m^3/10^6$ Yuan)	1.8	1.2	0.6	0.4
Industry water withdrawal (Mcm)	5732	7032	11165	19419

Food supply and irrigation area increase

Food supply in the YRB relies largely on irrigation, which makes irrigation the major water utilization sector in the YRB. At present, average food supply is 413 kg/capita and crop yield per unit of irrigation area is 10.25 ton/ha in the basin. It is reasonable to expect that the capita food consumption will increase with improved living conditions in future. It is assumed that the average food supply will reach 420kg/capita in 2010, 430kg/capita in 2030 and 440kg/capita in 2050. Also assumed is that the crop yield per unit of irrigation area remains the same. To response to steadily increasing food demand with growing population and economic development, irrigation area is predicted to increase. The results of the irrigation area extension are listed in Table 4-5. The investment involved in the irrigation area increase is not considered in this thesis. Other scenarios of some external conditions, i.e. irrigation productivity, industry productivity and GDP (Yuan/m^3) are included in Table 4-6 to Table 4-8.

Table 4-5 Scenario of irrigation area extension in the YRB (10^3ha)

Province	Arable land	Designed area	1999	2010	2030	2050
Gansu	2504.5	397.6	332.5	342.4	351.6	357.5
Henan	1181.4	680.1	761.1	767.5	774.0	778.0
Inner Mongolia	1261.1	815.0	867.8	898.2	912.1	923.4
Ningxia	1240.2	331.5	396.4	414.9	444.9	462.0
Qinghai	520.5	142.5	142.4	146.8	151.2	153.9
Shaanxi	2701.1	1115.1	560.2	576.4	590.9	600.1
Shandong	4598.6	3121.9	1476.7	1532.7	1578.0	1607.8
Shanxi	2294.0	764.2	740.4	767.6	791.9	807.5
Sichuan	7.3	0.3	1.3	1.4	1.6	1.7
Basin	16308.7	7368.4	5279.0	5448.0	5596.1	5691.8

Table 4-6 Scenario of irrigation productivity in the YRB (Yuan/m^3)

Province	1999	2010	2030	2050
Sichuan	1.2	1.9	3.8	8.1
Qinghai	2.0	3.2	6.8	15.3
Gansu	2.4	4.1	9.4	22.9
Ningxia	0.3	0.5	1.0	2.5
Inner Mongolia	1.1	2.0	5.3	13.8
Shaanxi	3.0	5.6	16.4	55.2
Shanxi	2.6	5.0	14.5	48.2
Henan	1.6	2.9	8.0	22.2
Shandong	2.4	4.8	15.2	49.0
Basin	1.7	3.2	8.9	26.2

Table 4-7 Scenario of industry productivity in the YRB (Yuan/m^3)

Province	1999	2010	2030	2050
Sichuan	55.4	78.3	131.2	184.9
Qinghai	19.8	28.0	47.0	66.2
Gansu	26.8	37.9	63.5	89.5
Ningxia	19.3	27.2	45.6	64.3
Inner Mongolia	54.8	82.4	151.5	227.0
Shaanxi	60.0	90.2	165.9	248.5
Shanxi	87.0	130.9	240.7	360.5
Henan	69.2	104.1	191.4	286.7
Shandong	111.6	178.8	360.7	574.5
Basin	56.8	86.7	164.9	257.5

Table 4-8 Scenario of GDP in the YRB (Yuan/m^3)

Province	1999	2010	2030	2050
Sichuan	7.6	16.3	30.3	58.4
Qinghai	3.2	4.8	9.8	19.8
Gansu	4.8	7.6	14.8	27.7
Ningxia	0.8	1.3	2.8	6.2
Inner Mongolia	3.2	5.6	14.2	33.9
Shaanxi	8.1	14.8	35.0	80.3
Shanxi	8.4	15.5	38.3	91.8
Henan	4.2	7.7	19.1	45.6
Shandong	7.4	13.9	42.2	124.1
Basin	4.9	9.0	23.1	58.4

4.2.1.2 Climate change

As described in section 1.2, global warming can lead to reduction of annual precipitation and consequently to decrease of natural runoff (IPCC,2001; Liu and Zhang, 2003). Base on possible temperature and precipitation changes predicted by three transient atmospheric Global Circulation Models (GCMs, developed by Geophysical Fluid Dynamic Laboratory, U.S.A for Scenario GFTR; by Hadley Centre, U.K for Scenario HCTR; and by Max-Planck Institute for Meteorology, Germany for Scenario MPTR), Kaczmarek (1998) assessed annual runoff variation for the YR and concluded that 'the sensitivities of hydrological processes in this basin to climate change are limited; higher sensitivity was found in some of the sub-basins…'; Wang (1997) provided simulated results by coupled climate-hydrology model system for the YR and concluded that by the year 2030, precipitation in the YR would change from minus 7.1 percent to positive 12.9 percent, while Runoff in YR would decrease by 12.6-20.9%. Under the four GCM scenarios (LLNL, Liu, 1997; UKMO-H3, Mitchell et al, 1989; OSU-B1, Schlesinger and Zhao, 1989; GISS-G1, Hansen et al, 1984), it is predicted that annual runoff in the YRB mostly tends to decrease by several percentages, as shown in Table 4-9 (Lee et al, 1997).

Table 4-9 Impact of climate change on annual runoff in the YRB (%)

Model	**General Circulation Model**			
Scenarios	LLNL(1)	UKMO-H3	OSU-B1	GISS-G1
Change of annual runoff	-7.2	-4.6	-2.6	4.0

(1) L. Gates, personal comments indicated that under the IPCC GCM scenarios, sub-regions of northern China have different ranges of runoff changes and the middle reaches of the YRB would be -12 to -5%. (Lin, 1994)

For this study, the conclusions obtained by other researchers are adopted and the principle of precaution is used to reflect the impacts of climate change. Scenario of climate change is interpreted as a reduction of natural runoff till 20%. Thus three scenarios are assumed,

Normal: no climate change
L_{10}: natural runoff decrease by 10%
L_{20}: natural runoff decrease by 20%

Other impacts of climate change on crop water demand and utilisation of effective rainfall are not considered, neither the interaction between SW and GW. Finally, the assumed natural runoff under climate change scenarios is listed in Table 4-10.

Table 4-10 Water availability under climate change in the YRB

Year	**Normal**	**L_{10}**	**L_{20}**
Natural runoff reduction (%)	0	-10	-20
SW (10^9 m^3)	57.7	51.3	45.1
Total SW and GW (10^9 m^3)	67.8	61.5	55.3

4.2.1.3 Combined effects of scenario design

When the water demand projections are combined with climate change assumptions, nine scenarios emerge for analysis of future water allocation problems, as expressed in Table 4-11. As expected, the total water demand of the YRB (DMI, irrigation and environment low flow) will indeed raise dramatically from 82539 Mcm on 1999 to 86967 Mcm on 2010, to 94575Mcm on 2030 and to 105478 Mcm on 2050. Simultaneously, total inflow would probably decline affected by climate change. Therefore, an increasing gap between water demand and water availability is projected in future in the YR. This will be analyzed in next section.

Table 4-11 Summary of scenario design for YR water allocation (10^9 m^3)

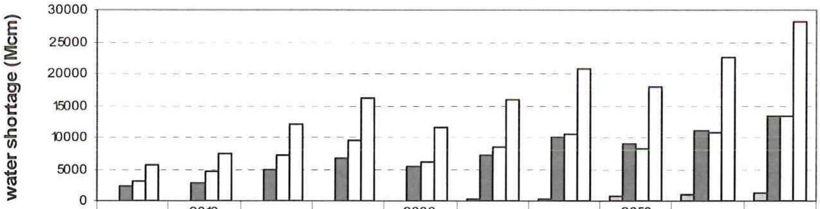
Scenario	DMI demand	Irrigation demand[1]	Environmental low flow demand	Total water demand	Total natural runoff
1999	11.6	50.9	20.0	82.5	67.8
2010 normal	14.3	52.7	20.0	87.0	67.8
2010 L_{10}	14.3	52.7	20.0	87.0	61.5
2010 L_{20}	14.3	52.7	20.0	87.0	55.3
2010 normal	20.1	54.4	20.0	94.6	67.8
2010 L_{10}	20.1	54.4	20.0	94.6	61.5
2010 L_{20}	20.1	54.4	20.0	94.6	55.3
2010 normal	29.9	55.5	20.0	105.5	67.8
2010 L_{10}	29.9	55.5	20.0	105.5	61.5
2010 L_{20}	29.9	55.5	20.0	105.5	55.3

[1] Irrigation demand is calculated by RIBASIM AGWAT module for different scenarios

4.2.2 Projected water shortage

Based on the simulated Business-As-Usual (BAU) results by RIBASIM for above designed 9 scenarios, future water shortage are predicted.

First of all, water shortage for DMI and irrigation will become more and more serious in increasing number of areas in the YRB in future, see Figure 4.4. Obtaining adequate water supplies for DMI would be difficult. Irrigation shortage might threaten food security in the YR, and it might even consequently affect food security in some other regions in China. In 1999, irrigation shortage is 2373.4 Mcm. In 2010, irrigation shortage is foreseen to increase to 2844.0 Mcm. If climate change is also considered, this figure should be doubled. In 2050, irrigation shortage will grow to 8917.9 Mcm without consideration of climate change impacts. When accounting for climate change, this figure may grow beyond 10.0 billion m^3.



	1999	2010 normal	2010 L10	2010 L20	2030 normal	2030 L10	2030 L20	2050 normal	2030 L10	2030 L20
□ DMI	9	18	34	48	102	180	348	803	1027	1363
■ irrigation	2373	2844	4866	6708	5358	7227	9927	8918	10987	13406
□ environmental low flow	3182	4594	7116	9423	6128	8452	10585	8105	10669	13371
□ total	5563	7456	12015	16179	11588	15860	20859	17825	22683	28141

Figure 4.4 Predicted water shortage in the YRB in different climate scenarios (BAU)

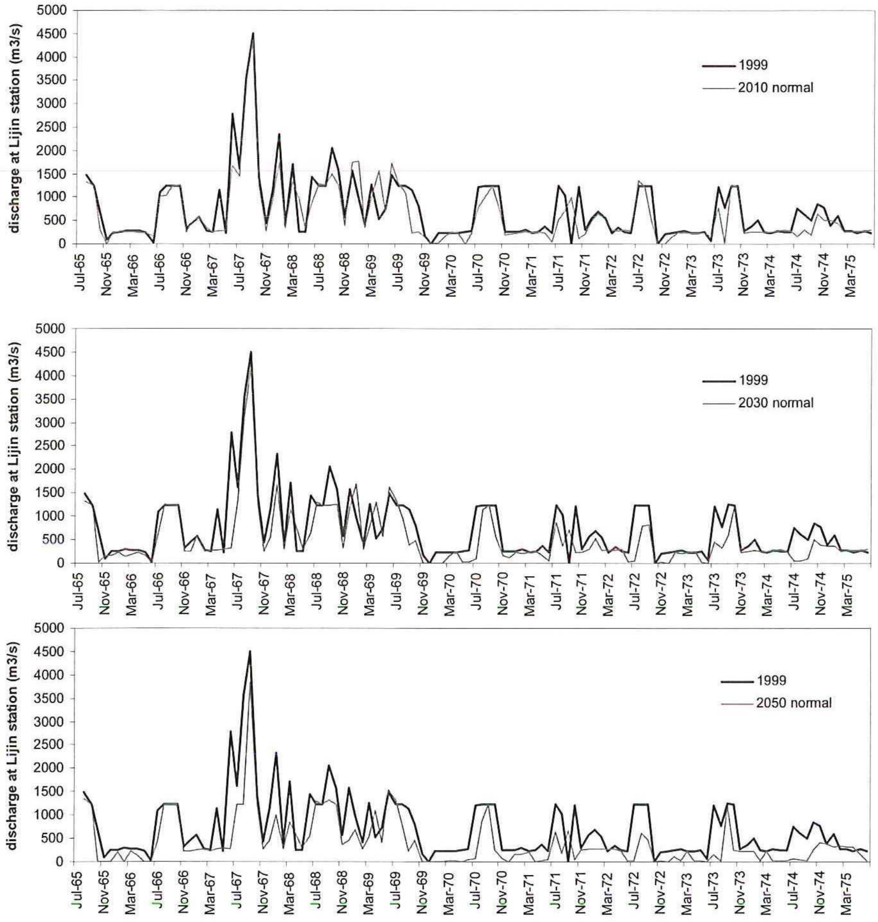


Figure 4.5 Predicted zero flow occurrences in the YRB in different climate scenarios (BAU)

Much attention should also be given to water shortage of environmental low flow. As shown in Figure 4.4, this shortage will increase in future as well. In 1999 environmental flow shortage is 3.2 billion m^3. In 2050, a shortage of more than 8.0

billion m^3 could occur without consideration of climate impact, while this figure could increase to over 10.0 billion m^3 for climate change scenario L_{10} and over 13.3 billion m^3 for climate change scenario L_{20}. As a consequence, zero low would reoccur frequently in future at Lijin station in the YRB (see Figure 4.5).

In terms of total basin water utilization (DMI, irrigation and environmental low flow), by 2010 total water shortages would increase from 5.56 billion m^3 on 1999 to 7.5 billion m^3 for scenario 2010 normal, to 12.01 billion m^3 for scenario 2010 L_{10} and to 16.18 billion m^3 for scenario 2010 L_{20} Then from 2030 to 2050, the quantity of total water shortages would become extremely large. Till 2050, the total water shortage would reach 17.8 billion for normal year, 22.68 billion m^3 for scenario L_{10} and even 28.1 billion m^3 for scenario L_{20}. Apparently, if no measures are adopted, conflicts deduced by water shortage would be seriously escalating in future.

4.3 Conclusions

Attracting increasing attention in the YRB, water allocation problems are particularly troublesome in this basin and climate change may have the potential to worsen already gloomy situations. More and more serious water shortages would be faced in all water use sectors in the YR. If taking no actions, both human and nature would be endangered by over extraction of water resources in future. As the extreme case of over extraction, the occurrence of zero flow would appear frequently again at Lijin station in future. Given the increasing water shortage, conflicts among provinces and across different water use sectors are foreseen to escalate in future. It is reasonable to conclude that water resources in the YR should be re-allocates based on the principle of equity of IWRM in order to realize sustainable basin development in the long term future. In the next chapter, application of equity principles of IWRM, the combined ethical approaches with scientific and technical approaches, will be introduced to explore solutions to mitigate escalating water shortage deduced conflicts among provinces in the YR.

5 Equitable water allocation schemes for the YRB

Given the fact that human population, water scarcity and conflicts over water resources are increasing rapidly in the YRB, it is important that the governments pave the way to a new era of integrated basin water allocation. In Chapter 2 it is argued that the prime mover of rational inter-provincial water allocation should be based on the principle of equity with consideration of reserve water to harmonise human with nature. This ethical approach will be 'interpreted' into different scheme design guidelines to formulate alternative inter-provincial water allocation schemes. These schemes will be realized (i.e. implemented and assessed) by the RIBASIM model and their effects will be evaluated. Afterwards, both YRCC and provinces' preference will be derived and presented by cooperation diagrams. From those cooperation diagrams, major cooperation contradictions among provinces will be addressed. The feedback will be valuable for the implementation of the scheme and for future research. The outline of Chapter 5 is shown in Figure 5.1 below.

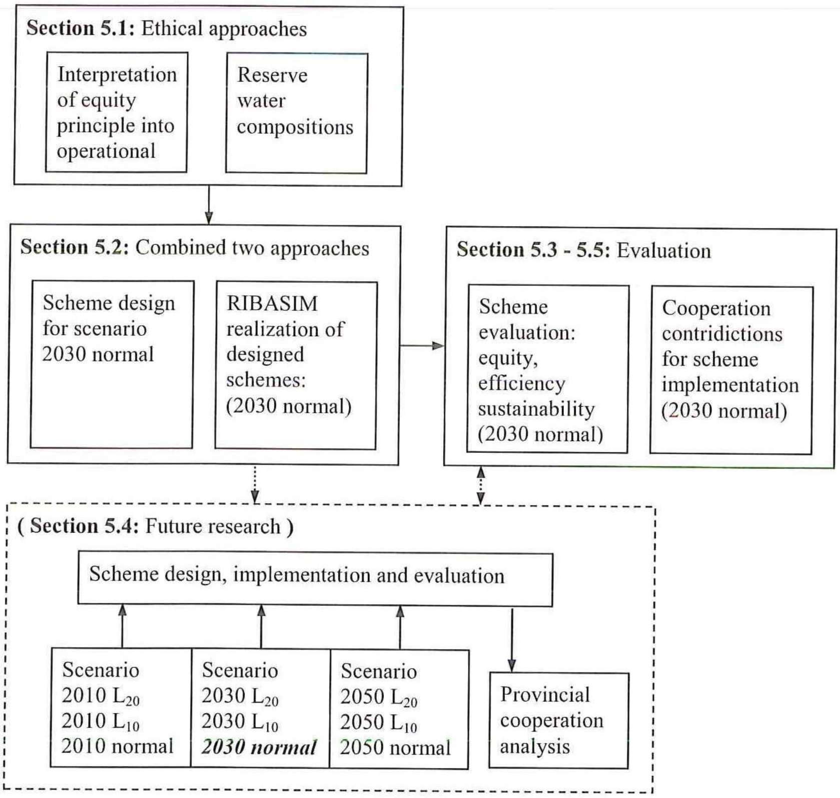


Figure 5.1 Outline of Chapter 5

5.1 Equity principle and reserve water

As discussed previously in Chapter 2, integrated water allocation in the YRB should no longer miss its philosophical basis. And it is further augured that in this particular basin of YR, proper philosophical basis of IWRM can be its indigenous Taoism to promote equity principle in basin water allocation. Specially, in this section, these ethical approaches will be 'translated' into water allocation guidelines. This ethical approach will be 'interpreted' into different scheme design guidelines to formulate alternative inter-provincial water allocation schemes.

5.1.1 Interpretation of equity principle

At the heart of water conflict management is the question of equity. The principle of (reasonable and) equitable use (Article 5 of the UN Convention) is defined in general terms, and is thus prone to subjective interpretation. 'Criteria for equity, a vague and relative term in any event, are particularly difficult to determine in water conflicts, where international water law is ambiguous and often contradictory...' (Wolf and Dinar, 1994; Wolf, 1996). Nevertheless, closely following the definition as used in social psychological literature and with reference to others definitions, the equity principle can be translated into practical and operationalized criteria to be used as the basic approach (with consideration of reserve water) to the design of equitable inter-provincial water allocation schemes.

5.1.1.1 Definition of equity

There are three different kinds of arguments against the use of equity. The first is that equity is merely a word that hypocritical people use to cloak self-interest – it has no *intrinsic* meaning so therefore fails to exist. The second is that even if equity does exist in some notional sense, it is so hopelessly subjective that it cannot be analyzed *scientifically* that it fails to exist in an *objective* sense. The third argument is that there is no *sensible* theory about it – thus it fails to exist in an *academic* sense (Young, 1994).

It happens often when government policies constantly state that (water) resources will be allocated 'equitably', least attention is paid to the definition of what is 'just', or 'fair' or 'equitable' as seen by the range of stakeholders in water allocation decisions. It is not enough for governments to espouse the policy of 'equitable allocation' when the determinations of equity are unclear. There is a need to understand how people interpret equity, justice and other principles when the outcomes of decision making affect them personally.

Syme et al (1999) turned to the social psychological literatures as a starting point to find the definition of equity. They identified that three concepts seemed to be pertinent: equity, and procedural and distributive justice. Authors such as Rasinski (1987) had shown in the context of social welfare policy that equity had two components, proportionality and egalitarianism. The first dimension of equity inferred that people should be distributed funds according to their effort or 'deservedness'. Egalitarianism suggested that everyone should be treated equally.

A review of procedural justice and how it may relate to natural-resource decisions is offered by Lawrence et al (1997). The major hypothesis of procedural justice is that if procedural justice is demonstrated in a decision-making process the outcome is more likely to be accepted. Distributive justice is a concept related to the evaluation of whether an outcome was just in terms of the distribution of resource between stakeholders. In this way equity and distributive justice are closely related concepts. The dimensions of equity seem to be the base on which individuals assess whether or not distributive justice has been achieved.

The concept of the fairness heuristic (e.g. van de Bos et al, 1997, Syme and Nancarrow, 1997) is preferred as a starting point. This concept avoids the large degree of overlap and correlation between people's views on procedural and distributive justice and the role of equity considerations within these judgments (e.g. Folger, 1996), while it considers the typical features of water resources allocation issues (which are ongoing; where there is unlikely to be a clear-cut end point; and when the individual's knowledge is incomplete). Later, Syme et al (1999) developed the terms *universal fairness* and *situational fairness* principles relating to water allocation judgments. Universal fairness considers the acceptability of decisions in general or disinterested terms, while situational fairness specifically identifies where the outcome is likely to impact personally or locally. The attitudes which contribute to these overall judgments are labelled *fairness criteria*. In the universal sense, they developed lay philosophies, or the principles and values that people wanted to see articulated in general terms in water allocation policies. They concluded that 'people have universal fairness criteria for judging the overall fairness of water allocation system at a general level, and these are useful for systematic derivation of accountable solutions at a local or situational level.' Fair decision-making processes are of paramount importance to community acceptance of water allocation decisions.

5.1.1.2 Operational criteria

The challenge now is how to translate the equity principle into water allocation practices. The previously described equity definition can already provide certain theoretical bases for equity operationalization. Relatively more sensible interpretation can be based on the two dimensions of equity definition of *proportionality* and *egalitarianism.*

Equity in the dimension of proportionality: distribution according to people's effort or deservedness. In this study, water demand is used to present these efforts as a quick fix (demand equity). It is assumed that the human efforts or deservedness is a function of total local water demand (including DMI, irrigation, environment, etc). Proportional water distribution then becomes simply in proportion to water demand. This assumption is not perfect, as tricky arguments might be raised. For instance, in the line of equity in the dimension of proportionality, users having high water demand due to low water use efficiency (or recycling or reuse) would not be willing to adopt water saving technologies in order to continue claiming high water allocation quantity. To overcome this shortcoming, it is simply assumed in this thesis that in the YRB ongoing efforts are being made to improve water use efficiency by all provinces across all sectors. This is also one of the tasks of YRCC.

Equity in the dimension of egalitarianism: everyone should be treated equally since every human being has a basic right to access to water (Gleick, 1999). This can be directly translated into water allocation in proportion to population (supply equity). For the Yellow River basin inter-provincial water allocation, equity in the dimensions of *proportionality* and *egalitarianism* can be translated into inter-provincial allocation in proportion to provincial water demand and in proportion to provincial population separately.

Other straight forward equity criteria are proposed by van der Zaag et al (2002) for international water resources: water (SW) equally share among countries or in proportion to each country's catchment area in the basin. Unfortunately, it is not always explicitly articulated why such translation of equity principle is believed equal, i.e. what kind of lay philosophy is related. The reason to propose this method is mostly because they are operational and simple.

In total, three ways of translation of equity principles will be presented for the YR inter-provincial water allocation: inter-provincial apportionment based on:

- provincial water demand,
- provincial population and
- provincial catchment area.

The first two translation ways should be believed as fair or just and the decision made would be more possibly accepted by the majority of its stakeholders. And the equity and rationality of the third criterion, catchment area, can be further argued. In general, the results of the alternative water allocation strategies from the three alternatives are likely to gain longer-term community acceptance.

In this chapter, the three ways of translation of equity principle are named as water allocation equity criteria: to simplify, they are expressed by abbreviations of:

1) criterion **WD** i.e. Water Demand: All waters generated in a river basin should be shared by the riparian provinces in proportion to each province's water demand in the basin;
2) criterion **PL** i.e. PopuLation: All waters generated in a river basin should be shared by the riparian provinces in proportion to each province's population in the basin;
3) criterion **CA** i.e. Catchment Area: All waters generated in a river basin should be shared by the riparian provinces in proportion to each province's catchment area in the basin.

Following these equity criteria (WD, PL and CA), allocation schemes can be made more clear rather than relying on undefined assertions that allocation is 'equitable'. It is believed that once stakeholders agree with these equity criteria, opportunities will emerge that gain longer-term community acceptance and can reduce negative social impacts as well.

5.1.2 Reserve water components

The 1987 Scheme puts aside 20 billion m^3 water as so-called environmental low flow. Clearly, this 20 billion m^3 water for basic ecosystem requirement can be regarded as reserved water out of negotiation. Depending on how far basic human demand can be reserved out of negotiation, three types of reserve water are proposed (see Table 5-1):

Res:1E:	only environmental low flow (no water for human demand)
Res:2E:	environmental low flow and domestic and municipal demand
Res:3E:	environmental low flow and DMI water demand

Table 5-1 Types of reserved water for basin water allocation

Components of reserved water		**Res:1E**	**Res:2E**	**Res:3E**
Human usage	Domestic and municipal demand		√	√
	Industry demand			√
Nature	Environmental low flow demand	√	√	√

The option of Res:1E actually reserves no water for basic human needs, just like the 1987 Scheme. By comparison with the other options, the disadvantage and advantages (or reasonability and necessity) of reserving water for basic human demand can be better illustrated. When reserved water increases from domestic and municipal water to DMI demand, i.e. comparison between Res:2E and Res:3E, stakeholders are able to judge whether it is wise to include industry water demand as reserve water. When industry water demand becomes a large proportion of total DMI demand, cautious should be given to judge whether to include Res:3E in scheme design guideline.

5.1.3 Design guidelines

When the 3 types of equity criteria are combined with the 3 types of reserved water components, 9 equitable water allocation guidelines come into being. Together with the 1987 Scheme policy, 10 water allocation guidelines are listed in Table 5-2.

Table 5-2 Guidelines for inter-provincial water allocation in the YRB

Reserve water / **Criterion**	**Res:1E**	**Res:2E**	**Res:3E**
WD	WD1E	WD2E	WD3E
PL	PL1E	PL2E	PL3E
CA	CA1E	CA2E	CA3E
	1987 Scheme		

5.2 Formulations of equitable schemes for scenario 2030 normal

Once general agreement is reached regarding appropriate allocation principles and criteria, the next step is to formulate different allocation schemes which define quantitative SW apportionments for each province. In designing the apportionment formula, it is necessary to address the fact that water is mobile, and its availability naturally fluctuates from year to year. Also important is the fact that all water systems have unique physical constraints that limit where and when water can be stored and diverted, and in what quantities and rates. Other important concerns are the need to respect established water uses, the importance of the GW and SW interaction. Further complicating emerges as the apportionment formula relies on easily obtainable data, such as reservoir storage elevations or stream flows at a given point. Although the different traditions and practices in different parts of the basin may lead to varying results, the effort should always be directed to securing an equitable apportionment without quibbling over formulas of water allocation.

5.2.1 Allocation algorithms

In this study, the allocation algorithms is developed to take into account equity criteria, reserve water *Res*, GW and some assumptions (van der Zaag et al, 2002).

Equity criteria of WD, PL and CA for inter-provincial water allocation

Keeping in mind that it is often not possible to pump water from down- to upstream provinces, the proposed procedure is not just to split the available water in proportion to provincial water demand, population or catchment area. The procedure moves from upstream to downstream whereby at each border crossing the remaining water is shared among the downstream provinces proportionally. Taking the equity criteria of WD as example, the following steps are proposed:

1. Assess for each of the basin province the amount of water (incl. SW and GW, Eq. 5.1) generated in that province.
2. Subtract the reserved water Res.
3. Calculate for each province its apportionment by multiplying the available non-reserved water by the demand that a riparian province requires in the basin, and dividing it by the remaining water demand (i.e. excluding the demand requested by upstream provinces). This calculation procedure is mathematically represented by Eq. 5.2. For the most upstream province this apportionment simply equals the total non-reserved water resources generated in the entire basin by multiply the water demand from this most upstream province and then dividing it by the total water demand of the whole basin.
4. Compare the calculated apportionment of the most upstream province with the non-reserved water generated in that province. Any excess water has to be passed on to the downstream province(s). In the meanwhile, if the calculated apportionment is larger than the non-reserved water generated in that province, the apportionment should reduce to the latter value as water can not be pumped from downstream to upstream. This step is repeated for all riparian. This calculation procedure is mathematically represented by Eq. 5.5.
5. Step 3 and 4 are now repeated for the second riparian province(s). Its apportionment is calculated by adding the water received from the upstream province to the non-reserved water generated in all riparian provinces except the most upstream, and multiplying it by the demand from the second riparian province(s), and dividing it by the remaining water demand (i.e. excluding the demand requested by the most upstream provinces). The second riparian province(s) surrenders any non-reserved water in excess of its own

apportionment to the next downstream riparian. This step is repeated for all riparian.

6. When every province's water apportionment is calculated, minus the apportionment of GW over and above reserve GW from provincial total apportionment, the equitable provincial SW apportionment can then be obtained, represented by Eq. 5.6 and Eq. 5.7.

$$Q_i = Q_i^{SW} + Q_i^{GW} \qquad \text{Eq. 5.1}$$

$$Q_{r,i} = \max\left(\min\left(Q_{t,i-1} + Q_i - \mathrm{Re}_i, (Q_{t,i-1} + \sum_i^n (Q_i - \mathrm{Re}_i))\frac{D_i}{\sum_i^m D})\right), Q_{r,i}^{GW}\right) \qquad \text{Eq. 5.2}$$

$$Q_{r,i} = \max\left(\min\left(Q_{t,i-1} + Q_i - \mathrm{Re}_i, (Q_{t,i-1} + \sum_i^n (Q_i - \mathrm{Re}_i))\frac{N_i}{\sum_i^m N})\right), Q_{r,i}^{GW}\right) \qquad \text{Eq. 5.3}$$

$$Q_{r,i} = \max\left(\min\left(Q_{t,i-1} + Q_i - \mathrm{Re}_i, (Q_{t,i-1} + \sum_i^n (Q_i - \mathrm{Re}_i))\frac{A_i}{\sum_i^m A})\right), Q_{r,i}^{GW}\right) \qquad \text{Eq. 5.4}$$

$$Q_{t,i} = Q_{t,i-1} + (Q_i - \mathrm{Re}_i) - Q_{r,i} \qquad \text{Eq. 5.5}$$

$$Q_{r,i}^{SW} = Q_{r,i} - Q_{r,i}^{GW} \qquad \text{Eq. 5.6}$$

$$Q_{r,i}^{GW} = Q_i^{GW} - \mathrm{Re}_i^{GW} \qquad \text{Eq. 5.7}$$

where

Q_i	SW and GW generated in a province *i* [Mcm/yr];
Q_i^{SW}	SW generated in a province *i* [Mcm/yr];
Q_i^{GW}	GW generated in a province *i* [Mcm/yr];
$Q_{r,i}$	apportionment of SW and GW of province *i* over and above the reserved water [Mcm/yr];
$Q_{t,i}$	surplus water to be transferred to downstream provinces [Mcm/yr];
Re_i	reserved water for a riparian province *i* [Mcm/yr];
Re_i^{GW}	reserved GW for a riparian province *i* [Mcm/yr];
D_i	water demand in a riparian province *i* [Mcm/yr];
$Q_{r,i}^{GW}$	apportionment of GW of province *i* over and above the reserved GW [Mcm/yr];
$Q_{r,i}^{SW}$	apportionment of SW of province *i* over and above the reserved GW [Mcm/yr];
N_i	the population living in that part of the river basin occupied by province *i*;
A_i	catchment area occupied by province *i* [km^2];
i	prefix for the riparian province involved, with *i*=1 for the upper most basin province, and *i*=*m* for the most downstream;
n:	total number of provinces in the basin.

For *equity criteria of PL*, the water apportionment of each riparian province is calculated by multiplying the available non-reserved water by the population of a riparian province living in the basin, and dividing it by the remaining population (i.e.

excluding the basin population living in upstream provinces), represented by Eq. 5.3. Any non-reserved water in excess of a province's apportionment is transferred downstream in exactly the same way as in the WD calculation procedure (Eq. 5.5).

For *equity criteria of CA*, the water apportionment of each riparian is calculated by multiplying the available non-reserved water by the catchment area of that riparian province in the basin, and dividing it by the remaining basin catchment area (i.e. excluding the area occupied by upstream provinces), represented by Eq. 5.4. Any non-reserved water in excess of a province's apportionment is transferred downstream in exactly the same way as in the WD calculation procedure (Eq. 5.5).

Another three assumptions are associated in terms of utilization of SW and GW:
1. First assumption is that domestic and municipal water demand has higher water allocation priority then industry, and industry has higher priority then irrigation. And DMI has higher priority than irrigation.
2. Second assumption is that local water demand first accounts on GW supply as much as possible and then on SW supply[1].
3. The third assumption is that environmental low flow is not supplied by GW (neglecting the dynamic SW and GW exchange).
The concerned water allocation assumptions are also illustrated in Figure 5.2.

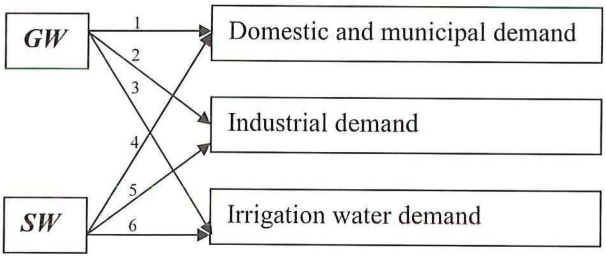


Figure 5.2 Water source priority in the YRB (priority 1 is the highest)

Different water allocation priority settings for the 10 alternative water allocation outlines are listed in Table 5-3 below.

Table 5-3 Allocation priority for different water allocation schemes (1 is the highest)

Scheme guideline	Water allocation priority
WD1E PU1E CA1E 1987 Scheme	1: environmental low flow 2: DMI demand 3: irrigation demand
WD2E PU2E CA2E	1: environmental low flow 1: domestic & municipal water demand 2: industry demand 3: irrigation demand
WD3E PU3E CA3E	1: environmental low flow and DMI demand 2: irrigation demand

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[1] In this study annual GW supply is assumed equal to annual GW utilization as described in section 3.3.2, therefore GW is used up in the end of each simulation year.

Consideration of the YRB schematization

In YR schematization Figure 3.1 one province is normally presented by several provincial sub-divisions. Accordingly, above water allocation algorithms are not directly applied to province *i* but to each provincial sub-divisions, see simplified basin network in Figure 5.3. Or, the water generated in one provincial sub-division's boundary is shared in proportion to each provincial sub-division's water demand (or sub-division's population or sub-division's catchment area). The total apportionment of a province is equal to the sum of the apportionments from all this province's sub-divisions.

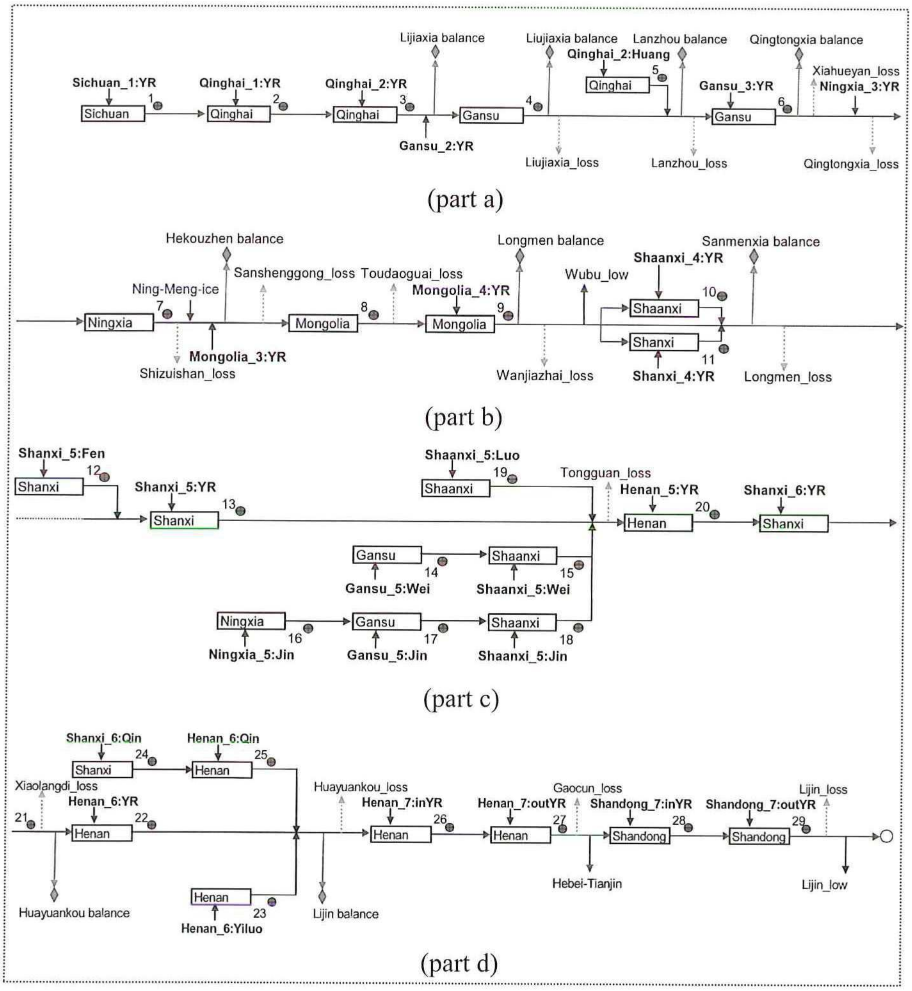
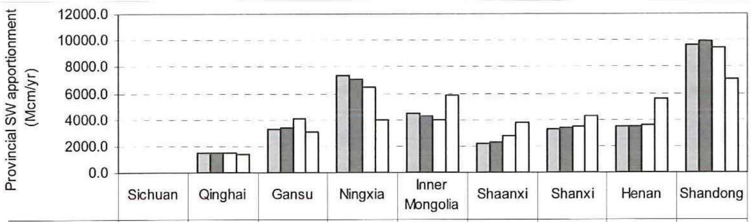


Figure 5.3 Basin network for inter-provincial water apportionment determination

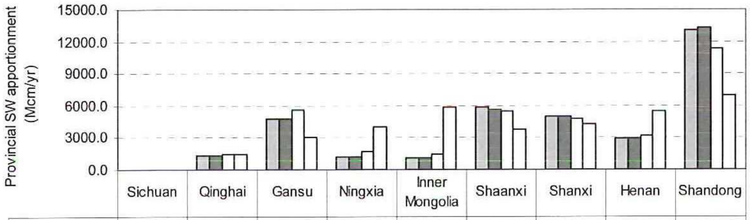
Note: 1. *Loss flow and balance flow (negative values) are marked at proper river crossings and will be subtracted for the determination of the access flow to downstream.*
2. *Hebei-Tianjin (outside basin) is always subtracted from total river flow.*
3. *Low flow nodes standing for environmental low flow requirements are inserted at proper positions to be subtracted from total river flow if regarded as reserve flow.*

5.2.2 Generated equitable schemes

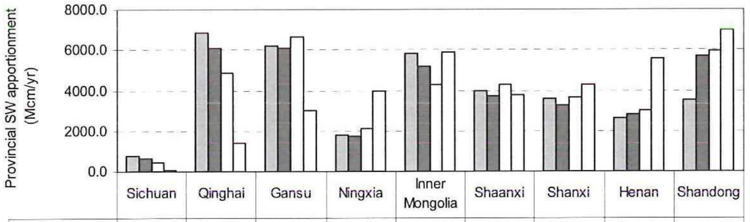
Following the above scheme design guidelines, algorithms and assumptions, the 9 equitable schemes for the YR for scenario 2030 normal are formulated. The reason to choose scenario 2030 normal is first of all to exclude the impact of climate change on water availability which is still unclear. Second reason is that projected water shortage in year 2030 is not extreme among the designed scenarios, therefore proposed measures can still be realistic to be referred in practices in future. The final results of the 9 equitable schemes are shown in Figure 5.4.



	Sichuan	Qinghai	Gansu	Ningxia	Inner Mongolia	Shaanxi	Shanxi	Henan	Shandong
□ WD 1E	7.5	1461.2	3307.3	7377.3	4501.9	2154.9	3241.5	3516.9	9641.6
■ WD 2E	8.1	1458.9	3376.1	7009.0	4307.4	2326.7	3329.1	3467.8	9927.1
□ WD 3E	8.5	1529.8	4028.6	6445.0	4014.6	2771.7	3485.7	3535.0	9391.1
□ 1987 Scheme	40.0	1410.0	3040.0	4000.0	5860.0	3800.0	4310.0	5540.0	7000.0



	Sichuan	Qinghai	Gansu	Ningxia	Inner Mongolia	Shaanxi	Shanxi	Henan	Shandong
□ PL 1E	23.6	1319.4	4703.3	1199.3	1107.4	5837.3	5049.9	2945.3	13024.8
■ PL 2E	22.6	1334.2	4733.9	1165.4	1120.3	5553.2	5013.2	2941.6	13325.7
□ PL 3E	19.4	1514.2	5669.7	1699.6	1441.8	5529.3	4723.1	3210.8	11402.0
□ 1987 Scheme	40.0	1410.0	3040.0	4000.0	5860.0	3800.0	4310.0	5540.0	7000.0

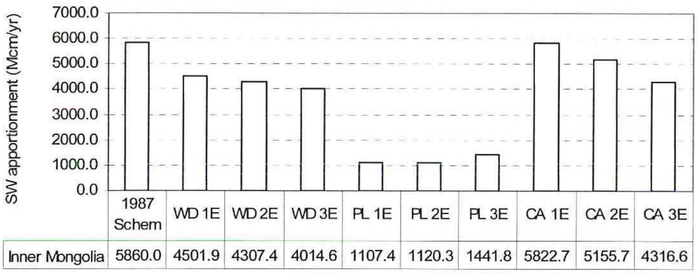


	Sichuan	Qinghai	Gansu	Ningxia	Inner Mongolia	Shaanxi	Shanxi	Henan	Shandong
□ CA 1E	746.8	6846.4	6239.0	1817.9	5822.7	3995.0	3599.8	2624.4	3518.2
■ CA 2E	641.5	6064.3	6058.9	1728.1	5155.7	3733.3	3287.8	2814.8	5725.7
□ CA 3E	460.3	4883.9	6629.2	2103.1	4316.6	4267.8	3618.9	2986.0	5944.4
□ 1987 Scheme	40.0	1410.0	3040.0	4000.0	5860.0	3800.0	4310.0	5540.0	7000.0

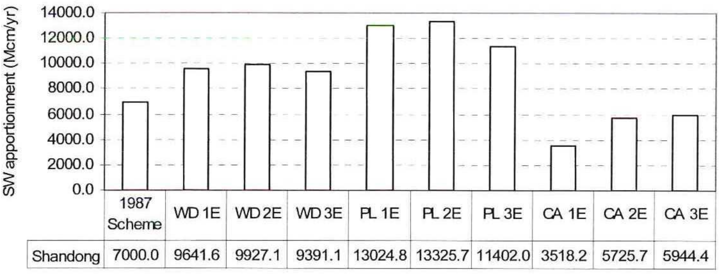
Figure 5.4 Provincial SW apportionments in the YR for scenario 2030 normal

The SW allocation algorithms (presented by Eq. 5.1 to Eq. 5.7) are not complicated. The weakness of the SW allocation algorithms is that the time variability of water availability and water demand within a year and for wet and dry year is not sufficiently taken into account. The strength of the method is that the algorithms are transparent and they may be easily understood by politicians and decision-makers. This will increase trust in the method as it is not seen as a 'black box' only to be understood (and manipulated) by experts. The methods of equitable scheme formulation are exploratory and conceptual. They are meant to stimulate critical thinking about the problem of sharing the waters in a river basin. The approach as developed here should not be considered a recipe that calculates the 'right' water allocations. It is a tool that may assist in opening up new options and perspectives when negotiations are tedious (van der Zaag et al, 2002).

Apparently, different equity guidelines result in rather different provincial apportionments. And these provincial apportionments are also very much different from the 1987 Scheme. Compared with the 1987 Scheme, certain equitable schemes can entitle some provinces much higher SW apportionments, but entitle some others much lower SW apportionments. For example, Scheme WD1E allocates much higher annual apportionments to Ningxia and Shandong than the 1987 Scheme, while Inner Mongolia, Shaanxi, Shanxi and Henan receive much lower annual apportionments than the 1987 Scheme. Scheme CA1E can double Sichuan, Qinghai, Gansu provinces' apportionments, while it can reduce Ningxia, Shanxi, Henan and Shandong's apportionments by folds, see Figure 5.5.



Inner Mongolia



Shandong

Figure 5.5 Inner Mongolia and Shandong provincial apportionments in different schemes for scenario 2030 normal

Such difference on provincial water allocation apportionments defined by different scheme guidelines can lead to rather complicated 'secondary' conflicts among provinces. Different provinces would probably prefer to different equitable schemes. For example, when plotting the SW apportionments of Inner Mongolia and

Shandong provinces, as determined by the 10 water allocation schemes, in one chart. It becomes very clearly that Inner Mongolia would be against all the PL related schemes which assign them least apportionments (see Figure 5.5). At the same time, Shandong province will look for every opportunity to provoke PL related schemes which define them highest apportionments. Probably, Inner Mongolia and Shandong would become 'opponents' concerning PL related schemes.

To obtain more insight in these preferences, a classification table will be derived to highlight every provincial attitude towards a certain equitable scheme (see Table 5-4). Denote δ as relative difference of a provincial apportionment from that of the 1987 Scheme, represented by Eq. 5.8:

$$\delta = \frac{Q_{\bar{r}}^{Eq-Scheme} - Q_{\bar{r}}^{1987scheme}}{Q_{\bar{r}}^{1987scheme}}$$

Eq. 5.8

where	δ	provincial apportionment's relative difference [%];
	$Q_{\bar{r}}^{1987scheme}$	provincial apportionment defined by 1987 Scheme [Mcm/yr];
	$Q_{\bar{r}}^{Eq-Scheme}$	provincial apportionment defined by a certain equitable scheme [Mcm/yr].

With reference to the 1987 Scheme, a province's attitude toward a certain equitable scheme has been classified as

--	great reluctance	if	$\delta \leq -25\%$
-	certain reluctance	if	$-5\% < \delta < -25\%$
±	standing by	if	$5\% \leq \delta \leq -5\%$
+	support	if	$5\% < \delta < 25\%$
++	great support	if	$\delta \geq 25\%$

By such, every province's attitude toward certain equitable scheme can be 'quantified', as shown in Table 5-4. Apparently, consensus would be rather difficult to reach by all the provinces to any equitable inter-provincial water allocation scheme.

Table 5-4 Provincial attitude toward equitable schemes with reference to the 1987 Scheme for scenario 2030 normal

Province	**Sichuan**	**Qinghai**	**Gansu**	**Ningxia**	**In.Mongo.**	**Shaanxi**	**Shanxi**	**Henan**	**Shandong**
WD 1E	-	±	+	++	-	--	-	--	++
WD 2E	--	±	+	++	--	--	-	--	++
WD 3E	--	+	++	++	--	--	-	--	++
PL 1E	--	-	++	--	--	++	+	--	++
PL 2E	--	-	++	--	--	++	+	--	++
PL 3E	--	+	++	--	--	++	+	--	++
CA 1E	++	++	++	--	±	+	-	--	--
CA 2E	++	++	++	--	-	±	-	--	-
CA 3E	++	++	++	--	--	+	-	--	-

Note: --: great reluctance -: certain reluctance ±: standing by +: support ++: great support

Table 5-4 is only a first-glance judgment when only provincial SW apportionment is concerned comparing with the 1987 Scheme. Actually, what do these different water allocation schemes exactly mean to each province or for the whole basin? Can every province really be able to divert SW as much as equitable scheme defines based on present infrastructural conditions (reservoir storage capacity)? Is environmental flow requirement really guaranteed by being reserved out of negotiation? Will higher provincial apportionment always bring higher provincial economic profits?

Above questions can be answered following a system analysis approaches (see modelling framework Figure 5.6). In next section, the RIBASIM model will be used, to realize and asses these equitable schemes together with the 1987 Scheme for comparison. Such modelling framework will serve both as a research tool for policy analysis and as a support system for water authorities in this procedure.

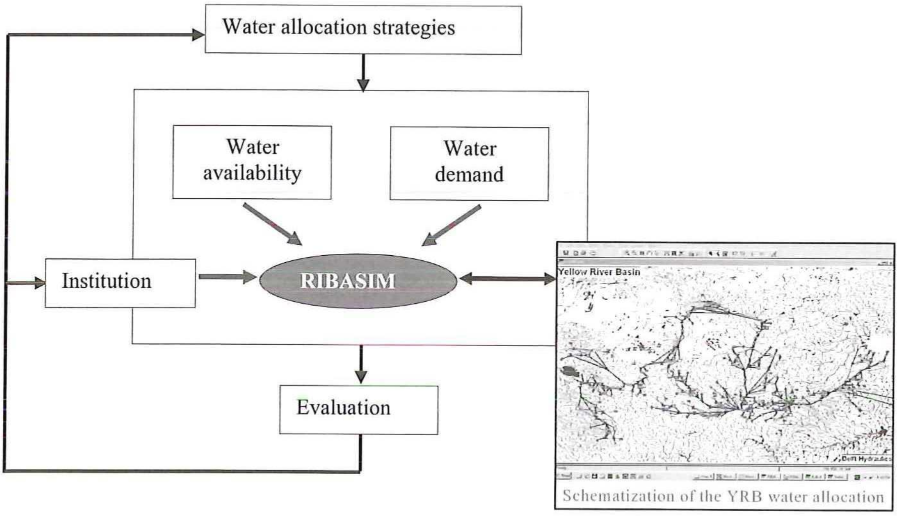


Figure 5.6 System approach for development of equitable basin water allocation in the YRB

5.2.3 RIBASIM Realization

5.2.3.1 Realization methods

Given hydrological, hydraulic and projected economical conditions for scenario 2030 normal (without impact from climate change), RIBASIM realization of the 9 equitable water allocation schemes as well as the 1987 Scheme means that:

- SW and GW supply obeys the priority shown in Table 5-3 for by a scheme.
- annual extraction of GW in each province (or provincial sub-division) is equal to the GW apportionment in the province (or provincial sub-division);
- annual extraction of SW in each province (or provincial sub-division) is equal to the SW apportionment defined by the scheme (as much as possible); and the quantity and utilisation purpose of reserved SW *Res* in each province (or provincial sub-division) should be ensured (as much as possible).

Without specification, the apportionment mentioned here *includes* reserved water.

To meet above requirements, RIBASIM simulation model needs to be further modified in the following aspects:

1. Set water supply priority according to Table 5-3 for different schemes.

2. Calculate monthly input data of SW and GW apportionments for every provincial sub-division, i.e. to each PWS node and advanced irrigation node.

> For the 1987 Scheme which only defines provincial annual SW apportionment, provincial sub-divisions' SW apportionments are assumed in proportion to their total water demand of DMI and irrigation.
>
> DMI demand and GW supply to DMI is assumed constant per month. Therefore, when both water allocation priority and water source priority is set (according to Table 5-3 and Figure 5.2), provincial monthly GW apportionment to PWS and to irrigation and provincial monthly SW apportionment to PWS are calculated and implemented by RIBASIM. Represented by Eq. 5.9, monthly SW apportionment to advanced irrigation node is assumed in proportion to monthly irrigation SW requirement (determined by module AGWAT).

$$\overline{D^{SW}_{irrigation,t}} = D_{irrigation,t} - Q^{GW}_{irrigation,t}{}'$$

$$\alpha_i = \frac{\overline{D^{SW}_{irrigation,t}}}{\sum_{t=1}^{12} \overline{D^{SW}_{irrigation,t}}}$$

$$Q^{SW,irrigation}_{r,t} = \alpha_t \times Q^{SW,irrigation}_{r} \qquad \text{Eq. 5.9}$$

where

$\overline{D^{SW}_{irrigation,t}}$	theoretical irrigation SW requirements for month *t* [m^3/s];
$D_{irrigation,t}$	average total gross irrigation demand for month *t* [m^3/s];
$Q^{GW}_{irrigation,t}{}'$	average monthly GW supply to irrigation for month *t* [m^3/s];
α_t	monthly irrigation SW requirement factor for month *t*;
$Q^{SW,irrigation}_{r}$	annual SW apportionment to irrigation [m^3/s];
$Q^{SW,irrigation}_{r,t}$	SW apportionment to irrigation for month *t* [m^3/s].

3. Constrain SW and GW extraction by each provincial sub-division according to provincial apportionments. Two steps are followed to reach this target:

> 1) Setting 'maximum diversion flow' in the diversion node connected to each advanced irrigation node *equal* to the monthly SW apportionment to irrigation $Q^{SW,irrigation}_{r,t}$. By such, SW extraction to irrigation does not *exceed* its irrigation SW apportionment $Q^{SW,irrigation}_{r,t}$.
>
> 2) An extra low flow node is inserted in front of every advanced irrigation nodes whose monthly low input is equal to $Q^{SW,irrigation}_{r,t}$. By such, SW extraction to irrigation is *no less than* $Q^{SW,irrigation}_{r,t}$. The water allocation priority of such low flow node should be equal to its connected irrigation node.

Combine the effects of above two steps, SW apportionment to irrigation is obeyed (as much as possible) in each advanced irrigation node.

5.2.3.2 Realization analysis

The above three steps from section 5.2.3.1 are followed for RIBASIM realization of the 10 schemes for scenario year 2030 normal. The examination of the implementation of these simulated schemes is carried out by the following 3 steps.

- First step is to examine whether GW and SW extraction in each province can indeed be in accordance with the scheme defined GW and SW apportionment.
- Second step is to examine whether scheme defined reserve water Res for environmental low flow and/or basic human needs are guaranteed.
- As reserved water from difference schemes does not always include demand for human survival by domestic and municipal usage, examination of water supply to human survival water demand is necessary.

Step 1: examination of implementation of GW and SW apportionments

The simulation results conform that GW and SW apportionments to PWS are strictly implemented and the maximum difference from all schemes is within 1.0%. Since the absolute difference between implemented GW extraction by irrigation and GW apportionment to irrigation was found less than 6.0%, no further efforts would be made to improve the accuracy of the implementation of GW apportionment to irrigation.

But SW apportionment to irrigation is not always ideally realized by RIBASIM. For example, for Scheme WD3E, its relative difference between $Q_{irrigation,i}^{SW}\,'$ (RIBASIM simulated SW allocation to irrigation) and $Q_{r,i}^{SW,irrigation}$ (Scheme WD3E defined SW apportionment to irrigation) varies from 0.02% to 26.46%. And the basin simulated $Q_{irrigation}^{SW}\,'$ is 11.07% less than the scheme defined $Q_{r}^{SW,irrigation}$.

Discussion: causes of poor realization of SW apportionment to irrigation

As pointed out previously, the weakness of the SW allocation algorithms is that the time variability of water availability and water demand within a year and for wet and dry year is not sufficiently taken into account. For instance, realization of irrigation SW apportionment can be constrained by irrigation water availability at certain time steps (monthly). Take Shaanxi_5:Fen from Scheme WD3E as example. The average SW availability to Shaanxi_5:Fen is 67.6m^3/s, larger than its irrigation SW apportionment of 46.7 m^3/s. However, when simulated SW allocation to Shaanxi_5:Fen is plotted together with its SW availability and SW apportionment in one chart (Figure 5.7), it becomes very clear that realized SW apportionment is constrained by irrigation SW availability at some time steps. This mostly happens during March to June or July when irrigation SW availability is less than SW apportionment.

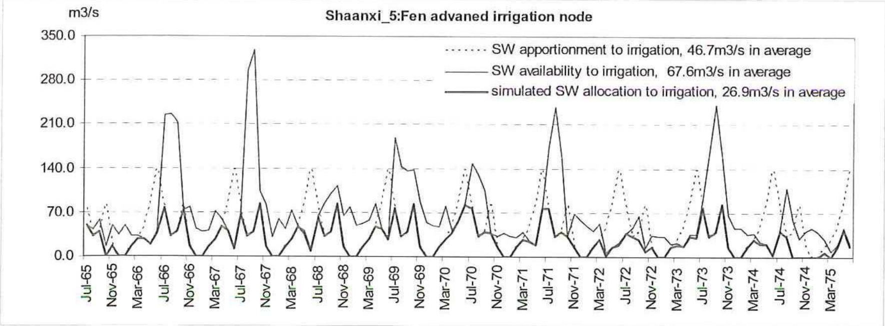


Figure 5.7 Realization of irrigation SW apportionment in Shaanxi_5:Fen of Scheme WD3E for scenario 2030 normal

Besides irrigation SW availability, irrigation water demand can also constrain realization of irrigation SW apportionment. Figure 5.8 is an example of Shaanxi_5:Luo for Scheme CA1E where an extra data series of irrigation water demand is also plotted. From Oct-1968 to Jan-1969, the simulated SW allocation to irrigation is constrained by irrigation water demand which is lower than either SW availability to irrigation or SW apportionment. From Apri-1968 to July-1968, the simulated SW allocation to irrigation is constrained by SW irrigation water availability.

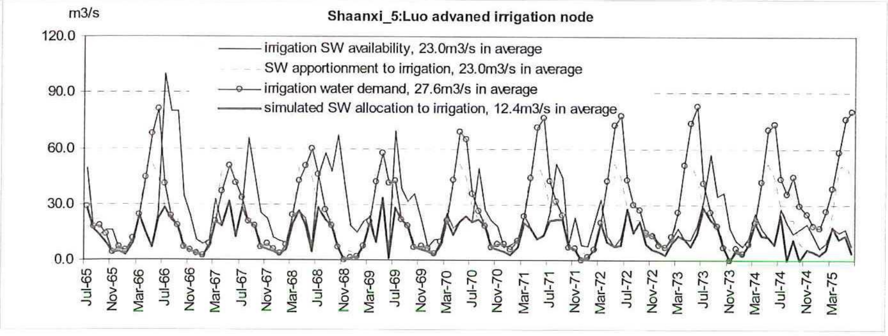


Figure 5.8 Realization of irrigation SW apportionment Shaanxi_5:Luo of Scheme CA1E for scenario 2030 normal

Most probably, realization of SW apportionment to irrigation can be improved by several methods. First of all, the allocation algorithms themselves should take into account monthly variability of water availability and water utilization in average, dry and wet years. Besides, regulation of SW availability can be improved by increasing the channel storage capacity (e.g. build more reservoirs or weirs); crop patterns can be changed to optimize irrigation demand. In future research, the effect of these methods can be studied. In this thesis, current river engineering and crop patterns will remain the same for scenario analysis.

The realization degree of SW apportionment is defined as the ratio of RIBASIM simulated SW allocation to the scheme defined SW apportionment. The associated computation methods of realization degree in provincial sub-division (denoted as $\varpi_{h_{ik}}$), in province (denoted as ϖ_i) and in the whole basin (denoted as ϖ), are presented by Eq. 5.10. The calculated realization degrees of SW apportionment for the 10 schemes are included in Table 5-5.

$$\varpi_{h_{ik}} = (Q^{SW}_{PWS,h_{ik}}{}' + Q^{SW}_{irrigation,h_{ik}}{}') / Q^{SW}_{\bar{r},h_{ik}} \qquad \text{(a)[1]}$$

$$\varpi_i = (\sum_{k=1}^{m_i} Q^{SW}_{PWS,h_{ik}}{}' + \sum_{k=1}^{s_i} Q^{SW}_{irrigation,h_{ik}}{}') / Q_{\bar{r},i}{}^{SW} \qquad \text{(b)}$$

$$\varpi = \sum_{i=1}^{n} Q_i^{SW'} / Q_{\bar{r}}{}^{SW} \qquad \text{(c)}$$

Eq. 5.10

where

h_{ik}	prefix for provincial sub-division k in province i;
$\varpi_{h_{ik}}$	realization degree for provincial subdivision h_{ik} [%];
ϖ_i	realization degree of a certain scheme for province i [%];
ϖ	realization degree of a certain scheme for the whole basin i [%];
$Q^{SW}_{PWS,h_{ik}}{}'$	realized SW allocation to PWS for provincial subdivision h_{ik} [Mcm/yr];
$Q^{SW}_{irrigation,h_{ik}}{}'$	realized SW allocation to irrigation for provincial subdivision h_{ik} [Mcm/yr], k=1,2,…, s_i;
s_i	total number of advanced irrigation nodes in province i;
$Q_i^{SW}{}'$	realized SW allocation to province i, including reserved water for human usage [Mcm/yr];
$Q^{SW}_{\bar{r},h_{ik}}$	SW appointment defined by certain scheme for provincial subdivision h_{ik}, including reserved water for human usage [Mcm/yr];
$Q^{SW}_{\bar{r},i}$	SW appointment defined by certain scheme for province i, including reserved water for human usage [Mcm/yr];
$Q^{SW}_{\bar{r}}$	SW appointment defined by certain scheme for the whole basin, including reserved water for human usage [Mcm/yr].

Table 5-5 Realization degree of SW apportionment for scenario 2030 normal (%)

Province	WD1E	WD2E	WD3E	PL1E	PL2E	PL3E	CA1E	CA2E	CA3E	1987 Scheme
Sichuan	52.2	100.4	100.0	24.8	65.6	76.7	1.0	2.3	3.2	17.0
Qinghai	94.5	96.3	97.1	92.7	97.1	99.3	11.6	16.0	28.0	94.5
Gansu	99.0	99.2	98.0	75.7	76.0	83.2	72.7	74.4	75.8	99.1
Ningxia	97.5	98.1	98.3	83.0	85.9	94.6	96.1	95.2	98.1	99.7
In.Mongo.	99.0	99.4	99.6	100.3	100.3	100.3	97.5	98.5	99.9	100.0
Shaanxi	91.2	92.1	89.8	66.8	67.2	66.5	38.5	41.8	62.2	82.7
Shanxi	83.2	82.7	80.1	66.8	66.4	67.3	46.7	54.7	59.5	74.9
Henan	92.3	95.8	90.4	69.9	73.3	64.6	87.8	87.4	92.0	80.0
Shandong	83.0	83.9	85.4	80.9	81.9	87.4	94.9	96.6	97.4	88.8
Basin	91.5	92.2	91.6	76.0	77.1	80.0	61.4	66.9	74.2	89.2

---

[1] RIBASIM schematization for the YRB is set such that there is only one pair of PWS node and advanced irrigation node in each provincial subdivision.

Step 2: Examination of the compliance of reserve water Res

In general, all the 10 schemes can ensure the environmental low flow requirement in average (see Figure 5.9) and the maximum difference is less than 5.0%. RIBASIM simulated output also indicates that *Res* for basic human needs can be guaranteed by all the schemes and the maximum shortage is less than 3%.

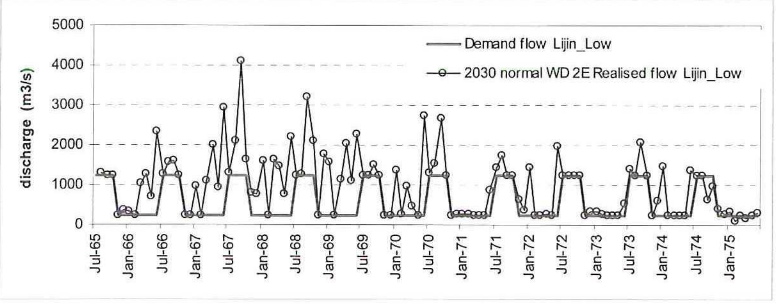


Figure 5.9 Realized flow at Lijin station from implementation of Scheme WD2E for scenario 2030 normal

When the above two aspects are considered together, the 10 schemes can indeed guarantee their reserve water Res for environmental low flow and for basic human needs for scenario 2030 normal.

Step 3: Guarantee of water supply for human survival

A scheme is not considered fair if water supply for human survival (domestic and municipal water) is not guaranteed. According to RIBASIM output, only Scheme CA1E has 25% of domestic and municipal water usage shortage in Shandong. The equity guideline of CA1E can thus not always guarantee water supply for human survival (as such demand is not reserved out of negotiation and its water allocation priority is next to environmental flow). Scheme CA1E is therefore excluded for strategy development for scenario 2030 normal.

Summary

It has been illustrated that all schemes except Scheme CA1E can meet all the premises of equal water allocation: provincial SW apportionments are reasonably obeyed by all the provinces (as much as possible), reserved water Res is ensured and water supply for human survival is guaranteed. When those premises are met, provinces may be willing to negotiate and cooperate to implement these schemes (see Table 5-6). The final 9 schemes selected are shown in Table 5-7.

Table 5-6 Pre-selected 9 guidelines for water allocation in the YRB for scenario 2030 normal

Reserve water Criterion	Res: 1E	Res: 2E	Res: 3E
WD	WD1E	WD2E	WD3E
PL	PL1E	PL2E	PL3E
CA		CA2E	CA3E
	1987 Scheme		

Table 5-7 Realized water allocation schemes for year 2030 normal (Mcm/yr)

Province	WD1E	WD2E	WD3E	PL1E	PL2E	PL3E	CA2E	CA3E	1987 Scheme
Sichuan	3.9	8.1	8.5	5.9	14.9	14.9	14.9	14.9	6.8
Qinghai	1380.3	1404.8	1484.7	1222.5	1295.2	1503.2	967.8	1369.1	1332.4
Gansu	3273.7	3348.5	3948.9	3557.9	3597.8	4714.3	4505.3	5021.3	3013.6
Ningxia	7189.4	6877.1	6335.2	995.4	1000.8	1608.1	1645.8	2062.7	3989.3
In. Mongo.	4458.5	4282.2	3998.5	1110.8	1123.7	1445.6	5075.8	4313.3	5862.2
Shaanxi	1965.3	2142.9	2489.2	3896.8	3731.8	3676.1	1558.7	2654.7	3143.3
Shanxi	2698.1	2754.0	2790.5	3373.8	3328.5	3180.6	1797.1	2151.5	3226.3
Henan	3247.2	3323.1	3193.9	2058.2	2156.1	2074.1	2458.6	2748.0	4432.6
Shandong	8002.3	8326.2	8016.7	10538.4	10910.3	9961.5	5528.2	5786.6	6216.1
Basin	32218.7	32466.9	32266.3	26759.4	27159.0	28178.5	23552.1	26122.1	31222.6

5.3 Compare different allocation schemes for scenario 2030 normal

Essentially, water allocation can be considered as a way to balance water use benefits categorized into social, economic and environmental objectives. These benefits are associated with water allocation in terms of equity, efficiency and sustainability. As explained before, equity in allocation means that all users should have a fair access to the water for their needs in a reasonable manner. Here, efficiency refers to maximizing the overall benefit to society in the distribution of water. And sustainability can be understood to be the capacity of a system to endure or to ensure the continuing health of water resources and the environment. When each of these social objectives is represented by indicators, the balances between these three categories of indicators can be interpreted as a way to balance the social, economic and environmental outcome.

5.3.1 Identification of indicators

Equity involves the degree of fairness and inclusiveness with which resources are distributed, opportunities afforded and decisions made. Judgment of equity is a logic concept. In this study, employment of equity principles itself already ensures a scheme is equal, i.e. the pre-selected schemes are designed based on operationalized equity criterion of water demand (WD), population (PL) and catchment area (CA).

Equity objectives may or may not be consistent with **efficiency** objectives. With increased competition over scarce water resources, it is of increasing importance that water resources be allocated more efficiently. Efficiency requires that water should be allocated to uses that produce higher rather than lower value. Actually, economic gain of water allocation across sectors is considered as one of the main driving forces of water withdrawal and, also regarded as the financial capacity to promote effective water use. In this aspect, irrigation output (Yuan), industry economic output (Yuan), crop yield (ton/yr) and GDP (Yuan) are used as indicators.

Sustainability can be understood as the capacity of a system to endure. The higher the sustainability of a system is, the less the vulnerability the system is. Over-allocating SW can affect stream life, placing community water supplies at risk and threaten recreational and cultural values. For the YRB, water shortage degree of environmental low flow (%) and duration of zero flow (% of time) at Lijin station have already been accepted widely as important indicators to present the sustainability of the YR system.

The selection of indicators is essential as they are used to simplify, quantity, communicate and create order within complex data. Indicators chosen structure and provide information required for assessing the state of water resources and should be able to give a clear picture of the issue being assessed. For this reason, only above mentioned indicators, combined with logic judgement, are identified in this thesis in terms of equity, efficiency and sustainability with consideration of unique situations in the YRB, although much more indicators have been discussed in literature (e.g. water stress index by Falkenmark 1990, virtual water and water stress by Allan 1992, rural sustainability indicators by Winograd et al 1999, environmental performance indicators by World Bank 1999, water use indicators by Moldan and Billharz 1997, water poverty index by Sullivan and Meigh 2003, water conflict indicators by Tamas 2003.) The indicators chosen are listed in Table 5-8 with regard to equity, efficiency and sustainability for evaluation of inter-provincial allocation schemes in the YRB.

Table 5-8 Indicators for evaluation of water allocation schemes in the YRB

Target	Manner	Indicator	Unit	Calculation method
Social	Equity	Logic judgment 1) employment of equity scheme design guideline 2) apportionment realization	--	--
Economic	Efficiency	Irrigation product	Yuan	RIBASIM simulated irrigation allocation (SW and GW) multiply projected irrigation productivity
		Industry output	Yuan	RIBASIM simulated industry water allocation[1] multiply projected industry productivity
		Crop yield	ton/yr	Crop yield obtained from advanced irrigation nodes
		GDP	Yuan	RIBASIM simulated (SW and GW) allocation to (irrigation and PWS nodes) multiply projected GDP (Yuan/m^3)
Environment	Sustainability[2]	Water shortage degree of environment low flow	%	RIBASIM simulated average shortage degree at environment low flow nodes
		Duration of zero flow	%	RIBASIM simulated time steps (month) of zero flow (discharge < 0.001m^3/s) divided by total time steps at Lijin station (for 10 year period)

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[1] Industry water allocation equals to PWS minus domestic and municipal water allocation assuming domestic and municipal water is always fully supplied as guaranteed by *Res* or highest water allocation priority.

[2] Sustainability related indicators are only calculated for the whole basin.

5.3.2 Calculation of indicators

Calculated indicator values are included in Table 5-9 where BAU stands for Business-As-Usual.

Table 5-9 Calculated indicator values for the 9 schemes for scenario 2030 normal

(1) Equity: logic judgment

	WD1E	WD2E	WD3E	PL1E	PL2E	PL3E	CA2E	CA3E	1987 Scheme	BAU
Basin	YES	YES	YES	YES	YES	YES	YES	YES	No	No

(2) Efficiency: irrigation output (10^9Yuan)

Province	WD1E	WD2E	WD3E	PL1E	PL2E	PL3E	CA2E	CA3E	1987 Scheme	BAU
Sichuan	0.01	0.03	0.03	0.02	0.06	0.06	0.04	0.04	0.02	0.06
Qinghai	10.2	11.6	13.6	10.4	13.3	17.6	4.1	9.0	9.5	27.2
Gansu	8.2	10.0	16.4	22.1	22.4	28.3	27.9	29.7	8.2	30.3
Ningxia	7.0	6.8	6.2	1.8	1.8	2.4	2.4	2.8	3.9	11.6
In. Mongo.	24.0	23.0	21.5	6.1	6.2	7.8	27.8	23.6	31.5	41.3
Shaanxi	22.8	25.8	32.2	55.2	54.2	53.6	17.4	34.8	43.4	57.4
Shanxi	24.5	26.4	30.0	43.1	42.7	41.0	24.5	29.8	27.7	54.9
Henan	19.8	21.4	23.8	17.8	19.2	19.9	15.7	18.6	33.5	45.4
Shandong	73.9	78.5	74.1	110.3	115.6	101.9	39.3	41.7	48.6	171.4
Basin	190.5	203.6	217.8	266.8	275.4	272.5	159.3	190.1	206.1	439.5

(3) Efficiency: industry output (10^9Yuan)

Province	WD1E	WD2E	WD3E	PL1E	PL2E	PL3E	CA2E	CA3E	1987 Scheme	BAU
Sichuan	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Qinghai	24.4	24.4	24.4	24.4	24.4	24.4	17.3	24.4	24.4	24.3
Gansu	145.0	145.9	145.9	145.9	145.9	145.9	145.9	145.9	145.4	145.7
Ningxia	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	43.7	42.8
In. Mongo.	132.3	132.3	132.3	132.3	132.3	132.3	132.3	132.3	132.3	132.2
Shaanxi	343.4	344.5	344.5	344.5	344.5	344.5	331.1	344.5	344.3	344.5
Shanxi	349.2	352.8	352.8	352.8	352.8	352.8	352.8	352.8	351.5	352.8
Henan	303.3	310.1	310.0	302.8	310.0	310.0	229.0	310.1	301.7	309.5
Shandong	487.2	487.2	487.2	487.2	487.2	487.2	452.0	487.2	487.2	461.2
Basin	1829.6	1841.4	1841.3	1835.1	1841.3	1841.3	1717.2	1841.4	1831.9	1824.8

(4) Efficiency: crop yield (10^3 ton/yr)

Province	WD1E	WD2E	WD3E	PL1E	PL2E	PL3E	CA2E	CA3E	1987 Scheme	BAU
Sichuan	2	5	6	3	11	11	5	6	4	11
Qinghai	517	550	647	493	563	773	550	647	481	1284
Gansu	1311	1581	2512	3424	3459	4326	1581	2512	1303	4644
Ningxia	1372	1332	1216	376	376	490	1332	1216	758	2252
In. Mongo.	1919	1843	1722	507	511	640	1843	1722	2515	3310
Shaanxi	3373	3891	5098	8977	8866	8811	3891	5098	7182	9157
Shanxi	2481	2594	2756	3851	3775	3574	2594	2756	2941	5089
Henan	2716	2900	3051	2186	2364	2328	2900	3051	4103	6017
Shandong	10072	10732	9978	16162	16887	14482	10732	9978	6523	23778
Basin	23763	25427	26986	35980	36812	35435	25427	26986	25812	55542

(5) Efficiency: GDP (10^9Yuan)

Province	**WD1E**	**WD2E**	**WD3E**	**PL1E**	**PL2E**	**PL3E**	**CA2E**	**CA3E**	1987 Scheme	**BAU**
Sichuan	0.3	0.4	0.4	0.3	0.6	0.6	0.6	0.6	0.3	0.6
Qinghai	32.1	32.9	35.6	32.0	33.7	39.4	17.5	28.1	31.2	52.6
Gansu	77.0	79.0	91.1	87.8	88.6	108.0	105.8	113.0	73.5	119.5
Ningxia	23.1	22.3	20.7	6.0	6.0	7.7	7.8	9.0	13.9	35.0
In. Mongo.	86.0	83.3	79.0	35.5	35.7	40.4	96.4	84.7	107.2	134.6
Shaanxi	199.4	207.8	227.8	287.9	285.9	285.1	168.6	224.6	262.6	291.3
Shanxi	203.0	207.8	217.1	244.5	244.6	242.5	195.9	212.7	217.5	278.1
Henan	139.9	146.2	153.6	136.5	143.1	146.0	107.5	140.4	162.3	202.9
Shandong	381.2	395.8	380.5	505.6	522.0	474.0	245.9	260.3	301.9	683.9
Basin	1141.8	1175.3	1205.7	1336.0	1359.9	1343.7	945.9	1073.3	1170.5	1798.3

(6) Sustainability: water shortage degree of environmental low flow (%)

	WD1E	**WD2E**	**WD3E**	**PL1E**	**PL2E**	**PL3E**	**CA2E**	**CA3E**	1987 Scheme	**BAU**
Basin	0.9	1.8	1.8	0.0	0.0	0.0	0.0	0.0	0.2	**30.6**

(7) Sustainability: duration of time steps of zero flow in 10 years at Lijin station (%)

	WD1E	**WD2E**	**WD3E**	**PL1E**	**PL2E**	**PL3E**	**CA2E**	**CA3E**	1987 Scheme	**BAU**
Basin	0	0	0	0	0	0	0	0	0	**2**

5.3.3 Comparison focuses

In brief, the main difference between BAU and the 1987 Scheme is on efficiency and sustainability, between the 1987 Scheme and the 8 equity schemes is on equity and efficiency. Among the 8 equity schemes themselves, the main different is on efficiency, see Table 5-10.

Table 5-10 Major comparison aspects of different schemes for YR water allocation

Scheme	**BAU**	**1987 Scheme**	**Equitable schemes**
Allocation mechanism	Demand driven and water availability constrained		Equity principle by criterion of WD, PL, CA
Major difference	Sustainability and efficiency		
		Equity and efficiency	
			efficiency

In next section, the comparison between BAU and the 1987 Scheme and the comparison among equitable schemes with reference to the 1987 Scheme will be addressed.

5.4 Gain and loss of the 1987 Scheme

BAU is no longer a choice in YR water allocation as the 1987 Scheme has already been implemented by YRCC. However, comparison of the two schemes can tell the gain and loss of implementation of the 1987 Scheme instead of BAU.

Basin sustainability: gain from implementation of the 1987 Scheme

For scenario 2030 normal, BAU would neither guarantee environmental low flow nor prevent zero flow at Lijin station. In average, the total shortage of environmental low flow would be 6128.0 Mcm/yr, 30.6% of environmental low flow demand. The zero flow at Lijin station would last for 2 months during 10 year (see Table 5-9 (6) and (7)). The duration of the low flow would be much longer than 2 months, see Figure 5.10. While the 1987 Scheme would successfully ensure the environmental low flow and avoid zero flow occurrences at Lijin station. This basin sustainability is what can be *gained* over BAU using the 1987 Scheme.

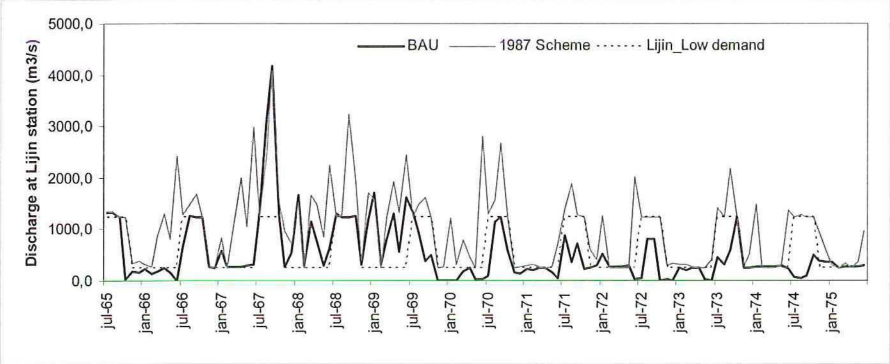


Figure 5.10 Discharge at Lijin station (BAU vs. the 1987 Scheme for scenario 2030 normal)

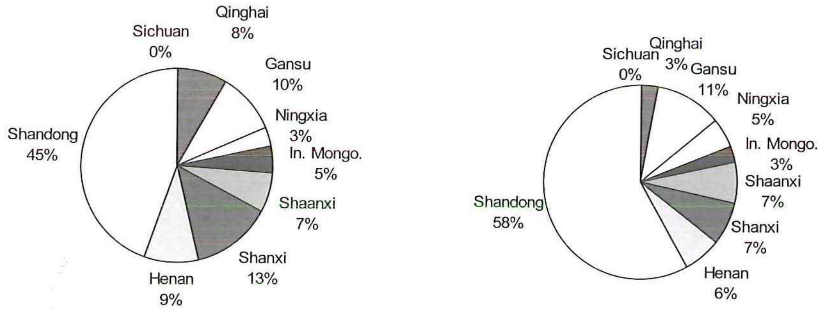
Economic loss: cost of implementation of the 1987 Scheme

Compared to BAU, the cost of guarantee environmental low flow by the implementation of the 1987 Scheme is considerable amount of economic loss. From Table 5-9 (2)-(5), the economic loss for scenario 2030 normal from basin point of view would be a reduction of irrigation output of 233.5 billion Yuan, a drop of industrial output by 17.5 billion Yuan, a decrease of crop yield by 29730 ton/yr and a decline of GDP by 627.9 billion Yuan.

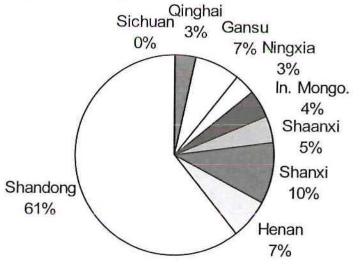
From province point of view, their economic burden (economic benefit reduction compared with BAU) differs from province to province. Uneven provincial burdens of total basin economic loss (%) are shown in Table 5-11 and Figure 5.11 for scenario 2030 normal. It becomes clear that most down stream province Shandong will burden most economic loss. Since the 1987 Scheme already replaced the BAU scheme, social economic growth at the cost of serious environmental deterioration is no longer an option for YR.

Table 5-11 Economic loss as a result of guarantee of environmental low flow (the 1987 Scheme vs. BAU for scenario 2030 normal)

Province	Industry and irrigation output		Crop yield		GDP	
	Loss (10^9 Yuan/yr)	Provincial burden (%)	Loss (10^3 ton/yr)	Provincial burden (%)	Loss (10^9Yuan/yr)	Provincial burden (%)
Sichuan	-0.04	0.0	-7.0	0.0	-0.23	0.0
Qinghai	-17.7	8.2	-803.0	2.7	-21.4	3.4
Gansu	-22.4	10.4	-3341.0	11.2	-46.0	7.3
Ningxia	-6.7	3.1	-1494.0	5.0	-21.1	3.4
In. Mongo.	-9.8	4.5	-795.0	2.7	-27.4	4.4
Shaanxi	-14.2	6.6	-1975.0	6.6	-28.7	4.6
Shanxi	-28.5	13.2	-2148.0	7.2	-60.6	9.6
Henan	-19.8	9.2	-1914.0	6.4	-40.6	6.5
Shandong	-96.8	44.8	-17255.0	58.0	-381.9	60.8
Basin	-215.9	100.0	-29730.0	100.0	-627.9	100.0



a. Industry and irrigation output **b. Crop yield**



c. GDP

Figure 5.11 Provincial burden of basin economic loss from implementation of the 1987 Scheme instead of BAU for scenario 2030 normal

5.5 Basin cooperation for equitable schemes

The next question is to find out which equitable scheme is a good substitute for the 1987 Scheme. A good substitute is a scheme that can

- attain the primary objectives of the 1987 Scheme (i.e. guarantee environmental low flow, avoid zero flow at Lijin and ensure human survival water supply),
- gain higher basin economic benefit than 1987 Scheme, and
- be more smoothly implemented (gain better provincial cooperation)?

As argued in section 5.2.3.2, the selected 8 equitable schemes can already achieve the primary objectives of the 1987 Scheme, i.e. guarantee environmental low flow, prevention of zero flow at Lijin and ensure human survival water supply. Further, the 8 schemes are based on equity principle while the 1987 Scheme is not. Thus the 8 schemes already have the potential that they would gain more cooperation among provinces for its implementation at very beginning. Once provinces understand the scheme, they will most probably be more prepared to accept the consequent burden of economic loss. Therefore, the comparison of these 8 equitable schemes then mainly focuses on economic aspects, identifying which ones can achieve higher economic benefit than the 1987 Scheme.

5.5.1 Scorecard of equitable schemes

To compare basin economic benefit from the 8 equity schemes with the 1987 Scheme, Table 5-9 (2)-(5) are referred. To further simplify the comparison, three sensitive indicators are used from the basin point of view (versus the individual provincial point of view): industry and irrigation output, crop yield and regional GDP. The results of their relative basin economic benefit are shown in Table 5-12 .

Table 5-12 Relative basin economic benefit of equitable schemes with reference to the 1987 Scheme for scenario 2030 normal

Indicator	WD1E	WD2E	WD3E	PL1E	PL2E	PL3E	CA2E	CA3E
Basin industry and irrigation output (10^9Yuan/yr)	-17.9	7.0	21.1	63.9	78.7	75.8	-161.6	-6.5
Basin crop yield (10^6 ton/yr)	-2.0	-0.4	1.2	10.2	11.0	9.6	-0.4	1.2
Basin GDP (10^9 Yuan/yr)	-28.6	4.9	35.2	165.6	189.5	173.3	-224.5	-97.1

From Table 5-12, a comprehensive basin scorecard of different equitable schemes for scenario 2030 normal is prepared, as shown in Table 5-13. The scores of each indicator are obtained by dividing each value by the largest absolute one. Assuming each economic indicator is of similar importance, the favourability of a scheme from the basin point of view, can be expressed by the sum of the three scores, named *basin favourability score*. A positive basin favourability score means that a scheme is, from the basin's point of view (YRCC), more favoured than the 1987 Scheme. A negative basin favourability score means that a scheme is less favoured than the 1987 Scheme.

Table 5-13 clearly shows that there are 4 schemes which would, from the basin's point of view (YRCC), be more favoured then the 1987 Scheme under scenario 2030 normal conditions: Scheme PL2E, Scheme PL3E, Scheme PL1E and Scheme

WD3E. Among them, Scheme PL2E would be the first choice for the basin. Basin favourability score of Scheme WD2E is close to zero, therefore it could be hardly any better than the 1987 Scheme. The other three schemes are less favoured: Scheme CA3D, Scheme WD1E and Scheme CA2E. Among them Scheme CA2E would be the last choice for the basin. The order of basin favourability score is included in the last row of Table 5-13.

Table 5-13 Basin favourability scorecard of different equitable schemes for scenario 2030 normal

Indicator	**WD1E**	**WD2E**	**WD3E**	**PL1E**	**PL2E**	**PL3E**	**CA2E**	**CA3E**
Basin industry and irrigation output	-0.11	0.04	0.13	0.40	0.49	0.47	-1.00	-0.04
Basin crop yield	-0.19	-0.04	0.11	0.92	1.00	0.88	-0.04	0.11
Basin GDP	-0.13	0.02	0.16	0.74	0.84	0.77	-1.00	-0.43
Basin favourability score	**-0.43**	**0.03**	**0.39**	**2.06**	**2.33**	**2.12**	**-2.04**	**-0.37**
Order	**Nr. 7**	**Nr. 5**	**Nr. 4**	**Nr. 3**	**Nr. 1**	**Nr. 2**	**Nr. 8**	**Nr. 6**

5.5.2 Analysis of basin cooperation

5.5.2.1 Provincial relative economic loss

Following the order of basin favourability score in Table 5-13, provincial relative economic benefit from each equitable scheme is shown in Table 5-14 for scenario 2030 normal with reference to Table 5-9 (2)-(5).

Clearly, from province point of view, the order of basin favourability is not necessarily the order of province favourability toward a scheme. For instance, for the basin most preferred scheme of PL2E (nr.1) or PL3E (nr.2), Ningxia, Inner Mongolia, and Henan could get lest economic benefit from them. While for the basin lest preferred scheme of WD1E (nr.7) or CA2E (nr.8), Ningxia, Gansu and Inner Mongolia would get most economic benefit from them.

For individual provinces, if they can have their own choice independent from basin's point of view, they would be probably in favour of those schemes which can bring them the highest economic benefit. For instance, in Ningxia's opinion, Scheme WD1E (nr.7 from YRCC) is her favorite choice. In Inner Mongolia's opinion, Scheme CA2E (nr.8 from YRCC) is her most favoured. For Henan, Scheme WD3E (nr.4 from YRCC) is the most beneficial one.

Table 5-14 Provincial relative economic benefit for scenario 2030 normal

Province	Indicator	PL2E	PL3E	PL1E	WD3E	WD2E	CA3E	WD1E	CA2E
Sichuan	Irrig. & ind. output (10^9Yuan/yr)	0.04	0.04	0.00	0.01	0.01	0.02	-0.01	0.02
	Crop yield (10^3 ton/yr)	7	7	-1	2	1	2	-2	1
	GDP (10^9Yuan/yr)	0.3	0.3	0.0	0.1	0.1	0.3	0.0	0.3
Qinghai	Irrig. & ind. output (10^9Yuan/yr)	3.8	8.1	0.9	4.1	2.1	-0.5	0.7	-12.5
	Crop yield (10^3 ton/yr)	82	292	12	166	69	166	36	69
	GDP (10^9Yuan/yr)	2.5	8.2	0.8	4.4	1.7	-3.1	0.9	-13.7
Gansu	Irrig. & ind. output (10^9Yuan/yr)	14.7	20.6	14.4	8.7	2.3	22.0	-0.4	20.2
	Crop yield (10^3 ton/yr)	2156	3023	2121	1209	278	1209	8	278
	GDP (10^9Yuan/yr)	15.1	34.5	14.3	17.6	5.5	39.5	3.5	32.3
Ningxia	Irrig. & ind. output (10^9Yuan/yr)	-2.1	-1.5	-2.1	2.3	2.9	-1.1	3.1	-1.5
	Crop yield (10^3 ton/yr)	-382	-268	-382	458	574	458	614	574
	GDP (10^9Yuan/yr)	-7.9	-6.2	-7.9	6.8	8.4	-4.9	9.2	-6.1
In. Mongo.	Irrig. & ind. output (10^9Yuan/yr)	-25.3	-23.7	-25.4	-10.0	-8.5	-7.9	-7.5	-3.7
	Crop yield (10^3 ton/yr)	-2004	-1875	-2008	-793	-672	-793	-596	-672
	GDP (10^9Yuan/yr)	-71.5	-66.8	-71.7	-28.2	-23.9	-22.5	-21.2	-10.8
Shaanxi	Irrig. & ind. output (10^9Yuan/yr)	11.0	10.4	12.0	-11.0	-17.4	-8.4	-21.5	-39.2
	Crop yield (10^3 ton/yr)	1684	1629	1795	-2084	-3291	-2084	-3809	-3291
	GDP (10^9Yuan/yr)	23.3	22.5	25.3	-34.8	-54.8	-38.0	-63.2	-94.0
Shanxi	Irrig. & ind. output (10^9Yuan/yr)	16.3	14.6	16.7	3.6	0.0	3.4	-5.5	-1.9
	Crop yield (10^3 ton/yr)	834	633	910	-185	-347	-185	-460	-347
	GDP (10^9Yuan/yr)	27.1	25.0	27.0	-0.4	-9.7	-4.8	-14.5	-21.6
Henan	Irrig. & ind. output (10^9Yuan/yr)	-6.0	-5.3	-14.6	-1.4	-3.7	-6.5	-12.1	-90.5
	Crop yield (10^3 ton/yr)	-1739	-1775	-1917	-1052	-1203	-1052	-1387	-1203
	GDP (10^9Yuan/yr)	-19.2	-16.3	-25.8	-8.7	-16.1	-21.9	-22.4	-54.8
Shandong	Irrig. & ind. output (10^9Yuan/yr)	67.0	53.3	61.7	25.5	29.9	-6.9	25.3	-44.5
	Crop yield (10^3 ton/yr)	10364	7959	9639	3455	4209	3455	3549	4209
	GDP (10^9Yuan/yr)	220.1	172.1	203.7	78.6	93.9	-41.6	79.3	-56.0

5.5.2.2 Provincial scorecard and attitude

With reference to Table 5-14, provincial favourability scorecard can be calculated in the same method as described in section 5.5.1. Depending on provincial favourability scores, their attitudes toward different schemes can be categorized into five groups: named as supportive, standing by, slightly against, against and strongly against as shown in Table 5-15. In general, a province would support those schemes which bring them highest economic benefits. A 'Standing-by' attitude will be held if a province can reach similar economic benefit from the reference scheme, i.e. the 1987 Scheme. A province would object those schemes whose economic benefit is the worst among all the alternatives. Depending on how worse their economic benefit would be, a province would be slightly against, against or strongly against a scheme. Correspondingly, the effort to persuade them to cooperate will be more and more tedious.

Table 5-15 Individual provincial attitude toward different water allocation schemes for scenario 2030 normal

Province	Provincial favourability	Supportive	Standing-by	Against		
				Slightly against	Against	Strongly against
Sichuan	Score scale	1.64 – 3.0	0.57 – 0.75	-0.27	-0.88	
	Scheme	**PL2E, PL3E, CA3E, CA2E**	**WD3E, WD2E**	**PL1E,** 1987 Scheme	**WD1E**	
Qinghai	Score scale	0.78 – 2.26	0.18 – 0.54	0 – 0.31		-1.76
	Scheme	**PL3E, WD3E, PL2E**	**WD2E, WD1E, PL1E**	**CA3E,** 1987 Scheme		**CA2E**
Gansu	Score scale	1.24 – 2.81	0.08 – 0.34	0		
	Scheme	**PL3E, CA3E, CA2E, PL2E, PL1E, WD3E**	**WD2E, WD1E**	1987 Scheme		
Ningxia	Score scale	2.23 – 3.0	0	-0.18 – -0.14	-1.57	-2.14
	Scheme	**WD1E, WD2E, WD3E**	1987 Scheme	**CA2E, CA3E**	**PL3E**	**PL1E, PL2E**
Inner Mongolia	Score scale	0		-0.89 – -0.63	-1.18 – -1.0	-3.0 – -2.8
	Scheme	1987 Scheme		**CA2E, WD1E**	**WD2E, CA3E, WD3E**	**PL3E, PL1E, PL2E**
Shaanxi	Score scale	0.93 – 1.04	0		-1.20– -1.17	-2.86– -1.89
	Scheme	**PL1E, PL2E, PL3E**	1987 Scheme		**CA3E, WD3E**	**WD2E, WD1E, CA2E**
Shanxi	Score scale	2.49 – 3.0	-0.74 – 0		-1.37– -1.29	
	Scheme	**PL1E, PL2E, PL3E**	**WD3E, CA3E,** 1987 Scheme		**WD2E, CA2E, WD1E**	
Henan	Score scale	0		-1.02 – -0.72	-1.27– -1.63	-2.63
	Scheme	1987 Scheme		**WD3E, WD2E, CA3E**	**WD1E, PL3E, PL2E, PL1E**	**CA2E**
Shandong	Score scale	2.35 – 3.0	1.07 – 1.28	-0.51 – 0.04		
	Scheme	**PL2E, PL1E, PL3E**	**WD2E, WD1E, WD3E**	**CA3E, CA2E** 1987 Scheme		

As argued above, the positions from basin point of view (YRCC) and from individual province point of view would be clearly different. Here, the contradiction on basin cooperation is illustrated by a diagram, as showed in by Figure 5.12 and Figure 5.13. In each diagram, the basin preference is marked by a number and the preference of the provinces is presented by their attitude. The basin preference is simply a sorting of the results based on the total economic benefits of the water allocation (from highest to lowest). The provincial attitude ranks from supportive, standing by, slightly against, against to strongly against. Such cooperation analysis diagram can help YRCC to easily clarify the main conflicts involved and can help provinces to become aware of the standing point of YRCC who looks at the whole basin.

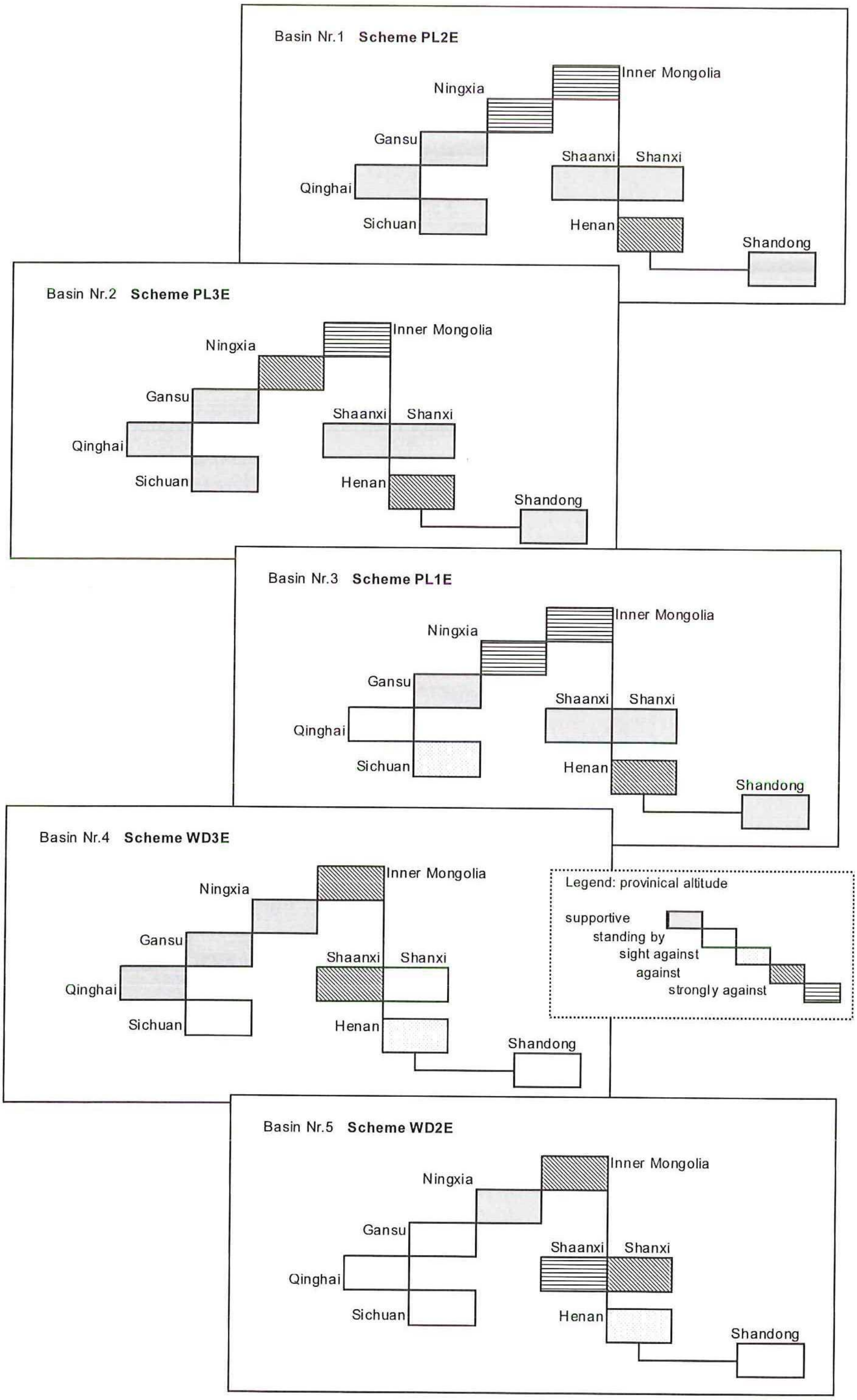


Figure 5.12 Diagram of basin cooperation for the basin preferred schemes from Nr.1 to Nr.5

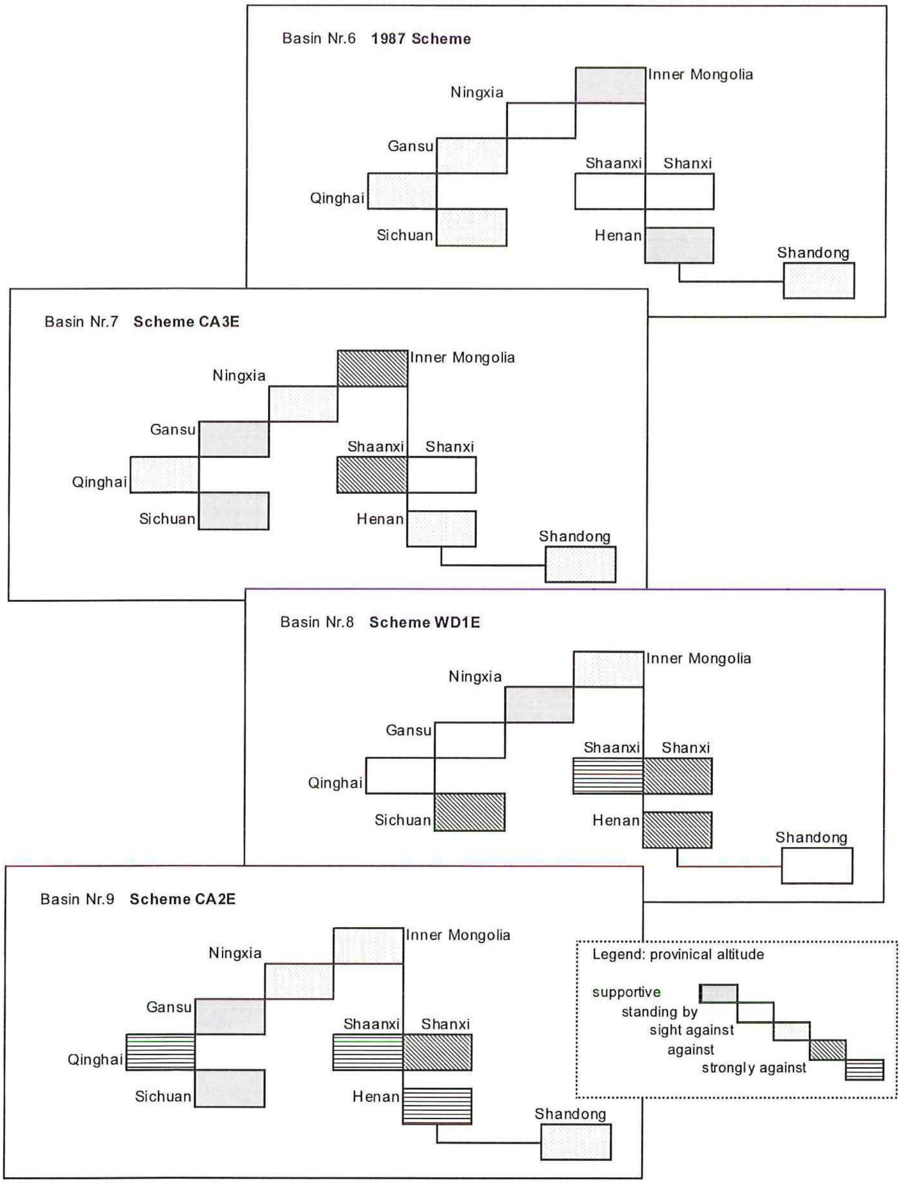


Figure 5.13 Diagram of basin cooperation for the basin preferred schemes from Nr.6 to Nr.9

5.5.2.3 Provincial cooperation analysis

Following above analysis procedure, provincial cooperation contradictions and issues for the 8 pre-selected equitable schemes as well the 1987 Scheme can be briefly summarized in Table 5-16 for the scenario 2030 normal.

Table 5-16 Provincial cooperation analysis for different schemes for scenario 2030 normal

Basin prefer.	Scheme	Supporter	Stander-by	Opponent			Main cooperation issues based on economic benefit analysis
				Sight	Medium	Strong	
Nr. 1	PL2E	Sichuan Qinghai Gansu Shaanxi Shanxi Shandong			Henan	Ningxia Inner Mongolia	Majority provinces do support. 1. Rather difficult to persuade Henan to cooperate. 2. Very difficult to get Ningxia and Inner Mongolia to cooperate.
Nr. 2	PL3E	Sichuan Qinghai Gansu Shaanxi Shanxi Shandong			Ningxia Henan	Inner Mongolia	Majority provinces do support. 1. Rather difficult to persuade Ningxia and Henan to cooperate. 2. Very difficult to get Inner Mongolia to cooperate.
Nr. 3	PL1E	Gansu Shaanxi Shanxi Shandong	Qinghai	Sichuan	Henan	Ningxia Inner Mongolia	Majority provinces do support as Qinghai prefer PL1E to the 1987 Scheme. 1. Fairly difficult to persuade Sichuan to cooperate. 2. Rather difficult to persuade Henan to cooperate. 3. Very difficult to get Ningxia and Inner Mongolia to cooperate.
Nr. 4	WD3E	Qinghai Gansu Ningxia	Sichuan Shanxi* Shandong	Henan	Inner Mongolia Shaanxi		Majority provinces do support because Sichuan and Shandong will prefer WD3E to the 1987 Scheme. 1. Fairly difficult to persuade Shanxi and Henan to cooperate. 3. Rather difficult to get Inner Mongolia and Shaanxi to cooperate.
Nr. 5	WD2E	Ningxia	Sichuan Qinghai Gansu Shandong	Henan	Inner Mongolia Shanxi	Shaanxi	Majority provinces do not object as standers-by prefer WD2E to the 1987 Scheme. 1. Fairly difficult to persuade Henan to cooperate. 2. Rather difficult to persuade Inner Mongolia and Shanxi to cooperate. 3. Very difficult to get Shaanxi to cooperate.
Nr. 6	1987 Scheme	Inner Mongolia Henan	Ningxia Shaanxi Shanxi	Sichuan Qinghai Gansu Shandong			Supposed to implement anyway. 1. Ningxia, Shaanxi and Shanxi are not enthusiastic. 2. Sichuan, Qinghai, Gansu and Shandong are reluctantly to obey.
Nr. 7	CA3E	Sichuan Gansu	Shanxi*	Qinghai Ningxia Henan Shandong	Inner Mongolia Shaanxi		Majority provinces do object. 1. Fairly difficult to persuade Shanxi, Qinghai, Ningxia, Henan and Shandong to cooperate. If fail, majority still object WD1E. 3. Rather difficult to get Inner Mongolia and Shaanxi to cooperate.
Nr. 8	WD1E	Ningxia	Qinghai Gansu Shandong	Inner Mongolia	Sichuan Henan Shanxi	Shaanxi	Majority provinces do object. 1. Qinghai, Gansu and Shandong would cooperate as they prefer WD1E to the 1987 Scheme, majority still object. 2. Fairly difficult to persuade Inner Mongolia to cooperate. If fail, majority still object WD1E. 3. Rather difficult to persuade Sichuan, Henan and Shanxi to cooperate. 4. Very difficult to get Shaanxi to cooperate.
Nr. 9	CA2E	Sichuan Gansu		Ningxia Inner Mongolia Shandong	Shanxi	Qinghai Shaanxi Henan	Majority provinces are not willing to cooperate. Sichuan and Gansu stand little chance to convince the other provinces to consider the possibility of implementation of CA2E.

Note: The 1987 Scheme is referred to for the analysis of cooperation contradictions.

All provinces' default preference is the 1987 Scheme.

Table 5-16 shows that consensus can hardly be reached by all the provinces even for the basin most preferred equitable Schemes PL2E (see Figure 5.12). For Scheme PL2E, 6 provinces of Sichuan, Qinghai, Gansu, Shaanxi, Shanxi and Shandong would positively support it for at least two common reasons. First, the scheme itself is based on equity principle (PL). Secondly, the scheme can enable them to obtain higher economic benefit than that from the 1987 Scheme. The remaining three provinces are against or strongly against Scheme PL2E. Among them, it is relatively harder to persuade Ningxia and Inner Mongolia to cooperate as Scheme PL2E is the last choice for them.

Nevertheless, the challenge is to get all provinces agree on cooperation to implement an equitable scheme. Above analysis of cooperation contradictions already means that, without proper legislation/institution arrangement or compensation mechanisms, even smooth implementation of the basin most preferred equitable Scheme PL2E is still questionable.

The following questions are relevant: what if the opponent provinces stick with the 1987 Scheme instead of an equitable scheme? Where is the space of negotiation for them to cooperate? What kind of compensation mechanism would be effective to motivate all the provinces to cooperate and implement the scheme? What kind of institutional arrangement and legislation should be proposed to facilitate provincial cooperation? All these issues will be discussed in next chapter for smooth implementation of equal, efficient and sustainable schemes for the YR in future.

5.6 Future study to test robustness of equitable schemes

In Chapter 4, nine scenarios are defined to project future water demand for year 2010, 2030 and 2050 together with limited consideration of climate change, see Table 4-11. In this chapter, following system analysis method, the scheme design, implementation and evaluation of alternative equitable inter-provincial water allocation are only tested for scenario 2030 normal. Without further robust test of the other 8 scenarios (2010 normal, 2010 L_{10}, 2010 L_{20}, 2030 L_{10}, 2030 L_{20}, 2050 normal, 2050 L_{10} and 2050 L_{20}), it can only temporally concluded that some of those equitable schemes are good substitutes for 1987 Scheme for the YR. To draw more convincing conclusions, the other 8 scenarios should be analyzed to illustrate the robustness of the equitable schemes. To reduce the analysis effort, a selection of them would be preferred if they can present the possible extreme conditions in future, i.e. 2010 L_{20}, 2050 L_{20}, 2050 normal.

This section briefly describes the four major steps of scenario analysis of the other 8 scenario years (or a selection of them) in future study.

1. Formulation of equitable inter-provincial water allocation schemes for different scenario years. Following the 9 equity scheme design guidelines (see Table 5-2), the allocation algorithms represented by Eq. 5.1 to Eq. 5.7 can be used to generate corresponding 9 equitable schemes for each scenario with consideration of associated assumptions. In each scenario, projected water demand and natural runoff (reduction of 20% for climate change of scenario L_{20}, reduction of 10% for climate change of scenario L_{10} and neglect of climate change of scenario Normal) should be carefully used in allocation algorithms.

2. Realization of formulated equitable schemes together with 1987 Scheme by RIBASIM simulation for each scenario. Follow the realization methods introduced in section 5.2.3.1 to conduct this step. Caution should be given to the SW inflow input to RIBASIM. For different climate change scenarios of L_{20}, L_{10} and Normal, coefficient of 0.8, 0.9 and 1.0 can be multiplied to natural runoff series of 1965-1974. The rainfall input data can remain the same in RIBASIM simulation as the major rainfall utilization in RIBASIM model is mostly considered by employment of natural runoff. Also Eq. 5.9 should be used to calculate input data of SW and GW apportionments to each PWS node and advanced irrigation node in RIBASIM.

3. Pre-selection of equitable schemes to meet the premises of water allocation: province compliance of a scheme, guarantee of reserve water and ensure of human survival water demand. Based on above RIBASIM simulation, the realized results should be carefully examined for each scenario following the three steps described in section 5.2.3.2. Any equitable scheme which can not guarantee water supply for human survival should be excluded, while the remaining ones should be evaluated by comparison to the 1987 Scheme.

4. Analysis of basin cooperation contradictions for implementation of selected equitable schemes. With reference to Eq. 5.10, the indicators identified in Table 5-8 should be calculated for each scenario. Using these indicators, the selected equitable schemes should be compared against the 1987 Scheme to illustrate basin preference (YRCC) and individual province' preference toward an equitable scheme. Tables and diagrams similar to the ones presented in Table 5-15, Figure 5.12 and Figure 5.13 should assist in this comparison. Then basin cooperation issues can be analyzed and summarized for each scenario as the one presented in Table 5-16.

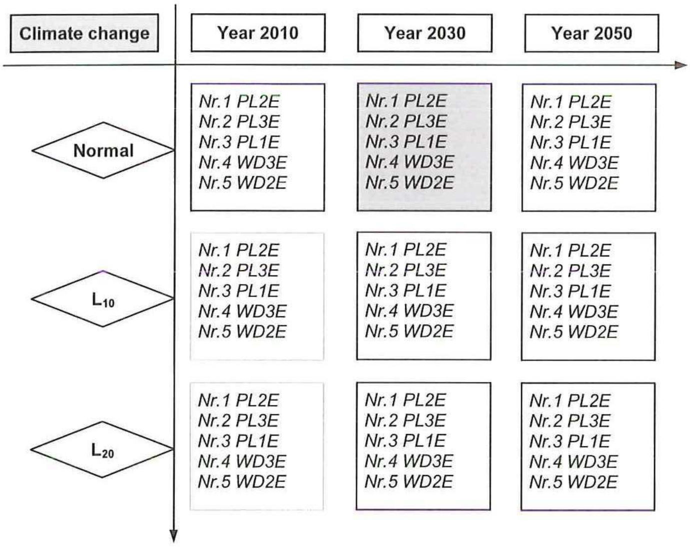


Figure 5.14 Promising equity schemes in different scenarios (imaginary)

As equity constitutes a major challenge mostly due to economical reasons, above analysis can already help to identify which equitable schemes are believed as good substitute for the 1987 Scheme at least from basin point of view. That is, those equitable schemes whose basin economic benefit is higher than that from the 1987 Scheme are believed ‘promising’ as their basin economic objective is compatible with its social objective. For scenario 2030 normal, the top 5 basin most preferred equitable schemes are promising (see Table 5-16). For the other scenarios, their promising equitable schemes can be different from scenario 2030 normal. An imaginary example is shown in Figure 5.14. Assuming each scenario analysis will result in 5 good substitutes of the 1987 Scheme, the common ones which appear most often in different scenarios would be the most preferred schemes. Their associated equity guidelines should be most robust and can be proposed for integrated water allocation in the YR.

6 Provincial cooperation for equitable basin water allocation

6.1 Introduction

The previous chapter pointed out that the main difference between the new pre-selected 8 equitable schemes and the 1987 Scheme is in the economic efficiency. At basin level five of the 8 equitable schemes proved to have a higher economic efficiency than the 1987 Scheme. However, some provinces actually gain less economic benefit in these five promising schemes compared to the 1987 Scheme. Therefore, Chapter 5 concluded that it is unlikely that consensus will be reached by all the provinces for the implementation of these equitable schemes.

Fortunately, the RIBASIM simulations of Chapter 5 also illustrated that the equitable schemes, as well as the 1987 Scheme, can not be fully realized, given the current engineering capacity constraints of the system in relation to the variability of supply and demand. This means that strict implementation of those schemes would result in unused water flowing into the sea. The non-utilized (i.e. un-realized) water can be re-allocated. Reallocating that water to the *economic affected provinces* (EAP) might help to make the equitable scheme more acceptable to them. Economic affected provinces are those provinces whose provincial economic benefit from an equitable scheme is lower than that from the 1987 Scheme. This reallocation, possibly supplemented by additional financial compensation from the *economic beneficial provinces* (EBPs) will be discussed in this chapter. Economically benefiting provinces are those provinces whose economic benefit from an equitable scheme is higher than the benefit from the 1987 Scheme. After water re-allocation, the implementation of an equitable scheme may encounter less friction or even no objection from the EAPs, dependent on the resulting increase of economic benefits.

The approach to re-distribute the unrealized SW apportionment to the EAP's as described in this chapter is just one approach to reach consensus on an improved water allocation scheme in the basin. Other approaches are, e.g. removing (physical) constraints that have led to the unrealized SW apportionment, or using the additional benefits of EBPs to compensate EAPs in monetary terms. Such strategy would be preferred from a basin-wide economic point of view. Both approaches are not investigated in this thesis as it is expected that such pure economic optimization approach will not be acceptable to the EAPs.

This chapter introduces the approach, compensation algorithms and results of three compensation mechanisms. Based on the results, the three mechanisms are compared and their implications on institutions and legislation are discussed. It is concluded that the proposed compensation mechanisms for provincial cooperation are feasible for both EBPs and EAPs to collaboratively implement equitable schemes in the YR.

The outline of Chapter 6 is illustrated by Figure 6.1.

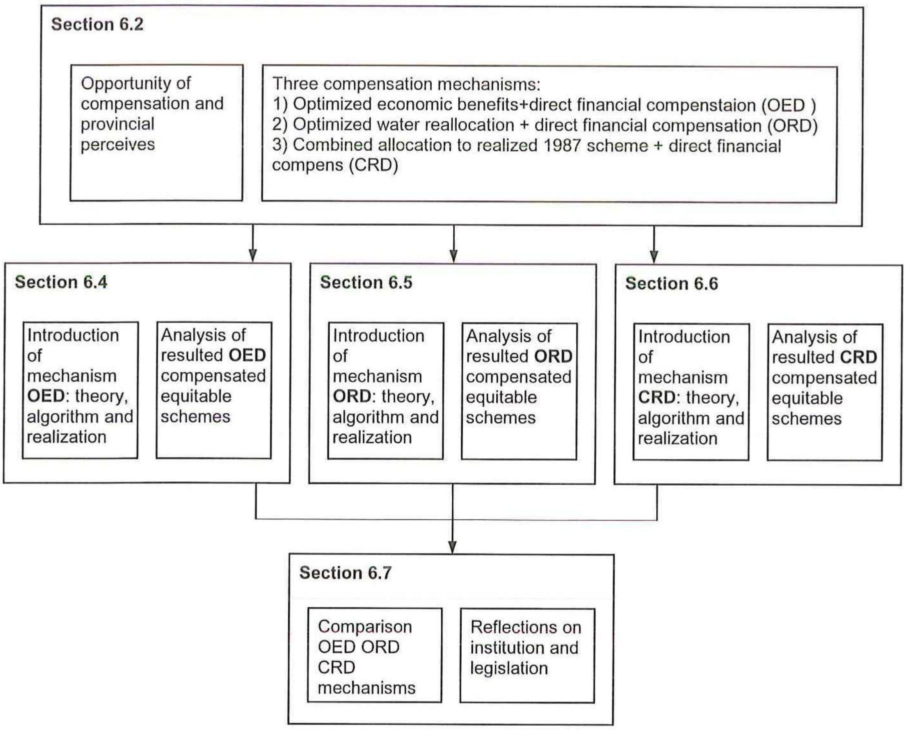


Figure 6.1 Outline of Chapter 6

6.2 Compensation mechanisms for provincial cooperation

6.2.1 EBPs and EAPs

In this section, the 8 pre-selected equitable schemes are compared with the 1987 Scheme in terms of provincial economic benefit. Such comparison results into two categories: *economic beneficial provinces* (EBP) whose economic benefit is higher compared to the 1987 Scheme and *economic affected provinces* (EAP) whose economic benefit is lower compared to the 1987 Scheme. Irrigation output is chosen for the comparison, since it is the most sensitive parameter once DMI is mostly met (equal) in those 8 equity schemes. With reference to the calculated irrigation output from Table 5-9 (2) in Chapter 5, Table 6-1 is prepared to show which provinces are in the group of EBPs and which are in the group of EAPs for different pre-selected equitable schemes. Compared to Table 5-16 in Chapter 5, all those opponent provinces are actually EAPs and those supporters and standers-by are EBPs.

EAPs may reject the implementation of equitable water allocation schemes unless their economic benefit loss is compensated. Only when this compensation is met, basin cooperation may be within reach. An EAP's claim of economic benefit compensation could be their benefit from the 1987 Scheme minus that from an equitable scheme. From Table 5-9 (2), EAPs' claim of economic benefit compensation in terms of irrigation output for different equitable schemes (scenario 2030 normal) are calculated, as given in Table 6-2.

Table 6-1 EAPs and EBPs in different equitable schemes for scenario 2030 normal

Basin preference	Scheme	EBPs	EAPs	$\{EBP^{Eq-Scheme}\}$	$\{EAP^{Eq-Scheme}\}$
Nr. 1	PL2E	Sichuan, Qinghai Gansu Shaanxi, Shanxi Shandong	Ningxia Inner Mongolia Henan	i= 1, 5, 6, 7, 8, 9	i = 2,3,4
Nr. 2	PL3E	Sichuan, Qinghai Gansu Shaanxi, Shanxi Shandong	Ningxia Inner Mongolia Henan	i= 1, 5, 6, 7, 8, 9	i = 2,3,4
Nr. 3	PL1E	Qinghai, Gansu Shaanxi, Shanxi Shandong	Sichuan Ningxia Inner Mongolia Henan	i= 1, 5, 6, 7, 8	i = 2,3,4, 9
Nr. 4	WD3E	Sichuan, Qinghai Gansu, Ningxia Shandong	Inner Mongolia Shaanxi, Shanxi Henan	i= 1, 4,5, 7, 9	i = 2,3,6,8
Nr. 5	WD2E	Sichuan, Qinghai Gansu, Ningxia Shandong	Inner Mongolia Shaanxi, Shanxi Henan	i= 1, 4,5, 7, 9	i = 2,3,6,8
Nr. 6	1987 Scheme	----	----	----	----
Nr. 7	CA3E	Sichuan, Gansu	Qinghai, Ningxia, Inner Mongolia Shanxi, Shaanxi, Henan, Shandong,	i = 1,9	i= 2,3,4,5,6,7,8
Nr. 8	WD1E	Qinghai, Gansu, Ningxia, Shandong	Sichuan, Inner Mongolia, Shanxi, Shaanxi, Henan	i= 1, 4,5, 7	i = 2,3,6,8,9
Nr. 9	CA2E	Sichuan Gansu	Qinghai, Ningxia, Inner Mongolia Shanxi, Shaanxi, Henan, Shandong,	i = 1,9	i= 2,3,4,5,6,7,8

Note: province prefix i (=1,2,...,9), defined in Table 6-8.

Table 6-2 EAP's claim of economic benefit compensation for different equitable schemes for scenario 2030 normal (irrigation output, 10^9 Yuan/yr)

Basin prefer.	**Nr. 1**	**Nr. 2**	**Nr. 3**	**Nr. 4**	**Nr. 5**	**Nr. 7**	**Nr. 8**	**Nr. 9**
Province	**PL2E**	**PL3E**	**PL1E**	**WD3E**	**WD2E**	**CA3E**	**WD1E**	**CA2E**
Sichuan			0.0				0.0	
Qinghai						0.4		5.4
Gansu								
Ningxia	2.1	1.5	2.1			1.1		1.5
In.Mongo.	25.4	23.7	25.4	10.0	8.5	7.9	7.5	3.7
Shaanxi				11.3	17.6	8.6	20.6	26.0
Shanxi				0.0	1.3	0.0	3.1	3.2
Henan	14.2	13.5	15.7	9.7	12.1	14.8	13.7	17.7
Shandong						6.9		9.2
Basin	41.7	38.7	43.1	30.9	39.5	39.7	44.9	66.7

6.2.2 Compensation mechanisms

6.2.2.1 SW compensation opportunities

As pointed out in Chapter 5, the SW apportionments for the different equitable schemes, including the 1987 Scheme itself, can not be fully realized for scenario 2030 normal. The provincial SW apportionments from the different equitable schemes were given in Figure 5.4, while their actual realized SW allocation quantities were listed in Table 5-7. The quantity of unrealized SW apportionment (i.e. SW apportionment minus implemented SW allocation) at basin level ranges from about 3,000 Mcm/yr in WD3E to more than 11,600 Mcm/yr in CA2E, see Table 6-3. At provincial level the unrealized SW apportionment ranges between 3.7 Mcm/yr (Inner Mongolia in CA3E) and 2.5 Mcm/yr (Shandong in PL1E).

This amount of unrealized SW apportionment (both from the EAPs and EBPs) is considerable and provides an 'opportunity' to compensate the EAPs. Redistribution may result in increasing economic benefits of the EAPs, thus positively influencing their attitude towards an equitable scheme. At the same time the economic benefit at basin level will be increased as well.

Table 6-3 Unrealized SW apportionment for different equitable schemes for scenario 2030 normal (Mcm/yr)

Basin prefer.	**Nr. 1**	**Nr. 2**	**Nr. 3**	**Nr. 4**	**Nr. 5**	**Nr. 6**	**Nr. 7**	**Nr. 8**	**Nr. 9**
Province	**PL2E**	**PL3E**	**PL1E**	**WD3E**	**WD2E**	**1987 Scheme**	**CA3E**	**WD1E**	**CA2E**
Sichuan	8	4	18	1	0	33	445	4	627
Qinghai	39	11	97	45	54	78	3515	81	5096
Gansu	1136	956	1145	80	28	26	1608	33	1554
Ningxia	164	92	204	110	132	11	40	188	82
In. Mongo.	0	0	0	17	25	0	4	44	80
Shaanxi	1821	1853	1940	283	184	657	1613	190	2174
Shanxi	1685	1542	1676	696	575	1084	1468	544	1491
Henan	786	1137	887	341	145	1107	238	270	356
Shandong	2416	1441	2487	1374	1601	784	157	1640	198
Basin	8051	7032	8451	2944	2743	3777	9088	2991	11658

From negotiation point of view, the EAPs are foreseen to request compensation of at least their economic benefit loss compared to the 1987 Scheme. Since only re-distribution of unrealized water will not be sufficient for full compensation, two compensation steps are suggested. Step one uses the unrealized water to decrease the economic losses of the EAPs. Any remaining losses of the EAPs will be compensated in step two by direct payments from the EBPs to the EAPs.

6.2.2.2 Possible EAPs' views on SW compensation

For the compensation associated with the first step, re-distribution of the basin unrealized SW apportionment, EAPs could possibly perceive such compensation in three ways:

Nr. 1: Claim of the 1987 Scheme's economic benefit. This choice assumes that economic benefit is the main concern for EAPs. EAPs wish that they gain at least as much economic benefits as from the 1987 Scheme.

Nr. 2: Claim of the 1987 Scheme's realized SW apportionment (their actual use under that Scheme). EAPs believe that receiving SW equal to that from the realized 1987 Scheme will ensure them a comparable economic benefit as from the 1987 Scheme.

Nr. 3: EAPs insists on the realized 1987 Scheme. At the same time EBPs wish to stick to equitable scheme.

The difference between EAPs' claim Nr. 2 and Nr. 3 is that in claim Nr.2 EAPs will be 'satisfied' if their provincial SW allocation is increased up to the realized 1987 Scheme. The method how to reach that target is left open, e.g. by economic optimization. For claim Nr.3 EAPs (actually EAPs' every provincial sub-division) will just divert SW according to the realized 1987 Scheme, e.g. on a first-come-first serve basis. This is a quite rigid SW compensation method. Analyzing such claim can reveal the advantages and disadvantages of above other two SW compensation mechanisms.

6.2.2.3 Three compensation mechanisms

The *objective* of the first step of SW compensation, i.e. to re-distribute unrealized SW apportionment in the basin to EAPs, is to reduce EAPs' claim of economic benefit compensation. If possible, the reduction should be maximized. In other words, the basin's increased economic benefit from SW compensation to EAPs should be maximized. This reduces the size of step two, the direct economic compensation to EAPs by EBPs. EAPs' different opinions on SW compensation can be regarded as *constraint conditions*, i.e. how should the basin's unrealized SW apportionment be compensated among them. In this way the three claims of EAPs' will lead to three SW compensation methods:

OED: economic **O**ptimization under the condition that each province will (as much as possible) get the realized 1987 **E**conomic benefits, followed by **D**irect financial compensation. This option maximizes the basin economic benefit by re-distribution of the unrealized SW apportionment among EAPs in such a way, that after SW compensation, every EAP's provincial economic benefit as far as possible is increased to at least the 1987 scheme realization level. This option follows claim nr. 1 as explained above. The remaining economic gap from the 1987 Scheme for EAPs is directly compensated by EBPs.

ORD: economic **O**ptimization under the condition that each province will as much as possible receive the **R**ealized 1987 Scheme apportionments, followed by **D**irect financial compensation. The option maximizes the basin increased economic benefit by re-distribution of basin unrealized SW apportionment among EAPs in such a way that after SW compensation, every EAP's provincial SW allocation is increased as far as possible up to that from the 1987 Scheme realization. This option embodies claim nr. 2 as stated previously. The remaining economic gap from the 1987 Scheme for EAPs is directly compensated by EBPs.

CRD: Combined basin SW allocation by EBPs implementing the equitable scheme while EAPs trying to withdraw SW according to the Realized 1987 Scheme, followed by Direct financial compensation. This option means that every EAP (actually every provincial sub-division in any EAP) will just divert SW according to realized 1987 Scheme. This option describes view nr. 3 mentioned before. Optimization objectives applied for EAPs' claim Nr. 1 and Nr. 2 (to maximize increased basin economic benefit by use of unrealized SW apportionments) are not applicable here any more. As it is obvious that the unrealized SW apportionment is never enough to meet all EAPs demand of SW compensation, it is necessary to determine which EAP's sub-division would have to divert SW less than that from the realized 1987 Scheme, or even will get no SW compensation at all. What is assumed here is that least efficient EAP sub-divisions will be the last ones to receive the SW compensation. By such, from a basin point of view, increased basin economic benefit by SW compensation can be relative high. The remaining economic gap from the 1987 Scheme for EAPs is to be directly compensated by EBPs.

6.2.2.4 Illustration of compensation schemes

Table 6-4 provides a highly simplified ideal illustration of the three options described in previous section. The basic information of the realized 1987 Scheme and an equitable scheme is listed in Table 6-4 (1) and (2) respectively. The provincial sub-divisions' data from the EAPs are also provided to illustrate the differences of the three SW compensation mechanism. The total unrealized SW apportionment both from the EAPs and the EBPs for the equitable scheme is 85 Mcm/yr.

Table 6-4 Illustration of the three compensation schemes

(1) Basic information of the 1987 Scheme

Provinces		**Irrigation output (a)**	**1987 Scheme**	**Realized 1987 Scheme**		
			SW apportion. (b)	**Realized SW apportion. (c)**	**Irrigation benefit (d)=(a)*(c)**	**Unrealized SW rapport. (e)=(b)-(c)**
		Yuan/m^3	**Mcm/yr**	**Mcm/yr**	**10^6 Yuan**	**Mcm/yr**
Provincial sub-division	P1-1	25	50	45	1125	5
	P1-2	15	90	80	1200	10
	P2-1	5	150	150	750	0
	P2-2	10	35	30	300	5
	P3-1	20	40	40	800	0
	P3-3	20	20	10	200	10
EAPs	P1		140	125	2325	15
	P2		185	180	1050	5
	P3		60	50	1000	10
Sub total EAPs			**385**	**355**	**4375**	**30**
Sub total EBPs			**815**	**810**	**9175**	**5**
Total			**1200**	**1165**	**13550**	**35**

(2) Basic information of equitable Scheme (arbitrary illustrative case)

Provinces			Equitable scheme	Realized equitable scheme			
		Irrigation SW demand (f)	**SW apportion. (g)**	**Realized SW apportion (h)**	**Irrigation benefit (i)=(a)*(h)**	**Unrealized SW rapport. (j)=(g)-(h)**	**Max. SW compens. to irrig. (k)= (d) - (e)**
		Mcm/yr	**Mcm/yr**	**Mcm/yr**	**10^6 Yuan**	**Mcm/yr**	**Mcm/yr**
Provincial sub-division	P1-1	50	50	45	1125	5	5
	P1-2	80	80	65	975	15	15
	P2-1	150	100	95	475	5	55
	P2-2	40	30	25	250	5	15
	P3-1	40	35	25	500	10	15
	P3-3	10	20	10	200	10	0
EAPs	P1	200	130	110	2100	20	20
	P2	250	130	120	725	10	70
	P3	100	55	35	700	20	15
Sub total EAPs			**315**	**265**	**3525**	**50**	**105**
Sub total EBPs			**885**	**850**	**10100**	**35**	
Total			**1200**	**1115**	**13625**	**85**	

Under the SW compensation mechanism **OED**, the unrealized SW apportionment of 85 Mcm/yr is allocated to those sub-divisions of the EAPs that have the highest efficiency (highest Yuan/m^3 as given in column (a)). The compensation apportionments are given in column (m) of Table 6-5. The table shows also that in this case no direct financial compensation is needed anymore (column (q)).

Table 6-5 SW compensation mechanism OED

Provinces		OED claim	SW compensation		Compensated scheme		Next step
		Irrig. Benefit. (l)	**SW compens. to irrigation (m)**	**Increased irrig. benefit (n)=(m)*(a)**	**SW quantity (o)=(h)+(m)**	**Irrig. benefit (p)=(o)*(a)**	**Direct compens. (q)=(d)-(p)**
		10^6 Yuan	**Mcm/yr**	**10^6 Yuan**	**Mcm/yr**	**10^6 Yuan**	**10^6 Yuan**
Provincial sub-division	P1-1		5	125	50	1250	
	P1-2		15	225	80	1200	
	P2-1		35	175	130	650	
	P2-2		15	150	40	400	
	P3-1		15	300	40	800	
	P3-3		0	0	10	200	
EAPs	P1	**225**	20	350	130	2450	-125
	P2	**325**	50	325	170	1050	0
	P3	**300**	15	300	50	1000	0
Sub total EAPs		**850**	**85**	**975**	**350**	**4500**	**0**
Sub total EBPs			**0**	**0**	**850**	**10100**	
Total			85	975	**1200**	**14600**	

Compensation mechanism **ORD** leads to a claim 90 Mcm/yr from the EAPs, see column (r) in Table 6-6. The optimization takes care that within each EAP, unrealized SW is first allocated to the more economic efficient sub-divisions. Compared to mechanism OED, the total increased basin economic benefit by ORD (represented by irrigation output) is a bit less (see column (v)). The required direct financial compensation is also in this case negative (no financial compensation needed).

Table 6-6 SW compensation mechanism ORD

Provinces		ORD claim	SW compensation		Compensated scheme		Next step
		SW compens. (r)=(c)-(h) Mcm/yr	**SW compens. to irrigation (s) Mcm/yr**	**Increased irrig. benefit (t) =(s)*(a) 10^6 Yuan**	**SW quantity (u)=(s)+(h) Mcm/yr**	**Irrig. benefit (v)=(u)*(a) 10^6 Yuan**	**Direct compens. (w)=(d)-(v) 10^6 Yuan**
Provincial sub-division	P1-1		5	125	50	1250	
	P1-2		10	150	75	1125	
	P2-1		40	200	135	675	
	P2-2		15	150	40	400	
	P3-1		15	300	40	800	
	P3-3		0	0	10	200	
EAPs	P1	**15**	15	275	125	2375	-50
	P2	**60**	55	350	175	1075	-25
	P3	**15**	15	300	50	1000	0
Sub total EAPs		**90**	**85**	**925**	**350**	**4450**	**0**
Sub total EBPs			**0**	**0**	**850**	**10100**	
Total			85	925	**1200**	**14550**	

The results of SW compensation mechanism **CRD** is given in Table 6-7. In this case, EAPs claim 90 Mcm/yr to reach their realized water allocation from the 1987 Scheme, while only 85 Mcm/yr is available. In this case, EAP subdivision P2-1 receives less SW compensation then the claimed. This is because its economic efficiency is the lowest. As a result this EAP will be the last to receive SW compensation (see column (aa)). CRD results in less basin economic benefits at basin level compared to ORD. The required direct financial compensation is 25 million Yuan (see column (ac)).

Table 6-7 SW compensation mechanism CRD

Provinces		CRD claim	SW compensation		Compensated scheme		Next step
		SW compens. (x)=(c)-(h) Mcm/yr	**SW compens. to irrigation (y)=(x) Mcm/yr**	**Increased irrig. benefit (z)=(y)*(a) 10^6 Yuan**	**SW quantity (aa)=(h)*(x) Mcm/yr**	**Irrig. benefit (ab)=(aa)*(a) 10^6 Yuan**	**Direct compens. (ac)=(d)-(ab) 10^6 Yuan**
Provincial sub-division	P1-1	**0**	0	0	45	1125	
	P1-2	**15**	15	225	80	1200	
	P2-1	**55**	50	250	145	725	
	P2-2	**5**	5	50	30	300	
	P3-1	**15**	15	300	40	800	
	P3-3	**0**	0	0	10	200	
EAPs	P1	15	15	225	125	2325	0
	P2	60	55	300	175	1025	25
	P3	15	15	300	50	1000	0
Sub total EAPs		**90**	**85**	**825**	**350**	**4350**	**25**
Sub total EBPs			**0**	**0**	**850**	**10100**	
Total			85	825	**1200**	**14450**	

In all 3 cases, OED, ORD and CRD, the direct financial compensation can be mostly reduced to zero. However, this example is only a theoretical illustration of how an ideal SW compensation can take place based on proposed mechanisms. In the next sections the mechanisms will be applied on the YRB by applying an optimization procedure in combination with RIBASIM simulation. In this case, engineering capacity constraints of the system, inter-action of altered SW withdrawal between EAPs and EBPs and their impacts on SW availability, will be incorporated in the analysis. The first step of SW compensation will largely reduce EAPs' claim of economic benefit compensation, but its claim will not be reduced to zero.

The compensation mechanism OED, ORC and CRD will be addressed in details in section 6.4, 6.5 and 6.6 respectively. The three mechanisms are compared in section 6.7. However, first a description will be given on the computational approach that is followed to find feasible allocations.

6.3 Determining feasible allocations by iteration

The compensation approach described in the previous section is based on general allocation rules. These general allocation rules can result from an optimization procedure (OED and ORD) or from a straightforward allocation process (CRD). These allocation rules are general in the sense that they do not take the conditions of the water resources system into account (such as capacity constraints) nor do they account for the temporal aspects of supply and demand and the interaction between the allocations. This means that it is very likely that not all (compensation) allocations can actually be realized by the system. It is impossible to include all conditions in the optimization process as this would make the computation too complicated and impractical to resolve. To account for system constraints and conditions, the RIBASIM application, described in Chapters 4 and 5, will be used. The method requires an iteration process between the optimization procedure and RIBASIM, as illustrated in Figure 6.2.

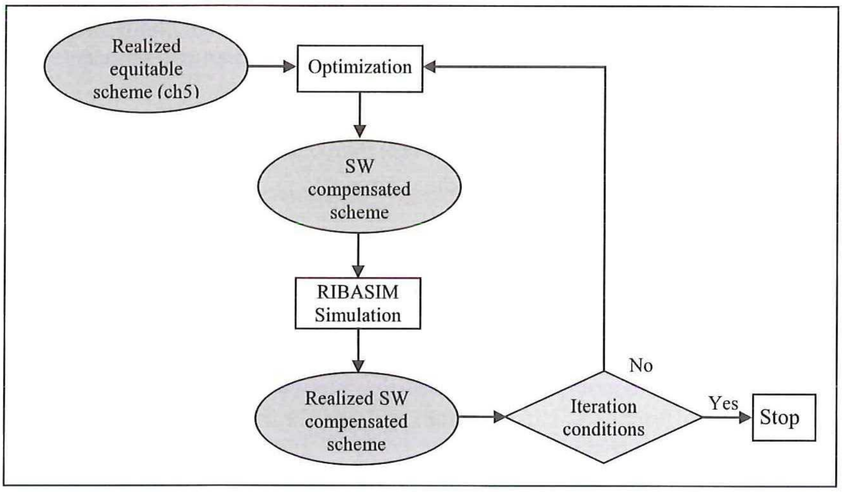


Figure 6.2 Iteration procedure of optimization and RIBASIM simulation of SW compensation BY mechanism OED and ORD

The steps of this procedure are as follows:

- **Step 1 Optimization.**
  - given the realized equitable scheme and the realized 1987 Scheme, the SW compensation quantity to every EAP's provincial sub-division can be

determined by optimization based on the objective of SW compensation mechanism OED or ORD.

- **Step 2 Simulation by RIBASIM**
  - the SW compensation quantity determined in the optimization will be taken into account in RIBASIM as an increased SW supply to the corresponding advanced irrigation node in its EAP sub-division. This is done by adding the increased SW compensation quantity to the original input to a) maximum diverted flow in diverted flow link and b) the flushing requirement to low flow node which are connected to the advanced irrigation node. This is implemented for all SW compensation quantities to all EAPs' sub-divisions.
  - the RIBASIM simulation calculates what actually can be realized of those increased allocations to EAP sub-divisions. Subsequently, increased provincial and basin economic benefits can be determined as well. The result of this RIBASIM simulation is a certain realizable SW compensated equitable scheme.
- **Iteration**
  - in some cases, an amount of unrealized SW apportionment can not be realized. This leads to a repetition of step 1, i.e. the remaining SW apportionment is redistributed among the (remained) EAPs in the basin through maximization of increased basin economic benefits by mechanism OED or ORD.
  - the iteration process is terminated if one of the following conditions is met:
    - the total basin's remaining unrealized SW apportionment is less than 1.0% of total basin's unrealized SW apportionment before SW compensation.
    - the reduction of the total basin's remaining unrealized SW apportionment between two adjacent RIBASIM simulation iterations is less than 0.5% of total basin's unrealized SW apportionment before SW compensation.
    - the basin's increased economic benefit by optimization is less than 1.5% of basin's economic benefit before SW compensation.
    - the realized increase in basin economic benefit between two adjacent RIBASIM simulation iterations is less than 0.5% of basin's economic benefit before SW compensation.

6.4 Compensation mechanism OED

Compensation mechanism OED is based on EAPs' claim Nr.1, i.e. claim of the realized 1987 economic benefits. It is assumed that the water requirement of DMI is already met in the different equitable schemes and that the SW compensation will be allocated to the irrigation sector in EAPs.

6.4.1 Objective function and constraints

SW compensation mechanism OED aims to maximize the basin's economic benefit by re-distribution of the basin's unrealized SW apportionment among EAPs in such a way, that after SW compensation, every EAPs' provincial economic benefit is increased to the 1987 Scheme as far as possible. Accordingly, the formulas for the optimization objective and constraints are given by Eq. 6.1 for SW compensation to a certain equitable scheme by mechanism OED.

$$\max f_{SW}^{Eq-scheme-OED} = \sum_{i=1}^{9}\sum_{k=1}^{s_i} p_{h_{ik}} \cdot qc_{h_{ik}}^{Eq-scheme-OED} \quad \text{such that}$$

$$\begin{cases} \sum_{i=1}^{9}\sum_{k=1}^{s_i} qc_{h_{ik}}^{Eq-Scheme-OED} \leq Q_{\bar{r}}^{SW,Eq-Scheme} - Q_{\bar{r}}^{SW,Eq-Scheme'} & & \text{(a)} \\ \sum_{k=1}^{s_i} p_{h_{ik}} \cdot qc_{h_{ik}}^{Eq-Scheme-OED} \geq \vartriangle e_{SWcps,i}^{Eq-Scheme} & i = 1,2,\dots,9 & \text{(b)} \\ 0 \leq qc_{h_{ik}}^{Eq-Scheme-OED} \leq D_{irrigation,h_{ik}}^{SW} - Q_{irrigation,h_{ik}}^{SW,Eq-Scheme'} & h_{ik} \in \{h_{ik} \mid k = 1,2,\dots,s_i; i \in \{EAP^{Eq-Scheme}\}\} & \text{(c)} \\ qc_{h_{ik}}^{Eq-Scheme-OED} = 0, & h_{ik} \in \{h_{ik} \mid k = 1,2,\dots,s_i; i \in \{EBP^{Eq-Scheme}\}\} & \text{(d)} \end{cases}$$

Eq. 6.1

where

$f_{SW}^{Eq-Scheme-OED}$	increased basin's irrigation output through SW compensation mechanism OED for an equitable scheme [10^6 Yuan/yr];
$p_{h_{ik}}$	irrigation productivity in provincial sub-division h_{ik} (sub-division k in province i) [Yuan/m^3];
$qc_{h_{ik}}^{Eq-Scheme-OED}$	SW compensation to provincial sub-division h_{ik} by mechanism OED for an equitable scheme [Mcm/yr];
$Q_{\bar{r}}^{SW,Eq-Scheme}$	basin's SW apportionment from an equitable scheme [Mcm/yr];
$Q_{\bar{r}}^{SW,Eq-Scheme'}$	basin's total realized SW apportionment from an equitable scheme [Mcm/yr];
$\vartriangle e_{SWcps,i}^{Eq-Scheme}$	claim of economic compensation by province i before SW compensation for an equitable scheme[10^6 Yuan/yr]; $\vartriangle e_{SWcps,i}^{Eq-Scheme} = \max((E_i^{1987Scheme} - E_i^{Eq-Scheme}), 0)$ in which $E_i^{1987Scheme}$ and $E_i^{Eq-Scheme}$ are irrigation output in province i from the 1987 Scheme and from an equitable scheme respectively[10^6 Yuan/yr];
$D_{irrigation,h_{ik}}^{SW}$	irrigation SW demand in provincial sub-division h_{ik} [Mcm/yr];
$Q_{irrigation,h_{ik}}^{SW,Eq-Scheme'}$	realized SW apportionment to irrigation in provincial sub-division h_{ik} from an equitable scheme [Mcm/yr].

The following constraint conditions are defined in Eq. 6.1:

- The total SW quantity of compensation should not exceed the total basin's unrealized SW apportionment (constraint a).
- The increased provincial irrigation output (benefit) by SW compensation is equal to or more than the provincial claim of economic benefit compensation, i.e. for EAPs it is the difference in economic benefit between the realized 1987 Scheme and the equitable scheme; for EBPs it is set to zero (constraint b).

- In a provincial sub-division, the compensated SW quantity is non-negative and will not exceed its total irrigation SW demand minus its realized SW apportionment to irrigation from an equitable scheme (constraint c).
- The SW compensation to any EBP will be zero (constraint d).

Situations may occur where the specified conditions can not be met at all times, e.g. in situations where insufficient unrealized water is available for reallocation. If no feasible solution of Eq. 6.1 can be obtained, it is most often caused by the constrain condition (b). In such a case, the sign $\geq$ should be changed into $\leq$ in condition (b) to ensure a feasible solution. It appears that most specific equity schemes as discussed in this thesis, except equity Scheme WD2E, can meet all the conditions and the optimization procedure was able to come up with a feasible solution.

Condition (b) in Eq. 6.1 indicates that no financial compensation would be required when applying SW compensation mechanism OED. But, due to the reasons explained in section 6.2 and at the beginning of section 6.3, when other conditions are considered in RIBASIM simulation, the SW compensation in most cases only result in largely reduced direct financial compensation. Details of direct economic compensation can be found in section 6.4.2.

The element of groups of $\{EAP^{Eq-Scheme}\}$ and $\{EBP^{Eq-Scheme}\}$, as used in Eq. 6.1, are specified in Table 6-1. The prefix specification for the 29 provincial sub-divisions in relation to the 9 provinces is shown in Table 6-8 and Figure 3.1.

Table 6-8 Prefix specification for the 29 provincial sub-divisions in the YRB

Province	**Province prefix i (i =1,2,...,9)**	**Number of provincial sub-divisions s_i (for h_{ik}, i=1,2,...,9; k=1,2,...,s_i)**
Gansu	1	4
Henan	2	6
Inner Mongolia	3	2
Ningxia	4	2
Qinghai	5	3
Shaanxi	6	4
Shandong	7	2
Shanxi	8	5
Sichuan	9	1

The solutions for optimization equation Eq. 6.1 have been calculated with the MATLAB[1] optimization toolbox for linear programming.

6.4.2 Resulting compensation allocation

As mentioned in Section 6.3 a combination of optimization and simulation is needed to find feasible allocations under compensation scheme OED. The ultimate results of

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[1] version 7.0.0.19920 (R14)

additional water allocations are given in Table 6-9. The total allocations are given in Table 6-10. The SW compensated OED scheme is denoted as Eq-scheme-oe here.

Table 6-9 Provincial SW compensation by mechanism OED for different equitable schemes for scenario 2030 normal (Mcm/yr)

Basin reference	Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	Nr. 7	Nr. 8	Nr. 9
Province	PL2E -oe	PL3E -oe	PL1E -oe	WD3E -oe	WD2E -oe	CA3E -oe	WD1E -oe	CA2E -oe
Sichuan	0	0	1	0	0	0	2	0
Qinghai	0	0	3	1	1	867	1	1129
Gansu	11	-19	0	-3	-9	-61	-11	-11
Ningxia	1999	1391	2004	-100	-190	980	-65	1399
In. Mongo.	6253	5798	4917	1782	1345	3077	1111	2346
Shaanxi	-51	-48	-70	798	994	1093	1119	2116
Shanxi	-8	-21	-19	-6	212	2	108	1554
Henan	525	346	1973	477	279	1459	199	487
Shandong	-1137	-875	-1551	-602	-521	1192	-409	2140
Basin	7591	6572	7258	2346	2110	8609	2055	11160

Note: shadow cells stand for EAPs *before* SW compensation.

Table 6-10 Total SW allocation by mechanism OED for scenario 2030 normal (Mcm/yr)

Basin reference	Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	Nr. 7	Nr. 8	Nr. 9
Province	PL2E -oe	PL3E -oe	PL1E -oe	WD3E -oe	WD2E -oe	CA3E -oe	WD1E -oe	CA2E -oe
Sichuan	15	15	7	9	8	15	6	15
Qinghai	1295	1503	1226	1485	1405	2236	1381	2097
Gansu	3608	4695	3557	3946	3339	4960	3263	4494
Ningxia	3000	2999	3000	6235	6687	3042	7124	3045
In. Mongo.	7377	7244	6028	5780	5627	7390	5570	7421
Shaanxi	3681	3628	3827	3287	3137	3748	3084	3675
Shanxi	3321	3159	3355	2785	2966	2154	2806	3351
Henan	2681	2420	4031	3670	3602	4207	3447	2946
Shandong	9773	9086	8987	7415	7805	6979	7593	7668
Basin	34751	34751	34018	34612	34577	34731	34274	34712

Note: shadow cells stand for EAPs *before* SW compensation.

Table 6-11 Provincial irrigation output for different SW compensated equitable schemes by mechanism OED for scenario 2030 normal (10^9 Yuan/yr)

Basin reference	Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	Nr. 7	Nr. 8	Nr. 9	Nr.6
Province	PL2E -oe	PL3E -oe	PL1E -oe	WD3E -oe	WD2E -oe	CA3E -oe	WD1E -oe	CA2E -oe	1987 Scheme
Sichuan	0.06	0.06	0.02	0.03	0.03	0.06	0.02	0.06	0.02
Qinghai	13.3	17.6	10.6	13.6	11.6	26.0	10.3	26.2	9.5
Gansu	22.7	28.5	22.4	16.4	10.0	29.6	8.2	28.0	8.2
Ningxia	3.9	3.9	3.9	6.2	6.7	3.9	7.0	3.9	3.9
In. Mongo.	40.0	39.3	32.8	31.4	30.6	40.0	30.3	40.2	31.5
Shaanxi	53.3	52.7	54.1	45.5	42.5	53.1	41.6	53.0	43.4
Shanxi	42.4	40.5	42.7	29.8	37.2	29.6	31.3	43.2	27.7
Henan	28.5	24.8	31.3	32.7	31.8	34.8	28.6	31.4	33.5
Shandong	99.4	89.5	88.2	65.6	71.2	59.0	68.1	70.2	48.6
Basin	303.5	303.5	286.0	241.2	241.6	276.0	225.5	296.0	206.1
Environmental low flow shortage (%)	0.2	0.1	0.2	2.0	2.1	1.9	1.2	1.2	0.2

Note: shadow cells stand for EAPs *before* SW compensation.

The resulting provincial economic benefits represented by irrigation output is given in Table 6-11. Clearly at basin level all SW compensated equitable schemes score better then the 1987 Scheme. And the environmental shortage percentage is less than 2.1%.

Table 6-12 is the resulted EAPs' claim for financial compensation. Comparing to Table 6-2 (economic claim before SW compensation) one can see that the EAPs' claim is dramatically reduced. For instance, the EAPs' total claim of PL2E drops from 41.7 billion Yuan to 5.0 billion Yuan and WD2E from 39.5 billion Yuan to 3.6 billion Yuan. In CA3E-oe, all EAP claims are reduced to zero by SW compensation.

Table 6-12 Provincial claim of economic benefit compensation for different SW compensated equitable schemes by mechanism OED for scenario 2030 normal (10^9 Yuan/yr)

Basin reference	Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	Nr. 7	Nr. 8	Nr. 9
Province	PL2E -oe	PL3E -oe	PL1E -oe	WD3E -oe	WD2E -oe	CA3E -oe	WD1E -oe	CA2E -oe
Sichuan			0.0				0.0	
Qinghai						0.0		0.0
Gansu								
Ningxia	0.0	0.0	0.0			0.0		0.0
In. Mongo.	0.0	0.0	0.0	0.1	0.9	0.0	1.2	0.0
Shaanxi				0.0	0.9	0.0	1.8	0.0
Shanxi				0.0	0.0	0.0	0.0	0.0
Henan	5.0	8.7	2.2	0.8	1.7	0.0	4.9	2.1
Shandong						0.0		0.0
Basin	5.0	8.7	2.2	0.9	3.6	0.0	7.9	2.1

Note: shadow cells stand for EAPs ***before*** SW compensation.

Actually, the negative values in Table 6-9 show that some EBPs already 'suffer' from reduction of SW allocation, and subsequently a possible decrease of provincial economic benefit. EBP Shandong suffers mostly in Scheme PL1E-oe, with its economic benefit decreasing from 110.3 billion Yuan to 88.2 billion Yuan (the most significant case among all, see Table 5-9 (2) and Table 6-11). This is most probably caused by the altered interaction between SW allocation to the EAPs and EBPs in the basin. Such SW compensation causes economic loss in EBPs, and this should be considered as their 'compensation' to EAPs. At the same time, some EBPs' economic benefit slightly increases for the same reasons during SW compensation. EBP Gansu benefits mostly in Scheme WD3E-oe, with its economic benefit increasing from 10.0 billion Yuan to 16.4 billion Yuan. In this study this amount of increase of economic benefit from SW compensation will not be corrected.

6.4.3 Direct economic compensation

After SW compensation, the remaining EAP claims for economic benefit compensation (Table 6-12) need to be compensated in money terms by EBPs. To determine how much an EBP should directly pay to the remained EAPs, it is simply assumed that the value will be in proportion to their provincial capacity of direct economic compensation. Here, EBP's provincial capacity of direct economic compensation is defined as their irrigation output from an equitable scheme after SW compensation *minus* their realized irrigation output from the 1987 Scheme. The calculation of EBP's direct economic compensation is introduced in Eq. 6.2. EBP's total economic benefit compensation to EAPs is the sum of their economic loss during SW compensation and their direct economic compensation.

$$for \quad \Delta e^{Eq-Scheme} < \Delta \overline{e}^{Eq-Scheme}, \quad i \in \{EBP^{Eq-Scheme}\}$$

$$\begin{cases} e^{Eq-Scheme} = \Delta e^{Eq-Scheme} \\ ec_{cps,i}^{Eq-Scheme} = el_{DEcps,i}^{Eq-Scheme} + el_{SWcps,i}^{Eq-Scheme} \\ el_{DEcps,i}^{Eq-Scheme} = \varepsilon_i \cdot e^{Eq-Scheme} \\ \varepsilon_i = \dfrac{\Delta \overline{e}_i^{Eq-Scheme}}{\Delta \overline{e}^{Eq-Scheme}} \end{cases}$$

$$for \quad \Delta e^{Eq-Scheme} \geq \Delta \overline{e}^{Eq-Scheme},$$

$$\begin{cases} e^{Eq-Scheme} = 0 \\ el_{DEcps,i}^{Eq-Scheme} = 0 & \qquad i \in \{EBP^{Eq-Scheme}\} \\ ec_{cps,i}^{Eq-Scheme} = el_{SWcps,i}^{Eq-Scheme} & \qquad i = 1,2,...,9 \end{cases}$$

Eq. 6.2

where

$\Delta e^{Eq-Scheme}$	total basin's claim of direct economic compensation after SW compensation for an equitable scheme [10^6 Yuan];
$\Delta \overline{e}^{Eq-Scheme}$	total basin's capacity of direct economic compensation after SW compensation for an equitable scheme [10^6 Yuan];
$e^{Eq-Scheme}$	total basin's direct economic compensation for implementation of an equitable scheme [10^6 Yuan];
$ec_{cps,i}^{Eq-Scheme}$	provincial total economic compensation of EBP *i* for implementation of an equitable scheme [10^6 Yuan];
$el_{DEcps,i}^{Eq-Scheme}$	provincial direct economic compensation by EBP *i* to EAPs for implementation of an equitable scheme [10^6 Yuan];
$el_{SW_{cps,i}}^{Eq-Scheme}$	provincial economic loss of EBP *i* during SW compensation [10^6 Yuan];
ε_i	proportional factor of provincial direct economic compensation of EBP *i*;
$\Delta \overline{e}_i^{Eq-Scheme}$	provincial capacity of direct economic compensation of EBP *i* after SW compensation for an equitable scheme [10^6 Yuan], $i \in \{EBP^{Eq-Scheme}\}$.

The provincial and basin's capacity for compensation is given in Table 6-13. Compared to Table 6-12, this table shows that the basin's capacity for direct economic benefit compensation is indeed higher that the remaining basin's claim after SW compensation by mechanism OED. Detailed EBPs direct and total economic compensations to EAPs are calculated by Eq. 6.2 and listed in Table 6-14 and Table 6-15 respectively. The final provincial economic benefits after SW compensation and direct economic benefit compensation are provided in Table 6-16. A completely compensated OED scheme is denoted as Eq-scheme-oed.

Table 6-13 Provincial capacity of direct economic compensation resulted from SW compensated equitable schemes by mechanism OED for scenario 2030 normal (10^9 Yuan/yr)

Basin reference	Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	Nr. 7	Nr. 8	Nr. 9
Province	PL2E -oe	PL3E -oe	PL1E -oe	WD3E -oe	WD2E -oe	CA3E -oe	WD1E -oe	CA2E -oe
Sichuan	0.04	0.04		0.01	0.01	0.04		0.04
Qinghai	3.9	8.1	1.1	4.1	2.2		0.8	
Gansu	14.5	20.4	14.2	8.3	1.8	21.4	0.1	19.8
Ningxia				2.3	2.8		3.2	
In. Mongo.								
Shaanxi	9.8	9.3	10.6					
Shanxi	14.8	12.8	15.1					
Henan								
Shandong	50.8	40.9	39.6	17.0	22.6		19.6	
Basin	93.9	91.6	80.7	31.8	29.5	21.4	23.6	19.9

Note: shadow cells stand for EAPs *before* SW compensation.

Table 6-14 EBPs provincial direct economic compensation for different SW compensated equitable schemes by mechanism OED for scenario 2030 normal (10^9 Yuan/yr)

Basin reference	Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	Nr. 7	Nr. 8	Nr. 9
Province	PL2E -oe	PL3E -oe	PL1E -oe	WD3E -oe	WD2E -oe	CA3E -oe	WD1E -oe	CA2E -oe
Sichuan	0.0	0.0		0.0	0.0	0.0		0.0
Qinghai	0.2	0.8	0.0	0.1	0.3		0.3	
Gansu	0.8	1.9	0.4	0.2	0.2	0.0	0.0	2.1
Ningxia				0.1	0.3		1.1	
In. Mongo.								
Shaanxi	0.5	0.9	0.3					
Shanxi	0.8	1.2	0.4					
Henan								
Shandong	2.7	3.9	1.1	0.5	2.7		6.6	
Basin	5.0	8.7	2.2	0.9	3.6	0.0	7.9	2.1

Note: shadow cells stand for EAPs *before* SW compensation.

Table 6-15 EBPs provincial total economic compensation for different completely compensated equitable schemes by mechanism OED for scenario 2030 normal (10^9 Yuan/yr)

Basin reference	Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	Nr. 7	Nr. 8	Nr. 9
Province	PL2E -oed	PL3E -oed	PL1E -oed	WD3E -oed	WD2E -oed	CA3E -oed	WD1E -oed	CA2E -oed
Sichuan	0.0	0.0		0.0	0.0	0.0		0.0
Qinghai	0.2	0.8	-0.1	-1.8	2.2		0.2	
Gansu	0.5	1.7	0.1	-6.2	6.6	0.1	0.0	2.0
Ningxia				0.7	-0.1		1.1	
In. Mongo.								
Shaanxi	1.4	1.7	1.4					
Shanxi	1.1	1.7	0.7					
Henan								
Shandong	18.9	16.3	23.2	13.4	5.6		12.3	
Basin	22.1	22.2	25.3	6.1	14.3	0.1	13.6	2.0

Note: shadow cells stand for EAPs *before* SW compensation.

The negative values in EBPs are caused by their increased economic benefit during SW compensation.

Table 6-16 Provincial economic benefit of different completely compensated equitable schemes by mechanism OED for scenario 2030 normal (10^9 Yuan/yr)

Province	PL2E -oed	PL3E -oed	PL1E -oed	WD3E -oed	WD2E -oed	CA3E -oed	WD1E -oed	CA2E -oed	1987 Scheme
Sichuan	0.06	0.05	0.02	0.03	0.03	0.06	0.02	0.06	0.02
Qinghai	13.1	16.8	10.5	13.5	11.4	26.0	10.0	26.2	9.5
Gansu	21.9	26.6	22.0	16.2	9.8	29.6	8.2	25.9	8.2
Ningxia	3.9	3.9	3.9	6.1	6.4	3.9	6.0	3.9	3.9
In. Mongo.	40.0	39.3	32.8	31.5	31.5	40.0	31.5	40.2	31.5
Shaanxi	52.7	51.9	53.8	45.5	43.4	53.1	43.4	53.0	43.4
Shanxi	41.6	39.3	42.3	29.8	37.2	29.6	31.3	43.2	27.7
Henan	33.5	33.5	33.5	33.5	33.5	34.8	33.5	33.5	33.5
Shandong	96.7	85.6	87.1	65.1	68.5	59.0	61.6	70.2	48.6
Basin	303.5	296.8	286.0	241.2	241.6	276.0	225.5	296.1	206.1
Basin prefer.	**Nr. 1**	**Nr. 2**	**Nr. 4**	**Nr. 7**	**Nr. 6**	**Nr. 5**	**Nr. 8**	**Nr. 3**	**Nr. 9**

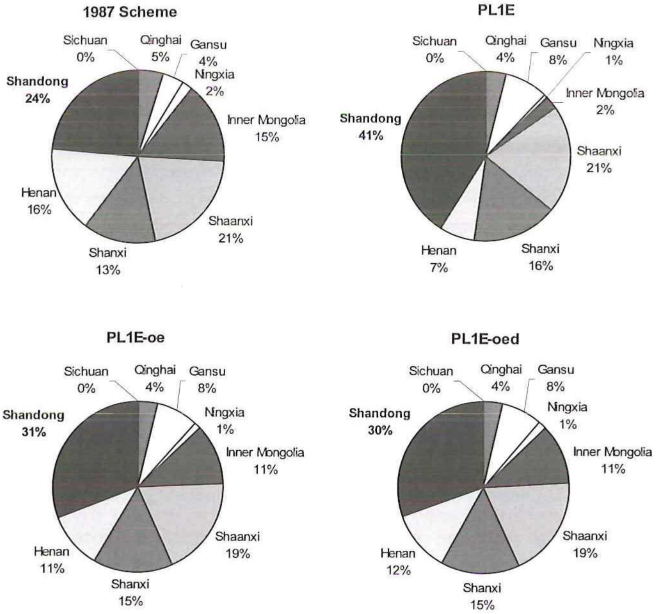
Note: shadow cells stand for EAPs ***before*** SW compensation.

In the end, both the provincial and the basin's economic benefits from all the completely compensated equitable schemes by mechanism OED are no less than those from the 1987 Scheme, see updated basin preference listed in Table 6-16. Among all completed compensated equitable schemes, the most favourable top three schemes appear to be PL2E-oed, PL3E-oed and CA2E-oed. Basin-wide cooperation for the implementation of these equitable schemes is believed to be most feasible and promising. This result provides a sound basis for basin cooperation to implement an equitable scheme facilitated by compensation mechanism OED.

Discussion

According to Table 6-15, basin cooperation to implement a completely compensated equitable scheme by mechanism OED will depend very much on Shandong province. This is because Shandong has the biggest share in the total economic benefit compensation to the EAPs for different compensated equitable schemes.

To analyse the feasibility of the OED approach, the extreme case of Scheme PL1E-oed is discussed here. In this case, Shandong's total economic compensation is the highest among all the compensated equitable schemes. Based on Table 5-9 (2), Table 6-11 and Table 6-16, Shandong provincial economic benefit for different schemes are shown in Figure 6.3: the 1987 Scheme, Scheme PL1E, the SW compensated equitable scheme PL1E-oe as well as the completely compensated scheme PL1E-oed. Clearly, even after direct economic compensation, Shandong provincial economic revenue is still more or less doubled compared to the 1987 Scheme. And, Shandong always has the highest economic benefit percentage among all the provinces. Therefore Shandong will be very willing to cooperate and accept the compensation scheme OED, including the direct financial compensation.



Note: Shandong provincial economic benefit: the 1987 Scheme: 48.6 billion Yuan, PL1E: 110.3 billion Yuan, PL1E-oe: 88.2 billion Yuan, PL1E-oed: 87.1 billion Yuan

Figure 6.3 Comparison of Shandong provincial economic benefit from the 1987 Scheme, PL1E, PL1E-oe and PL1E-oed for scenario 2030 normal

6.5 Compensation mechanism ORD

Compensation mechanism ORD refers to EAPs' claim Nr.2, i.e. the claim on the 1987 Scheme's realized apportionment, followed by direct economic compensation. Similar to SW compensation mechanism OED, the optimization and simulation combined iteration procedure of basin SW compensation, explained in section 6.3, is followed to implement SW compensation mechanism ORD. The optimization objective function and constraints is presented in Section 6.5.1. The resulting SW compensation schemes are only briefly analyzed in Section 6.5.2. Direct economic compensation is explained in Section 6.5.3.

6.5.1 Objective function and constraints

The objective function and constraints for SW compensation mechanism ORD are defined as follows:

$$\max f_{SW}^{Eq-Scheme-ORD} = \sum_{i=1}^{9}\sum_{k=1}^{s_i} p_{h_{ik}} \cdot qc_{h_{ik}}^{Eq-Scheme-ORD} \quad \text{such that}$$

$$\begin{cases} \sum_{i=1}^{9}\sum_{k=1}^{s_i} qc_{h_{ik}}^{Eq-Scheme-ORD} \le Q_{\bar{r}}^{SW,Eq-Scheme} - Q_{\bar{r}}^{SW,Eq-Scheme'} & & \text{(a)} \\ 0 \le \sum_{k=1}^{s_i} qc_{h_{ik}}^{Eq-Scheme-ORD} \le \max(Q_{\bar{r},i}^{SW,1987Scheme'} - Q_{\bar{r},i}^{SW,Eq-Scheme'}, 0) & i = 1,2,\ldots,9 & \text{(b)} \\ 0 \le qc_{h_{ik}}^{Eq-Scheme-ORD} \le D_{irrigation,h_{ik}}^{SW} - Q_{irrigation,h_{ik}}^{SW,Eq-Scheme'} & h_{ik} \in \{h_{ik} \mid k = 1,2,\ldots,s_i; i \in \{EAP^{Eq-Scheme}\}\} & \text{(c)} \\ qc_{h_{ik}}^{Eq-Scheme-ORD} = 0 & h_{ik} \in \{h_{ik} \mid k = 1,2,\ldots,s_i; i \in \{EBP^{Eq-Scheme}\}\} & \text{(d)} \end{cases}$$

Eq. 6.3

where

$f_{SW}^{Eq-Scheme-ORD}$ and $qc_{h_{ik}}^{Eq-Scheme-ORD}$ increased basin's irrigation output *and* SW compensation to provincial sub-division h_{ik} by mechanism ORD for an equitable scheme [Mcm/yr];

$Q_{\bar{r},i}^{SW,1987Scheme'}$ and $Q_{\bar{r},i}^{SW,Eq-Scheme'}$ realized SW apportionment in province *i* from the 1987 Scheme and from an equitable scheme respectively [Mcm/yr].

Compare to SW compensation mechanism OED presented by Eq. 6.1, Eq. 6.3 is nearly the same except for constrain (b). This constrain (b) reflects the EAPs' claim Nr.2: i.e. every EAP would expect that by SW compensation mechanism ORD, their provincial SW allocation will be as close as possible to the realized 1987 Scheme. That is, for every EAP, the upper boundary of SW compensation is the difference between their provincial SW apportionment realized by the 1987 Scheme and realized by an equitable scheme. For EBPs such SW compensation is set to zero.

6.5.2 SW compensated equitable schemes

The resulting SW compensated equitable schemes by mechanism ORD are generated in Table 6-17. The SW compensated ORD scheme is denoted as Eq-scheme-or.

Table 6-17 Total SW allocation by mechanism ORD for scenario 2030 normal (Mcm/yr)

Basin reference	Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	Nr. 7	Nr. 8	Nr. 9
Province	PL2E -or	PL3E -or	PL1E -or	WD3E -or	WD2E -or	CA3E -or	WD1E -or	CA2E -or
Sichuan	15	15	6	9	8	15	4	15
Qinghai	1295	1503	1226	1485	1410	1369	1381	1333
Gansu	3608	4693	3557	3946	3344	4949	3257	4480
Ningxia	3340	3252	3502	6236	6787	3986	7236	3987
In. Mongo.	5845	5873	5845	5813	5533	5859	5646	5859
Shaanxi	3681	3646	3827	3090	3108	3139	3060	3137
Shanxi	3323	3176	3355	3094	3066	2840	3066	2755
Henan	4009	3978	3986	3823	3861	4404	3690	4350
Shandong	9286	8458	8967	7263	7579	6149	7400	6158
Basin	34401	34593	34272	34760	34697	32711	34740	32073

Note: shadow cells stand for EAPs *before* SW compensation.

The positive message of mechanism ORD is the substantial increase of the basin's economic benefit, as shown in Table 6-18. From the basin's point of view, every SW compensated equitable scheme by mechanism ORD is more appreciated than the 1987 Scheme. In addition, SW compensation mechanism ORD does not affect environmental water allocation very much as its shortage is mostly less than 5.0%.

Table 6-18 Provincial irrigation output for different SW compensated equitable schemes by mechanism ORD for scenario 2030 normal (10^9 Yuan/yr)

Basin reference	Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	Nr. 7	Nr. 8	Nr. 9	Nr.6
Province	PL2E-or	PL3E-or	PL1E-or	WD3E-or	WD2E-or	CA3E-or	WD1E-or	CA2E-or	1987 Scheme
Sichuan	0.06	0.06	0.02	0.03	0.03	0.06	0.01	0.06	0.02
Qinghai	13.3	17.6	10.6	13.6	11.6	9.0	10.3	11.2	9.5
Gansu	22.7	28.4	22.4	16.4	10.1	29.5	8.2	28.0	8.2
Ningxia	4.2	4.1	4.3	6.2	6.8	4.8	7.1	4.8	3.9
In. Mongo.	31.8	32.0	31.8	31.6	30.1	31.9	30.7	31.9	31.5
Shaanxi	53.3	53.0	54.1	42.2	41.9	42.9	41.2	43.9	43.4
Shanxi	42.5	40.7	42.7	39.6	39.5	38.1	39.6	37.3	27.7
Henan	32.4	31.3	31.1	32.8	33.2	35.6	29.8	37.2	33.5
Shandong	92.5	80.6	87.9	63.4	68.0	47.2	65.4	48.6	48.6
Basin	292.7	287.7	285.0	245.9	241.3	238.9	232.4	243.0	206.1
Environmental low flow shortage (%)	0.8	0.7	0.1	4.3	2.0	2.1	1.4	1.9	0.2

Note: shadow cells stand for EAPs ***before*** SW compensation.

Compared with the provincial claim before SW compensation (as shown in Table 6-2), it is clear that total claim of economic compensation is tremendously reduced for most EAPs, see Table 6-19. However, to obtain smooth basin cooperation for implementation of an equitable scheme, step two of direct economic compensation is still necessary to compensate the remained EAPs' economic claim, see next section.

Table 6-19 Provincial claim of economic benefit compensation for different SW compensated equitable schemes by mechanism ORD for scenario 2030 normal (10^9 Yuan/yr)

Basin reference	Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	Nr. 7	Nr. 8	Nr. 9
Province	PL2E-or	PL3E-or	PL1E-or	WD3E-or	WD2E-or	CA3E-or	WD1E-or	CA2E-or
Sichuan			0.0				0.0	
Qinghai						0.4		0.0
Gansu								
Ningxia	0.0	0.0	0.0			0.0		0.0
In. Mongo.	0.0	0.0	0.0	0.0	1.4	0.0	0.8	0.0
Shaanxi				1.2	1.5	0.5	2.2	0.0
Shanxi				0.0	0.0	0.0	0.0	0.0
Henan	1.0	2.2	2.3	0.7	0.2	0.0	3.6	0.0
Shandong						1.4		0.0
Basin	1.0	2.2	2.3	1.9	3.1	2.4	6.6	0.0

Note: shadow cells stand for EAPs *before* SW compensation.

6.5.3 Direct economic compensation

The EBP's provincial capacity of direct economic compensation is calculated by Eq. 6.2, see Table 6-20. Compare to Table 6-19, those results confirm that the basin's capacity is much higher than the remaining claims in the basin. Using Eq. 6.2, total economic compensation can be calculated as shown in Table 6-21. The final provincial and basin's economic benefits from completely compensated ORD schemes (denoted as Eq-scheme-ord) are included in Table 6-22.

Table 6-20 Provincial capacity of direct economic compensation resulted from SW compensated equitable schemes by mechanism ORD for scenario 2030 normal (10^9 Yuan/yr)

Basin reference	Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	Nr. 7	Nr. 8	Nr. 9
Province	PL2E-or	PL3E-or	PL1E-or	WD3E-or	WD2E-or	CA3E-or	WD1E-or	CA2E-or
Sichuan	0.04	0.04		0.01	0.01	0.04		0.04
Qinghai	3.9	8.1	1.1	4.1	2.2		0.8	
Gansu	14.5	20.3	14.2	8.3	1.9	21.4	0.0	19.8
Ningxia				2.3	2.9		3.3	
In. Mongo.								
Shaanxi	9.8	9.6	10.6					
Shanxi	14.8	13.0	15.1					
Henan								
Shandong	43.9	32.0	39.3	14.9	19.4		16.8	
Basin	87.0	83.1	80.5	29.6	26.4	21.4	21.0	19.8

Note: shadow cells stand for EAPs *before* SW compensation.

Table 6-21 EBPs provincial total economic compensation for different completely compensated equitable schemes by mechanism ORD for scenario 2030 normal (10^9 Yuan/yr)

Basin reference	Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	Nr. 7	Nr. 8	Nr. 9
Province	PL2E-ord	PL3E-ord	PL1E-ord	WD3E-ord	WD2E-ord	CA3E-ord	WD1E-ord	CA2E-ord
Sichuan	0.0	0.0		0.0	0.0	0.0		0.0
Qinghai	0.0	0.2	0.0	0.3	0.3		0.3	
Gansu	0.2	0.5	0.4	0.5	0.2	2.4	0.0	0.0
Ningxia				0.1	0.3		1.0	
In. Mongo.								
Shaanxi	0.1	0.3	0.3					
Shanxi	0.2	0.3	0.4					
Henan								
Shandong	0.5	0.8	1.1	1.0	2.3		5.3	
Basin	1.0	2.2	2.3	1.9	3.1	2.4	6.6	0.0

Note: shadow cells stand for EAPs *before* SW compensation.

Clearly, for completed compensation equitable schemes by mechanic ORD, both provincial and basin economic benefits are higher than those from the realized 1987 Scheme. Simply ordered by basin economic benefit, updated basin preference is shown in Table 6-22. Three most preferred equitable schemes generated by compensation mechanism ORD are PL2E-ord, PL3E-ord and PL1E-ord from basin point of view. Basin cooperation for implementation of these three equitable schemes is believed most promising.

Table 6-22 Provincial economic benefit of different completely compensated equitable schemes by mechanism ORD for scenario 2030 normal (10^9 Yuan/yr)

Province	PL2E-ord	PL3E-ord	PL1E-ord	WD3E-ord	WD2E-ord	CA3E-ord	WD1E-ord	CA2E-ord	1987 Scheme
Sichuan	0.06	0.06	0.02	0.03	0.03	0.05	0.02	0.06	0.02
Qinghai	13.3	17.4	10.5	13.3	11.4	9.5	10.0	11.2	9.5
Gansu	22.5	27.9	22.0	15.9	9.8	27.1	8.2	28.0	8.2
Ningxia	4.2	4.1	4.3	6.1	6.5	4.8	6.1	4.8	3.9
In. Mongo.	31.8	32.0	31.8	31.6	31.5	31.9	31.5	31.9	31.5
Shaanxi	53.1	52.8	53.8	43.4	43.4	43.4	43.4	43.9	43.4
Shanxi	42.3	40.3	42.3	39.6	39.5	38.1	39.6	37.3	27.7
Henan	33.5	33.5	33.5	33.5	33.5	35.6	33.5	37.2	33.5
Shandong	91.9	79.7	86.8	62.5	65.7	48.6	60.1	48.6	48.6
Basin	292.7	287.7	285.0	245.9	241.3	238.9	232.4	243.0	206.1
Basin prefer.	**Nr. 1**	**Nr. 2**	**Nr. 3**	**Nr. 6**	**Nr. 7**	**Nr. 4**	**Nr. 8**	**Nr. 5**	**Nr. 9**

Note: shadow cells stand for EAPs before SW compensation.

6.6 Compensation mechanism CRD

Compensation mechanism CRD is based on EAPs' claim Nr.3: insistence on the 1987 Scheme when EBPs stick to an equitable scheme. This mechanism is included in this thesis to reveal the advantages and disadvantages of mechanisms OED and ORD. In Section 6.6.1 the method and RIBASIM simulation of basin SW compensation by mechanism CRD are briefly introduced. Then in Section 6.6.2 obtained SW compensated schemes are presented. Direct economic compensation for mechanism CRD is presented in Section 6.6.3.

6.6.1 SW compensation

SW compensation mechanism CRD can be directly realized in RIBASIM:

a) First, total unrealized SW apportionment for an equitable scheme is $Q_{\bar{r}}^{SW,Eq-Scheme} - Q_{\bar{r}}^{SW,Eq-Scheme'}$.

b) Then, calculate every EAP sub-division's claim of SW compensation, $q_{h_{ik}}^{SWclaim-CRD} = \max(Q_{irrigation,h_{ik}}^{SW,Eq-Scheme'} - Q_{irrigation,h_{ik}}^{SW,1987Scheme'},0)$.

c) Sort all EAP's provincial sub-division descending by their irrigation productivity. The obtained sequence will be followed for SW compensation to h_{ik}. That is, from top to down, unrealized SW apportionment will be allocated to h_{ik} according to their claim, till less then their claim and even to zero.

d) When $qc_{h_{ik}}^{Eq-Scheme-CRD}$ is determined for all EAPs, modify RIBASIM input and run RIBASIM simulation for realization of overall basin SW compensation.

e) Afterwards, based on RIBASIM simulation results, actual SW compensation quantity and basin economic benefit can be determined.

Obviously, compare to OED or ORD, SW compensation mechanism CRD is fairly simple.

6.6.2 SW compensated equitable schemes

Following the method described in above section, obtained SW compensated allocation schemes (denoted as Eq-Scheme-cr) are given in Table 6-23. Table 6-24 indicates that by SW compensation mechanism CRD, basin economic benefit can still increase considerably without affecting environmental water allocation (lowest environmental water shortage is 4.3%). Then largely reduced EAPs' provincial claim of economic benefit compensation is included in Table 6-25.

Table 6-23 SW compensated equitable schemes by mechanism CRD for scenario 2030 normal (Mcm/yr)

Basin reference	Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	Nr. 7	Nr. 8	Nr. 9
Province	PL2E -cr	PL3E -cr	PL1E -cr	WD3E -cr	WD2E -cr	CA3E -cr	WD1E -cr	CA2E -cr
Sichuan	15	15	6	9	8	15	4	15
Qinghai	1295	1503	1226	1485	1410	1552	1380	1404
Gansu	3608	4693	3557	3961	3361	4957	3272	4473
Ningxia	1839	1685	2258	6345	6882	2807	7236	3173
In. Mongo.	5863	5856	5860	5326	4980	5966	5163	5999
Shaanxi	3681	3651	3827	3241	3328	3653	3317	3596
Shanxi	3323	3176	3357	3368	3326	3568	3291	3573
Henan	2461	4490	4331	3374	3537	4567	3462	4212
Shandong	10002	8393	9046	7468	7630	6765	7577	6746
Basin	32087	33462	33468	34576	34461	33848	34701	33192

Note: shadow cells stand for EAPs before SW compensation.

Table 6-24 Provincial irrigation output for different SW compensated equitable schemes by mechanism CRD for scenario 2030 normal (10^9 Yuan)

Basin reference	Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	Nr. 7	Nr. 8	Nr. 9	Nr.6
Province	PL2E -cr	PL3E -cr	PL1E -cr	WD3E -cr	WD2E -cr	CA3E -cr	WD1E -cr	CA2E -cr	1987 Scheme
Sichuan	0.06	0.06	0.02	0.03	0.03	0.06	0.01	0.06	0.02
Qinghai	13.3	17.6	10.6	13.6	11.6	12.6	10.2	12.6	9.5
Gansu	22.7	28.4	22.4	16.6	10.1	29.4	8.3	27.8	8.2
Ningxia	2.7	2.6	3.1	6.3	6.9	3.6	7.2	4.0	3.9
In. Mongo.	31.5	31.5	31.5	28.6	26.8	32.4	27.7	32.7	31.5
Shaanxi	53.3	53.1	54.1	44.6	45.6	51.0	45.4	51.4	43.4
Shanxi	42.5	40.7	42.8	36.1	32.5	44.4	31.0	43.2	27.7
Henan	26.5	34.6	31.4	30.0	30.4	33.6	28.7	35.3	33.5
Shandong	102.7	79.6	89.0	66.3	68.7	56.0	67.9	57.1	48.6
Basin	295.2	288.1	284.9	242.2	232.7	263.2	226.4	264.1	206.1
Environmental low flow shortage (%)	0.8	0.7	0.1	4.3	2.0	2.1	1.1	1.9	0.8

Note: shadow cells stand for EAPs before SW compensation.

Table 6-25 Provincial claim of economic benefit compensation for different SW compensated equitable schemes by mechanism CRD for scenario 2030 normal (10^9 Yuan/yr)

Basin reference	Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	Nr. 7	Nr. 8	Nr. 9
Province	PL2E -cr	PL3E -cr	PL1E -cr	WD3E -cr	WD2E -cr	CA3E -cr	WD1E -cr	CA2E -cr
Sichuan			0.00				0.01	
Qinghai						0.0		0.0
Gansu								
Ningxia	1.1	1.3	0.7			0.3		0.0
In. Mongo.	0.0	0.0	0.0	2.9	4.7	0.0	3.8	0.0
Shaanxi				0.0	0.0	0.0	0.0	0.0
Shanxi				0.0	0.0	0.0	0.0	0.0
Henan	7.0	0.0	2.0	3.5	3.0	0.0	4.7	0.0
Shandong						0.0		0.0
Basin	8.1	1.3	2.8	6.3	7.8	0.3	8.5	0.0

Note: shadow cells stand for EAPs before SW compensation.

Anyway, SW compensation mechanism CRD can not ensure to make up every EAP's economic deficiency. Direct economic compensation is therefore accounted, see next section.

6.6.3 Direct economic compensation

The EBPs' provincial capacity of direct economic compensation is calculated and listed in Table 6-26. This result is larger than remained claim after SW compensation as shown in Table 6-25. This makes it positive to implement direct economic compensation for all the equitable schemes. By Eq. 6.2, the values of the EBPs' total economic compensation are calculated and listed in Table 6-27. Provincial and basin economic benefit of completely compensated equitable schemes by mechanism CRD (denoted as Eq-scheme-crd) are shown in Table 6-28.

Table 6-26 Provincial capacity of direct economic compensation resulted from SW compensated equitable schemes by mechanism CRD for scenario 2030 normal (10^9 Yuan/yr)

Basin reference	Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	Nr. 7	Nr. 8	Nr. 9
Province	PL2E -cr	PL3E -cr	PL1E -cr	WD3E -cr	WD2E -cr	CA3E -cr	WD1E -cr	CA2E -cr
Sichuan	0.04	0.04		0.01	0.01	0.04		0.04
Qinghai	3.9	8.1	1.1	4.1	2.2		0.7	
Gansu	14.5	20.3	14.2	8.4	2.0	21.3	0.1	19.6
Ningxia				2.4	3.0		3.3	
In. Mongo.								
Shaanxi	9.8	9.7	10.6					
Shanxi	14.8	13.0	15.1					
Henan								
Shandong	54.1	31.0	40.5	17.8	20.1		19.3	
Basin	97.2	82.2	81.6	32.8	27.3	21.3	23.5	19.7

Note: shadow cells stand for EAPs before SW compensation.

Table 6-27 EBPs provincial total economic compensation for different completely compensated equitable schemes by mechanism CRD for scenario 2030 normal (10^9 Yuan/yr)

Basin reference	Nr. 1	Nr. 2	Nr. 3	Nr. 4	Nr. 5	Nr. 7	Nr. 8	Nr. 9
Province	PL2E-crd	PL3E-crd	PL1E-crd	WD3E-crd	WD2E-crd	CA3E-crd	WD1E-crd	CA2E-crd
Sichuan	0.01	0.00		0.00	0.00	-0.02		-0.02
Qinghai	0.3	0.1	-0.1	-1.1	2.6		0.2	
Gansu	0.9	0.2	0.2	-4.9	6.8	0.5	0.0	0.1
Ningxia				1.0	0.2		1.1	
In. Mongo.								
Shaanxi	1.7	0.6	1.5					
Shanxi	1.5	0.5	0.8					
Henan								
Shandong	17.4	22.8	22.6	15.6	11.1		13.0	
Basin	21.9	24.2	25.0	10.5	20.6	0.5	14.3	0.1

Note: shadow cells stand for EAPs before SW compensation.

Table 6-28 Provincial economic benefit of different completely compensated equitable schemes by mechanism CRD for scenario 2030 normal (10^9 Yuan/yr)

Province	PL2E-crd	PL3E-crd	PL1E-crd	WD3E-crd	WD2E-crd	CA3E-crd	WD1E-crd	CA2E-crd	1987 Scheme
Sichuan	0.05	0.06	0.02	0.03	0.03	0.06	0.02	0.06	0.02
Qinghai	13.0	17.5	10.5	12.8	11.0	12.6	9.9	12.6	9.5
Gansu	21.5	28.1	21.9	15.0	9.6	29.2	8.3	27.8	8.2
Ningxia	3.9	3.9	3.9	5.8	6.0	3.9	6.0	4.0	3.9
In. Mongo.	31.5	31.5	31.5	31.5	31.5	32.4	31.5	32.7	31.5
Shaanxi	52.4	53.0	53.7	44.6	45.6	51.0	45.4	51.4	43.4
Shanxi	41.2	40.5	42.3	36.1	32.5	44.4	31.0	43.2	27.7
Henan	33.5	34.6	33.5	33.5	33.5	33.6	33.5	35.3	33.5
Shandong	98.1	79.1	87.7	62.9	63.0	56.0	60.9	57.1	48.6
Basin	295.2	288.1	284.9	242.2	232.7	263.2	226.4	264.1	206.1
Basin prefer.	**Nr. 1**	**Nr. 2**	**Nr. 3**	**Nr. 6**	**Nr. 7**	**Nr. 5**	**Nr. 8**	**Nr. 4**	**Nr. 9**

Note: shadow cells stand for EAPs before SW compensation.

Clearly, completed compensation equitable schemes result in higher provincial and basin economic benefits than those from realized the 1987 Scheme. Among all completed compensated equitable schemes by mechanism CRD, three most preferred equitable schemes are PL2E-crd, PL3E-crd and PL1E-crd from basin point of view.

6.7 Comparison of three compensation mechanisms

In this section, the similarities and differences of the three proposed compensation mechanisms OED, ORD and CRD will be summarized. Then, the advantages and disadvantages will be analyzed from a practical point of view. In the end, the implications of implementation of those compensation mechanisms on institutional arrangements and administrations will be discussed.

6.7.1 Comparison of three compensation mechanisms

1) Similarities

The similarities of the three proposed compensation mechanisms OED, ORD and CRD are briefly summarized below:

a) Unrealized SW apportionment can not be fully compensated to EAPs based on current river engineering capacity, projected water demand, water use patterns, etc.
b) SW compensation to EAPs is parallel with certain (small) degree of SW allocation reduction to some EBPs.
c) Provincial SW apportionment from an equitable scheme itself is not any more the upper boundary of provincial SW allocation after SW compensation.
d) SW compensation hardly affects water allocation to environmental low flow.
e) Basin economic benefit can be effectively increased by SW compensation.
f) Although SW compensation can already dramatically reduce provincial claim of economic compensation, second step of direct economic compensation, in most cases, is still needed to fill EAPs' remaining economic gap between an equitable scheme and the 1987 Scheme.
g) All completely compensated schemes enable all provinces obtain at least their provincial economic benefit from the realized 1987 Scheme. So purely from economic point of view, potential conflicts between EAPs and EBPs can only be avoided when both SW compensation and direct economic benefit compensation are applied.

2) Differences

The overall economic difference of the three compensation mechanisms can be presented in three terms, i.e. increased basin economic benefit, basin compensation possibility and EBPs' total economic compensation, see Table 6-29. Here, basin compensation possibility is measured by basin capacity of direct economic compensation *minus* basin total requirement of direct economic compensation. In average, it is found out that, mechanism OED can achieve *highest* increased basin economic benefit, *best* compensation possibility and *lowest* total economic compensation. While the mechanisms ORD and CRD are fairly comparable when the average values from all the equitable schemes are compared. The difference between mechanisms ORD and CRD becomes obvious when the average values from different equity criteria of PL, WD and CA are compared. For instance, in terms of increased basin economic benefit, mechanism CRD is better for equity criteria PL and CA, but not for equity criterion WD. Such comparison is summarized in Table 6-30.

Table 6-29 Economic effects of different compensation mechanisms for implementation of different equitable schemes for scenario 2030 normal (10^9 Yuan/yr)

Item	Increased basin economic benefit			Basin compensation possibility			EBPs total economic compensation		
Mechanism	OED	ORD	CRD	OED	ORD	CRD	OED	ORD	CRD
PL2E	28.1	17.3	19.8	88.9	86.0	89.1	22.1	25.0	21.9
PL3E	31.0	15.2	15.6	82.9	80.9	80.9	22.2	24.2	24.2
PL1E	19.1	18.2	18.1	78.5	78.1	78.8	25.3	25.7	25.0
WD3E	23.5	28.1	24.4	30.9	27.7	26.4	6.1	9.2	10.5
WD2E	38.0	37.7	29.1	25.9	23.3	19.5	14.3	16.9	20.6
WD1E	35.0	41.9	35.9	15.7	14.3	15.0	13.6	15.0	14.3
CA3E	85.9	48.8	73.0	21.4	19.0	21.0	0.1	2.5	0.5
CA2E	136.8	83.8	104.8	17.8	19.8	19.7	2.0	-0.1	0.1
Average	**49.7**	**36.4**	**40.1**	**45.3**	**43.6**	**43.8**	**13.2**	**14.8**	**14.6**
Average PL	26.1	16.9	17.9	83.5	81.7	82.9	23.2	25.0	23.7
Average WD	32.1	35.9	29.8	24.2	21.8	20.3	11.3	13.7	15.2
Average CA	111.4	66.3	88.9	19.6	19.4	20.4	1.0	1.2	0.3

Here, it is necessary to point out here that EAPs' different perceives of SW compensation are actually grounded from different degree of transparency of the function of SW allocation and economic benefit. If the box is white: the function is transparent, then EAPs are able to directly check whether their economic gap between an equitable scheme and the 1987 Scheme can be filled by SW compensation. This leaves the options open on how to increase basin economic benefit by re-distribution of unrealized SW apportionment, e.g. by optimization.

If the box is black: the function is not transparent, then EAPs would probably only be able to look at their SW quantities. They would have to believe that the way to safeguard their economic benefit is by withdraw comparable SW quantity from the realized 1987 Scheme. Then the option to optimize increased basin economic benefit is closed. Instead, the compensation becomes 'combination' of two groups of provinces' behaviour: EAPs' insisting on the 1987 Scheme and EBPs' abiding an equitable scheme.

Mechanism ORD is somewhere in between of OED and CRD. That is to say, the box is grey: the function is less transparent but still can be referred to in decision making. Then EAPs would be able to looking at two aspects. One is whether they can try to receive comparable amount of SW from the realized 1987 Scheme, and the other one is try to maximize increased economic benefit. Overall comparison of the three mechanisms of OED, ORD and CRD are summarized in Table 6-30.

Table 6-30 Comparison of the three compensation mechanisms of OED, ORD and CRD

Compensation mechanism		OED	ORD	CRD
Function of SW allocation and economic benefit		Transparent (white box)	Semi-transparent (grey box)	Not transparent (black box)
EAPs' perceive		EAPs claim economic benefit from the 1987 Scheme	EAPs claim realized SW apportionment from the 1987 Scheme	EAPs insist on the realized 1987 Scheme
EAPs concern		Increased economic benefit	Both quantity of SW compensation and increased economic benefit	Quantity of SW compensation
Determination of actual SW compensation		Complicated iteration: optimization and simulation combined procedure		Less complicated: simple calculation combined with simulation
Increased basin economic benefit	Criterion PL	High	Low	Media
	Criterion WD	High	Medium	Low
	Criterion CA	High	Low	Medium
Possibility to compensate	Criterion PL	High	Low	Medium
	Criterion WD	High	Medium	Low
	Criterion CA	Medium	Low	High
EBPs total economic compensation	Criterion PL	Low	High	Medium
	Criterion WD	Low	Medium	High
	Criterion CA	Medium	High	Low

6.7.2 Implications on institutional arrangements

Effective legal and institutional systems are essential for IWRM. Institutional capacity strengthening may well be one of the most important challenges nowadays. It offers potential solutions to many water resource problems including water shortage alleviation and conflicts mitigation. In this section implications of three compensation mechanisms to institutional arrangements are discussed in the following several aspects:

1) Data accessibility, accountability and reliability

Accessibility, accountability and reliability of water utilization and social economic data plays vital roles in choice making, formulation and implementation of completely compensated equitable schemes. YRCC should further strengthen their capability in data collection, data monitor and measurement in relation to SW and GW utilization, economic outputs, and environmental impacts in each provincial sub-division and in the whole basin. Local governments or organizations at provincial, county, irrigation district as well as at NGO levels should assist YRCC to carry out data investigation and collection. They should share their data with YRCC. In the meanwhile, YRCC should also publish and update data to them.

2) Consensus building and conflicts mitigation

Consensus building requires strong institutional capacity of YRCC to act as a platform and coordinator for provinces to participate, cooperate and negotiate with each other. YRCC should facilitate smooth communication among all provinces to make choices. Provided with good information transparency, YRCC should be able to prepare reliable equitable schemes by different compensation mechanisms. And YRCC should convincingly illustrate the advantage and disadvantages of different mechanisms both from provincial and from basin's point of view. Also, when conflicts appear between provinces, YRCC should be able to find out the causes of the conflicts and to come up with solutions to mitigate the tension. Negotiation and trade-off options should be open and problem solving. Then, the final decision can be made by provinces based on democracy principles under YRCC supervision.

3) Implementation of agreed schemes

YRCC should be entitled to strictly regulate mainstream and tributary water allocation according to the agreed compensated scheme. Provinces should be required to give feedback to YRCC to timely update their actual data of SW withdrawal and associated province economic benefit. YRCC should also be authorized to 'charge' EBPs for direct economic compensation to EAPs.

4) Economic incentives

YRCC can apply economic incentives to improve implementation of compensated schemes. For those provinces who disobey the basin agreed scheme, YRCC should be able to 'punish' them by collecting certain fee. For those behaving provinces, they would get certain 'reward', for instance, from punishment fee collected by YRCC.

An overview of compensation mechanism implications on administrative arrangement is included in Figure 6.4.

Considering the reality in the YRB, it is reasonable to believe that at this moment, YRCC can not promote compensation mechanism OED yet due to lack of information transparency, limited capacity building and problematic provinces' cooperation. In future, ORD and CRD are hopefully to be replaced by OED to harmonize further human and water development in the YRB.

Information transparency	White	Grey	Black
YRCC capacity	YRCC can regulate SW allocation in mainstream and tributaries YRCC can have their own evaluation of provincial economic benefit and can compare it with provincial reports YRCC can prepare completed compensated equitable schemes by three mechanisms YRCC can convincingly illustrate what provinces would gain and loss from every scheme by every compensation mechanism YRCC can facilitate provinces to reach consensus on choice of an equitable scheme by compensation mechanism OED, ORD or CRD YRCC can apply economic incentives of punishment and rewards to ensure implementation of agreed completely compensated scheme by all provinces	YRCC can regulate SW allocation in mainstream and some tributaries YRCC can have rough evaluation of provincial economic benefit with reference to provincial reports YRCC can prepare completed compensated equitable schemes by two mechanisms ORD and CRD YRCC can illustrate what provinces would gain and loss from every scheme by compensation mechanism ORD and CRD YRCC can facilitate negotiation procedure of provincial choice of an equitable scheme by compensation mechanism ORD or CRD YRCC can encounter resistance from provinces to ensure implementation of agreed completely compensated scheme	YRCC can regulate SW allocation in mainstream and some tributaries YRCC can have rough evaluation of provincial economic benefit based on provincial reports YRCC can prepare completely compensated equitable schemes by mechanism CRD YRCC can estimate what provinces would gain and loss from different schemes by compensation mechanism CRD YRCC can facilitate negotiation procedure of provincial choice of equitable scheme by compensation mechanism CRD YRCC can not promise smooth implementation of direct economic compensation
Province open response	Provinces cooperate in data communication Provinces can choose compensation mechanism OED, ORD or CRD Provinces obey mainstream / tributaries' SW allocation defined by agreed SW compensated scheme Provinces implement / account on direct economic compensation Provinces give in time feedback to YRCC and submit reliable economic evaluation reports	Provinces can cooperate in data communication Provinces can choose compensation mechanism ORD or CRD Provinces obey at least mainstream SW allocation defined by agreed SW compensated scheme Provinces do not always implement and account on direct economic compensation Province feedback to YRCC and reports of economic evaluation can be twisted	Province would not be willing to share their social economic data Provinces would only claim compensation mechanism CRD Provinces obey mainstream SW allocation defined by agreed SW compensated scheme Provinces may not implement or account lest on direct economic compensation Province feedback to YRCC is twisted and submit lest reliable economic report
Province hidden response	Provinces have less necessity to redistribute SW within their administration boundary	Provinces would consider necessity to redistribute SW within their administration boundary to optimize their provincial economic benefit	Provinces aim to get as much SW as possible Provinces aim to redistribute SW in their administration boundary to optimize their provincial economic benefit
Basin preferred mechanism	Mechanism OED	Mechanism ORD or CRD	Mechanism CRD

Figure 6.4 Compensation mechanism implications on administration arrangements

6.7.3 Implications on legislation

Dealing with above issues requires clear legal specification in the water law on the jurisdiction and authorities of the river basin organisation for river basin management.

A special national law (Yellow River Law) was drafted and is presently in the process of review. This law aims to legalize YRCC to implement IWRM for the YRB. For instance, the operation of the large projects (hydropower stations) on the main stream would be in the charge of YRCC, which traditionally were supervised by different ministries/departments under the State Council. And the withdrawal of the YR water should be well coordinated and operated on the basis of water demand management. As the concrete responsibilities of all water allocation related departments or units would be specified by the coming Yellow River Law, thus, when conflicts appear, YRCC will go through proper procedures and channels to mitigate related users.

Water legislation that provides for an institutional framework of allocation must always provide for a complementary framework of judicial control of water user-ship and other purposes. Generally, this will be evident in water legislation in the form of a review or appeal system to mediators, conflict resolution bodies including water user groups with such a function, tribunals or courts. Wherever possible, legislation should remove uncertainty and clarify the water rights and what they entitle the holder of the rights to do. There must be a legal framework to enable water to be shared among recognized users and according to firmly established policies. A legal system of this nature has institutional requirements of a legal nature and an accepted procedures for determining new uses, for reviewing existing uses and, very important, for resolving disputes about access to water.

In this respect, the water drawing permission system is concerned. Those who draw water from SW or GW, using water-works or water-drawing facilities, must apply for water-drawing permission from water administrative departments. No water-drawing permission is necessary for household livestock or poultry water usage, for withdrawal of small amounts for irrigation, or for withdrawal small amounts by manpower or livestock for other uses. It is also no need to apply permission in case water is taken for agriculture in emergency drought period, for construction or for safety of underground construction and for prevention or reduction of disasters for public security. And water-drawing permission must be in accordance with integrated basin planning, local (and national) long-term water demand and supply plan, and approved water quota allocation or related agreement.

7 Conclusions and Recommendations

7.1 Summarizing conclusions

The objective of the research described in this thesis was *to develop a framework for the application of the concepts of IWRM in the Yellow River basin with a particular focus on alleviating the conflicts between provinces on the water allocation.*

The framework as developed in the research consists of a combined ethical and technical approach to the allocation issues in the basin, applied in a systems analysis framework. The system analysis framework provides a logical sequence of steps (the analytical framework) and a set of models and databases that can be used in the analysis (the computational framework).

The application of this framework on the IWRM problems in the Yellow River and the conflicts between provinces has followed the specific research questions as mentioned in Section 1.5.

The **first research question** was as follows: *What is the present situation in the Yellow River basin on supply and demand and what kind of changes are expected if environmental conditions are taken into account?*

The Yellow River is a relative dry basin and the limited water resources available pose constraints to social economic development and environmental sustainability. In the last decades of the century zero flow frequently occurred in the lower reach of the YR and shortages occurred mostly in the downstream provinces. This exposed serious conflicts and tensions among the provinces and water sectors and between human and environment. From 1999 onward, YRCC started to implement the 1987 Policy of basin wide inter-provincial water allocation scheme. This policy is regarded as a start of applying IWRM in the YR. Indeed, it succeeded in the prevention of zero flow in the lower reach and it addressed the environmental sustainability issue. However, water shortage deduced conflicts and tensions were only made more transparent but not averted due to differences of opinions and the huge gap between supply and demand under changing economic and demographic developments. Equity principles are hardly taking into account in the 1987 Policy while equity is considered to be the third main criteria for IWRM and equally important as the socio-economic efficiency and sustainability criteria. Therefore, it is needed to continue to implement the various concepts of IWRM in order to ultimately formulate an alternative inter-provincial water allocation scheme that mitigates the conflicts among provinces and to further harmonize human and environment in the basin.

The **second research question** was: *How can IWRM be applied in the Yellow River basin and are there specific requirements for a successful application?*

Not only in the YR, but also elsewhere in the world, IWRM practises that focus on the scientific and technical aspects only do not always provide satisfying solutions.

A review of the long history of water management in this culture-rich YR basin recalls the ethical approaches to the management of the river. These ethical approaches may provide the proper philosophical basis of IWRM in the YR. It is argued that combining ethical approaches with scientific and technical approaches may provide the solution for the water management problems in the basin. An ethical approach is essential to motivate the provinces (and the people) to understand, accept and agree on alternative integrated inter-provincial allocation schemes. As lack of equity is one of the deep-rooted causes of the current conflicts among provinces, applying the equity principle in the formulation of rational YR inter-provincial water allocation may help to avoid the conflicts among provinces. Besides providing a proper philosophical basis of IWRM, an ethical approach is also crucial to convince the people to reserve (more) water for the environment. Therefore, alternative inter-provincial water allocation schemes for the YR basin, should be formulated based on equity principles provided by ethical approaches and combined with scientific-and-technical-approaches in the context of IWRM.

Based on this the **third research question** could be addressed: *What aspects should be taken into account and how can these aspects be quantified to enable a trading off of the interests involved?*

First of all the equity principles should be operationalized. Different approaches are possible to translate the principles in clear criteria. Three simple criteria are selected to illustrate the approach, i.e. to express equity in terms of the population of the provinces, their present water demand and their catchment area. The available surface water can be distributed accordingly. To ensure that certain basic needs (environmental flow, drinking water demand, etc.) are guaranteed these components are taken out of the available water and labelled as ‘reserve water’.

The ultimate goal is to develop alternative water allocation schemes for the basin. To quantify the impacts of the schemes for the provinces and to enable a balancing of interest an computational tool is need. A river basin model was applied that keeps track of the water balance in the basin and determines the resulting (dis)benefits for the provinces of these alternative water allocation schemes. The calibrated and validated RIBASIM model for the Yellow River basin is able to give a quantitative description of the present situation but in particular could be used to explore opportunities to improve the situation. A detailed analysis was conducted of the present status and trends both with respect to the supply (developments in storage, water conservation and - to a limited extent - climate change) as well as to the demand (expansion of irrigation areas, population growth and urbanization, industrialization, water re-use and efficiencies, environmental flows, etc.).

The results of the analysis clearly confirmed that the gap between water availability and water demand will become wider and wider in future. If no action is taken, water shortage deduced conflicts will escalate as a result of the on-going social economic development. It is concluded that preparation and implementation of a rational inter-provincial water allocation scheme by wise application of IWRM concepts is very necessary to mitigate these water shortage deduced conflicts.

Having defined the aspects involved and having developed a tool to analyse those aspects the research could address the **fourth research question**: *What alternative* *approaches for a more equitable distribution of the water allocation can be developed, including compensation of those users/regions who will receive less water than before?*

Based on different water allocation guidelines, several alternative equitable inter-provincial water allocation schemes were generated. A simple allocation algorithm determines then the provincial SW apportionments. The river basin model reveals that capacity constraints in the system cause that not all these SW apportionments can actually be realized. That 'unrealized water' can be used to make the new schemes more acceptable for those provinces that are negatively affected by the new schemes. This thesis explores some compensation mechanisms using that unrealized water, using an optimization technique in combination with the river basin model described above. The compensated equity schemes and the existing 1987 Scheme as comparison case are simulated by the model for one external scenario: 2030 normal (without impacts from climate change). The results are evaluated based on indicators: equity, efficiency and sustainability. The conflicts between the basin and provincial points of view and the basin cooperation contradictions for each equitable scheme are illustrated by a cooperation analysis diagram. In such a diagram, the basin preference, which is the best from an overall basin perspective, is marked by a score (indicating the order of its basin economic benefit among all schemes) and the province preference is presented by their attitude (from supportive to strongly opposing). Such cooperation analysis diagram can help YRCC to easily clarify the main conflicts among the provinces and can help the provinces to be aware of the point of view if the whole basin is considered (YRCC).

Overall conclusion

Taking into account needed institutional arrangements, the research resulted in a framework to develop alternative integrated inter-provincial water allocation schemes for the YR, based on a combination of an ethical and a scientific / technical approach. The equity objectives of IWRM are made compatible to the economic objectives and environmental sustainability is being addressed. As a result the tension of water shortage deduced conflicts among provinces and water sectors can be relieved. Provinces can be motivated to reach cooperation at basin level for the implementation of alternative (compensated) equitable schemes.

It is concluded that both ethical approaches and scientific and technical approaches in the context of IWRM are important to mitigate the conflicts among provinces on water shortage in the Yellow River basin. The combined approach is embodied in the developed rational inter-provincial water allocation schemes that are based on the principle of equity, taking into consideration a certain 'reserved water' for basic human needs and for nature and complemented by several possible compensation mechanisms. A strong institutional capacity is required to stimulate the provinces to cooperate on these schemes. In this way a more integrated water resources management can be realized in the Yellow River basin.

7.2 Recommendations

The focus of this thesis is to explore the application of the equity principle of IWRM to cope with water shortage deduced conflicts among provinces and water sectors in the YRB. To enable such application it is first of all recommended to include an ethical approaches based on the indigenous Daoism philosophy in water allocation considerations. All stakeholders, from government to the grassroots level, should be made aware of the equity principles of IWRM by taking Daoism as a guiding principle. They should also be encouraged to adopt more environmental friendly life styles and to support conservation efforts in their daily activities. Awareness building can help to achieve these goals by convincing local communities and developers alike of the value of protecting habitats and biodiversity in order to reap long term sustainable benefits that the water resource system can provide. Education or awareness building should help people to accomplish these goals themselves by alerting them to programs or actions in this field promoted by agencies, groups, and governments. In the long term, they will provide major social, economic and environmental benefits to their communities.

The ultimately developed compensated equity allocation schemes are based on the use of ‘unrealized’ water. Actually, this is only one option out of many that can be considered to reach a more equitable water allocation. Other options are modifying the water use pattern, increasing the storage capacity, etc. These options should also be considered before decision making can take place, including the determination of the impacts of these measures on overall water availability and on vital ecosystem.

If financial compensation is indeed considered as a viable option this should be done in a flexible way. Such compensation does not always need to take place through financial flows between provinces. Other means are exchange of commercial goods (or food) or knowledge and technology.

In order to get full cooperation between provinces it is needed that the transparency of information should be improved that is used to determine the more rational inter-provincial water allocation schemes the reasonable compensation methods. By strengthening the institutional capacity and enacting specific legislation on basin water allocation, YRCC should be authorized to formulate, implement, evaluate and improve integrated inter-provincial water allocation schemes. Transparency of the approach and data used by YRCC is required. On the other hand, the provinces should also be motivated to share their socio-economic data and they should participate, negotiate and cooperate in the implementation of the new basin water allocation schemes. Jointly with YRCC they should invest in water demand management measures.

7.3 Future research

Within the timeframe of this PhD research it was only possible to carry out limited analysis with an emphasis on the development of the methodology. In a real-time application of the approach it will be needed to complement the analysis with more detail, more (allocation) options and more external scenario situations. Fore example, in this research only one scenario was considered: the year 2030 normal.

Actually a full scenario analysis should be carried out to test the robustness of the developed equity approaches. The methods to conduct the analysis for other scenario years are also introduced in Section 5.6. At least one should include some extreme conditions in this scenario analysis, i.e. a situation with high water demand vs. reduced natural runoff as a result of social and climate changes in the basin. Scenario 2010 low, 2050 low and 2050 normal (see Chapter 4) can be a good selection to cover such extreme conditions. Once such further research is carried out, the most robust equity guidelines can be found.

Secondly, the river basin analysis model applied, based on RIBASIM, should be improved. This includes a more detailed basin schematization and more reliable data on water availability and water utilization. The present schematization contains only the main infrastructure. This should be complemented with important middle scale infrastructural works like reservoirs, pump stations, sluices, etc. Especially the large and middle scale irrigation districts should be separately presented in the schematization by adding more irrigation nodes. The quantity and utilization of groundwater should also be more carefully investigated, in interaction with the more dynamic behaviour of the surface water system. It is furthermore needed to more precisely define the quantity of the environmental water demand. With such improved RIBASIM Yellow River water allocation model a better insight can be gained of the basin water allocation. This makes it possible to better explain why and how the surface water apportionment can not be fully realized for a particular equitable scheme. This, by the way, might result in a decrease in the possibility to use unrealized water to compensate the negatively impacted provinces.

Finally, research should be carried out on the promotion of participatory management in the Yellow River basin. People should be stimulated to participate and to suggest other possibilities to interpret the equity principles and translate them into operational criteria. A more participatory approach can contribute to establish a more sound and broadly supported basis for water allocation in the Yellow River basin. As mentioned under the recommendations, a more transparent and reliable information and communication system will help the stakeholders to better understand the simulation results of the models. Through a more active stakeholder involvement during the whole process of scheme design and scheme implementation/compensation, they will be enabled to make a more informed choice and finally reach consensus.

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Annex Self-defined terms

Terms on reserve water components for basin water allocation:

Res:1E	Reserve water composition: only environmental low flow (no water for human demand) is reserved out of negotiation
Res:2E	Reserve water composition: environmental low flow and domestic and municipal demand is reserved out of negotiation
Res:3E	Reserve water composition: environmental low flow and DMI water demand is reserved out of negotiation

Terms on equity criteria for basin water allocation:

CA	Inter-provincial apportionment of Catchment Area: all waters generated in a river basin should be shared by the riparian provinces in proportion to each province's catchment area in the basin
PL	Inter-provincial apportionment of PopuLation: All waters generated in a river basin should be shared by the riparian provinces in proportion to each province's population in the basin
WD	Inter-provincial apportionment of Water Demand: all waters generated in a river basin should be shared by the riparian provinces in proportion to each province's water demand in the basin

Terms on design guidelines for equitable basin water allocation:

CA1E	Only environmental low flow is reserved outside of negotiation, the rest water generated in a river basin is to be shared by riparian provinces in proportion to each province's catchment area in the basin
CA2E	Environmental low flow and domestic and municipal demand is reserved outside of negotiation, the rest water generated in a river basin is to be shared by riparian provinces in proportion to each province's catchment area in the basin
CA3E	Environmental low flow and DMI water demand is reserved outside of negotiation, the rest water generated in a river basin is to be shared by riparian provinces in proportion to each province's catchment area in the basin
PL1E	Only environmental low flow is reserved outside of negotiation, the rest water generated in a river basin is to be shared by riparian provinces in proportion to each province's population in the basin
PL2E	Environmental low flow and domestic and municipal demand is reserved outside of negotiation, the rest water generated in a river basin is to be shared by riparian provinces in proportion to each province's population in the basin
PL3E	Environmental low flow and DMI water demand is reserved outside of negotiation, the rest water generated in a river basin is to be shared by riparian provinces in proportion to each province's population in the basin
WD1E	Only environmental low flow is reserved outside of negotiation, the rest water generated in a river basin is to be shared by riparian provinces in proportion to each province's water demand in the basin
WD2E	Environmental low flow and domestic and municipal demand is reserved outside of negotiation, the rest water generated in a river basin is to be shared by riparian provinces in proportion to each province's water demand in the basin
WD3E	Environmental low flow and DMI water demand is reserved outside of negotiation, the rest water generated in a river basin is to be shared by riparian provinces in proportion to each province's water demand in the basin

Terms on province status resulted from equitable basin water allocation:

EAP	Economic Affected Provinces in the Yellow River basin, whose provincial economic benefit from an equitable scheme is lower than that from the 1987 Scheme
EBP	Economic Beneficial Provinces in the Yellow River basin, whose provincial economic benefit from an equitable scheme is higher than that from the 1987 Scheme

Terms on compensation mechanisms for implementation of equitable scheme:

CRD	Combination - Scheme defined allocation quantity - Direct compensation, i.e. re-allocation of unrealized SW apportionment from an equitable scheme considering that EAPs intend to obtain comparable apportionment of the 1987 Scheme and EBPs intend to obtain comparable apportionment of an equitable scheme. The resulted narrowed economic gap from the 1987 Scheme for EAPs is then directly compensated by EBPs
OED	Optimization - Economic benefit - Direct compensation, i.e. Optimization of basin increased economic benefit by re-allocation of unrealized SW apportionment from an equitable scheme considering that EAPs intend to obtain comparable economic benefit from realization of the 1987 Scheme. The resulted narrowed economic gap from the 1987 Scheme for EAPs is then directly compensated by EBPs
ORD	Optimization - Realizable allocation quantity - Direct compensation, i.e. Optimization of basin increased economic benefit by re-allocation of unrealized SW apportionment from an equitable scheme considering that EAPs intend to obtain comparable realized SW apportionment from the 1987 Scheme. The resulted narrowed economic gap from the 1987 Scheme for EAPs is then directly compensated by EBPs

Terms on compensated equitable schemes:

In the previous the design guidelines and compensation mechanisms are defined. In the work a SW compensated equitable scheme according to a certain guideline will be indicated like for example:

CA2E-oe	Equitable Scheme CA2E after SW compensation by mechanism OED (before direct economic compensation from EBPs to EAPs)
WD2E-cr	Equitable Scheme WD2E after SW compensation by mechanism CRD (before direct economic compensation from EBPs to EAPs)

And a completely compensated equitable scheme (SW compensation followed by direct finance compensation) according to a certain guideline will be indicated like for example:

CA2E-oed	Equitable Scheme CA2E after completed compensation by mechanism OED (by SW compensation and direct economic compensation)
WD2E-crd	Equitable Scheme WD2E after completed compensation by mechanism CRD (by SW compensation and direct economic compensation)

Curriculum Vitae

Rongchao Li was born in Hai'an, Jiangsu province in China, on Feb. 25 1975. In Sept. 1993, she started studying at Hohai University and graduated in June 1997 with distinction at the College of Water Conservancy and Hydropower Engineering. Afterwards, she continued her study in Sept 1997 and got her MSc degree in April 2000 in water saving irrigation in the same college of Hohai University.

Her MsC thesis is based on field experiments of rice cultivation in plastic film mulched dryland. The main output is determination of crop water requirement and crop coefficient, establishment of a dry matter accumulation model and exploration of its relations to the canopy light interception. Her thesis contributed to the China 9th 5-year national project of 'Water saving irrigation techniques on paddy field' and to the China national key project of 'water saving irrigation in Ningxia province'.

Thanks to the China/Delft Cluster Water Engineering Project, she was selected as a sandwich PhD student by TUDelft and Hohai University on Sept 2000. Since then till Sept 2004, she worked at TU Delft on her PhD research on Application of equity principles of integrated water resources management in the Yellow River Basin in China. From Oct. 2004 till Jun. 2006, she continued and concluded her research at Deltares (then still WL|Delft Hydraulics). From Sept. 2006 she started full time working at the R&D department of MTI Holland BV in the field of sustainable dredging technology.

During her PhD research, she gave guest lectures in the course 'integrated water management' at TU Delft and Wageningen University. She also supervized scholars from Yellow River Water Concervancy Commission from China on integrated water allocation at TUDelft.

Currently at MTI Holland BV, she is engaged on development of sustainable dredging technology, environmental impact assessment, turbidity control, and other related subjects.