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中国北方
地下水可持续管理

Sustainable Groundwater Management for North China

黄河水利出版社

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内 容 提 要

本书精选了联合国教科文组织第二届“中国北方地下水可持续管理”培训班中30篇文章，反映出目前地下水可持续管理的最新研究成果。其主要内容包括地下水可持续发展的原则、地下水和地表水联合运用、地下水污染和保护、地下水保护监测和模型、地下水非点源污染控制、水生态、地下水有效管理的经济效益、城市雨水管理、污水处理及回用、济南供水保泉等。

本书适合从事地下水科研、教学、管理及有关部门人员参考。

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序 一

水资源是人类生存和发展不可替代的宝贵的自然资源，又是生态环境的重要组成部分。我国要实现社会经济的可持续发展，无论是经济建设还是生态建设都需要加强对水资源的保护和合理利用。我国淡水资源总量约为28 124亿m^3/a，人均占有淡水资源量为2 163 m^3/a，不到全球人均占有淡水资源量的1/4。全国地下淡水天然补给资源量约为8 840亿m^3/a，地下淡水可开采资源量为3 527亿m^3/a，其中北方地下淡水可采资源量为1 536亿m^3/a，占全国淡水可采资源量的43.5%。目前全国平均地下水开采程度为36%，北方15个省、区、市地下水开采程度则达到60%，其中华北地区平均高达76%，东北地区65%，西北地区25%，有37个城市和地区处于超采状态。因此，中国的水资源问题主要在北方。一方面，自然区域条件形成北方水少，水资源短缺问题突出；另一方面，人为因素又加剧了北方的缺水状况。

地下水是我国北方整个水资源系统中极其重要的组成部分，随着人口增长和经济发展，地下水开发不合理、供需紧张等问题的加剧，地下水资源的保护和可持续利用越来越受到人们的关注。近年来，中国北方地区超采地下水诱发的地面沉降、地面塌陷、海水入侵等一系列地质灾害现象，给我国的经济、社会和自然环境带来重大损失。因此，加强地下水资源保护和科学利用极其重要。联合国教科文组织于2007年3月在济南大学召开第二届“中国北方地下水可持续管理”培训会议，中外专家、学者共同研讨地下水可持续发展的原则、地下水和地表水联合运用、地下水污染和保护、地下水保护监测和模型、雨水管理的效果、污水处理及回用、地下水非点源污染控制、水生态、地下水有效管理的经济效益及济南供水保泉等议题，并组织编撰论文集。希望《中国北方地下水可持续管理》一书的出版，能有助于进一步推动地下水资源可持续利用与管理方面的工作，为水资源科学发展做出积极贡献。特为之序。

济南大学校长：[signature]

2008年2月，济南

序 二

水是生命之本，是人类的文明之源。地下水作为地球水文循环中的重要一环，在人类赖以生存的水资源中占据着极其重要的地位。在经济社会持续快速发展的今天，人类对水的需求与日俱增，中国正面临着水资源严重短缺的危机。与地表水相比较，由于地下水具有调蓄能力强、供水保证率高、水质优、分布广、开采方便等特点，它在水资源的配置和环境保护中发挥着特殊的作用，它是重要的经济资源、环境资源和战略资源。

山东是一个农业大省、经济大省和人口大省，也是一个水资源严重短缺的省份，山东以仅占全国水资源总量的1.1%的水，养育着占全国7.1%的人口，灌溉着占全国7.4%的耕地，生产着占全国10%的粮食，支撑着全国9.3%的国内生产总值，其中，地下水供水量占总供水量的50%以上，地下水在支撑经济社会持续快速发展方面功不可没。但是也应当看到，多年来由于对地下水资源不合理开采，引发了区域内局部地下水位下降、海水入侵、水质污染等问题。因此，科学规划、合理开发和有效保护地下水资源已经成为近年来水资源管理工作的重点。尽管我们在地下水资源开发利用和节约保护方面做了许多工作，但是离实现人水和谐共处的目标还有差距，如何更好地加强地下水资源开发利用管理和保护仍然是摆在我们面前的一个重大课题。

联合国教科文组织(UNESCO)将第二届“中国北方地下水可持续管理”培训班安排在山东济南举办，组织国际和国内地下水专家有针对性地就地下水可持续利用原则、地下水和地表水联合运用、地下水污染和非点源污染控制以及水生态保护、地下水管理经济费用分析等方面内容进行专题授课，不仅为我省水资源管理工作提供了一次难得的学习机会，而且必将对山东地下水资源开发利用、科学管理和有效保护工作起到极大的促进作用。专家授课讲义的编著成册，也必将为水资源管理工作者提供一本良好的教科书。

借此机会，真诚地感谢联合国教科文组织(UNESCO)对山东水资源管理工作的帮助，感谢专家教授和会议组织者为此付出的辛勤劳动，感谢社会各界的关心和支持。

山东省水利厅副厅长：

2008年2月，济南

前言

地下水资源是人类饮用水的优质水源，是中国北方地区城市生活和工业主要的供水水源。中国北方地区水资源短缺，由于地下水超采严重，引发了大范围的地下水漏斗、地下水资源枯竭、水质恶化、海水入侵、地面沉降、岩溶塌陷以及生态环境恶化等现象。同时，由于工业化和城市化进程的加快，城市生活污水和工业废水部分未经处理或经处理后污染物总量不能达到自然界本身净化的能力，河流污染致使河流附近呈线状地下水污染；部分企业在生产过程中，污染物的跑、冒、滴、漏以及突发事故致使呈点状地下水污染；农业施用农药、化肥造成的面状地下水污染。地下水过量开采和污染正在威胁着我们的生存环境和健康。特别是这种看不见的地下水污染，越来越引起国内外科学技术界的重视。

联合国教科文组织(UNESCO)于 2005 年设置了水资源可持续管理教席，由 W. F. Geiger 教授担任，目的是增进交流和以大学、企业合作的形式，通过举办一系列培训班、研讨会、展览等方式加强可持续用水管理方面知识的学习。在济南大学举办的“中国北方地下水可持续管理”培训班是该教席的第二次活动。现今世界上有 11 亿人口没有获得安全卫生的饮用水，按联合国千年发展计划，到 2015 年将有 5.5 亿人口的饮用水安全问题得以解决。应重点考虑农业生产率高的地区，这些地方已经对水资源，特别是地下水带来压力。为了解决当前水和未来水的问题，必须建立一个可持续用水管理的，特别是应用到地下水管理方面的新范例。尽管我们的水管理已有很长的历史，然而要想创立一新的范例就必须要有水管理的新方法才行。

由联合国教科文组织(UNESCO)和济南大学举办的第二届“中国北方地下水可持续管理”培训班，邀请了德国、澳大利亚以及国内高校、科研、管理等部门的教授和专家，从不同的学术观点、不同的方面，多角度地对地下水可持续管理的有关问题进行讲座和研讨，涉及到浅层和深层地下水、孔隙水和岩溶水、地表水与地下水联合调度、地下水污染与控制、再生水灌溉对地下水环境的影响、城市雨水回灌岩溶地下水、地下水监测、地下水可持续管理、地下水模型、水生态修复以及新方法、新技术在地下水研究方面的应用等，在研究内容上互相补充，各具特色。

该培训班得到了联合国教科文组织(UNESCO)、济南大学、山东省水利厅、济南市水利局、山东水利学会、山东侨务办公室以及武汉中地公司的支持。本书出版得到了山东省重点学科(试验室)基金项目资助。

书中不当之处，敬请读者批评指正。

作　者

2008 年 3 月

目 录

Sustainability Principles for Water Management

W. F. Geiger
(UNESCO Chair in Sustainable Water Management)

1 Introduction

Population together with the expansion of irrigated agriculture and industrial development have increased in the past 50 years significantly. While in 1950 30% of the world's population lived in urban areas, today it is more than 50%. This created tremendous pressure on water resources. Worldwide water demand amplified by a factor of six between 1900 and 1995 while population only doubled. Water resources are exploited and polluted, overlooking environmental degradation. Results are flooding, droughts, abuse of water resources, sinking groundwater levels, saltwater intrusion along costs, land subsidence, pollution, which makes water unusable, and global changes, that lead to more frequent occurrences of disasters. The higher economic growth is, the higher environmental damage seems to be.

Despite of overexploitation of water resources inadequate water supply and sanitation have been identified by the World Summit in Johannesburg 2002 to be the major problems. Today, there are 1.1×10^9 people without access to safe water supply, 2.4×10^9 people without adequate sanitation and even more who are short of water for food production. To meet the Millennium Development goals set by the World Summit in Johannesburg, namely to half the number of people lacking access to safe water supply and adequate sanitation by 2015 requires politicians, planners and users to review inherited thinking, planning measures used in the past, which evidently were not suitable or too inflexible to cope with the problem so far.

Also in China in the past 50 years, water demand increased as rapid as economic development and population. In 2004, the total national water consumption has increased to 554.8 m^3 as against 103.1×10^9 m^3 in 1949. Allocation among diverse users changed too. Agriculture still is the major user with 64.6% of the total water consumption.

At present, two thirds of Chinese cities face serious water shortage. Northern China and parts of Western China are known to have serious water shortages. Losses in water storage capacity add to the problem of water shortage. The total storage capacity of 601 large-sized and medium-sized reservoirs in the Yellow River basin i.e. was 52.3×10^9 m^3, 10.9×10^9 m^3 of which (21% of the total) had been lost due to sedimentation until 1989. Regulation of upstream reservoirs made peak floods decrease greatly in the Lower Yellow River during the past two decades, leading most sediment to deposit in the main channel of the river. This and irrational use of floodplains along the river, caused shrinking of the channels. The loss of storage capacities not only aggravates the risk of flooding and droughts, but also ecological deterioration.

Presently ,in China an area of 3.56×10^6 km^2 is eroded, accounting for 37% of the total territory, causing annually 5×10^9 t of eroded soil. This led to: an annual loss of arable land of more than 66×10^3 hm^2 in the past 50 years, degradation of grassland of 1×10^6 km^2 in total, land desertification of 2.46×10^3 km^2 a year since 1990, and sedimentation in reservoirs and rivers, reducing their flood regulation and conveyance capacity. The ecological degradation in eroded areas worsens poverty. Over 90% of the poor in China live in such areas.

Pollution is an even more serious problem in China. River reaches of about 1×10^5 km have grade Ⅳ or worse accounting for 47% of the total length. More than 75% of the lakes are heavily polluted. A study on drinking water of 118 cities indicates that groundwater has been polluted to a varying degree in 97% of the cities, 64% of which are seriously aggravating water shortages further. In addition water pollution increases ecological deterioration reducing the value of water not only for domestic, industrial and agricultural use, but also for recreation.

2 Imbalances and barriers obstructing water management

Introduced problems lead to social, environmental and economic inequity. While UNESCO in the 70ies of 20th century through its International Hydrologic Programmes (IHP) pointed out these dimensions of water problems and endorsed sustainable and integrated water management and though sustainability was addressed in World Summits and World Water Congresses for decades, problems became larger. While governments passed laws requiring integrated water management and sustainability, and while 179 nations signed the Agenda 21 in 1992 including the paradigm of 'Sustainable Development' as the basis for future policies, reality in acting sustainable despite of all verbal insight and available techniques lacks behind.

2.1 Changing hydrologic and social situation distressing water managers

Above problems mainly are man-made, i.e. land use alterations resulting in more runoff and pollution, population growth and migration from rural to urban areas resulting in more urbanization, illegal discharges of solid and liquid wastes and last not least human behavior and consumerism resulting in global warming affecting sea levels and causing more frequent disasters. All along an ecological crisis and social changes are observed. It is not understood, what causes such socio-ecological transformations, where they lead to and which development potential is contained in these processes. However they are strongly linked to the water crises.

In the 1,034 km^2 Huangshui river basin in Shandong for example per year 120×10^6 m^3 of runoff can be utilized, while water demand with 162×10^6 m^3/a exceeds renewable water resources by about 25% (Geiger et al., 2005). In 1998 in Shandong more than 4 million people in 30 cities suffered water scarcity. Citizens had to use water just part time and limited. Groundwater was overused causing saltwater intrusion, which affects agricultural production badly. Food production was reduced by 9.65×10^6 t and annual economic losses only due to water scarcity are estimated over 5 billion Yuan for the province. Even more because lack of water, many have to drink low-quality water. This again increases the incidence of diseases.

Due to economic development and population increase a lot of water originally available for agriculture is now being used for supply of cities and industry. This causes conflicts between towns and counties, production and living, not even considering environmental needs. It is unclear how much options the different social parties have. Action without clear goals and insufficient means lead to progressing dynamics of problems which get out of control. Social justice gets lost and social solidarity decreases. This is the case not only at the Huangshui river.

2.2 Increasing insight and new technologies upsetting decision makers

Water management today can benefit from the rapid development of monitoring, i.e. remote sensing, data processing, i.e. GIS systems and modelling techniques. Further, background knowledge on hydrologic and bio-chemical processes has never been as large as it is today. These advantages, however, are counteracted by some managers and administrators not keeping pace with the necessary knowledge needed to operate latest techniques. In effect decision makers often relay on modelling results produced by technically qualified, but in water management less experienced (computer) specialists. It is merely impossible for them to check if options are reasonable or not. The risk, that money is wasted, increases.

Even more, the definition of the catchments' boundary always was a difficult task, as it depends on the problem to be solved. Management strategies on different scales at last must go with each other. Aside the technical difficulties for integrated planning different responsibilities, political priorities and ignored law offences make it impossible to satisfy all including environment's interest.

Traditional water resources management also suffers from the difference between the long times (up to ten years) that are required to assess existing conditions by monitoring and modelling quantity and quality processes in river catchments and the short times available for deciding on individual measures (sometimes less than one year, in case of chemical accidents minutes). In consequence measures taken cannot be checked if they fit into long-term water management objectives. This usually results in low efficiencies and high costs.

2.3 Administrative constraints hampering water management

Sometimes problems seem to be technical at a first glance, but actually are administrative:

- Data established in earlier plans are lost in many instances. New projects, often dealing with issues that have been addressed previously, have to start from zero.
- Another deficiency is the lack and inappropriate use of data. The time and space resolution needed often are not available from standard data sources.
- Fast growth and changes make it difficult to make correct forecasts. While remote sensing data could always be updated, this often is found too expensive for water management.
- Planning often not adapts to specific conditions. A widespread fault is copying procedures from somewhere else, which usually are inappropriate to solve the problem at hand.
- Financial and social data are equally important. Different dimensions, conventions and responsibilities for these sectors make integrated planning very difficult.

The major constraints are not technical but organizational. Insufficient institutional competence at various government levels not only hinders to develop alternative and locally adapted innovations, but also hamper the creation of adequate traditional infrastructures. The artificial subdivision of reality into different sectors opposes interdisciplinary thinking.

Maybe the biggest administrative constraint is shifting responsibilities, a phenomenon met in developing and developed countries alike (UNESCO, 1996). It implies that when a problem is recognized, parties affected decide that they do not want to be mixed up, especially when high costs may be met or difficult political hurdles are seen. The general attitude in such cases is either to deny responsibility for the recognized problem or to take up the standpoint that the problem is not as big as thought. What it boils down to is not only the question of who is legally responsible, but also who is prepared to take it up and actually starts improvements.

2.4 Political priorities and corruption paralyzing water management

Political constraints often are more significant than technical and administrative altogether:

- Financial and technical tasks often differ. When selecting a solution for a water scarcity, pollution or remediation problem, a purely technical approach unconnected with financial realities can create unrealistic solutions. The final decision lies with political decision makers, who may have little or no technical and economic background.

●General organization and management structures often are unable to recognize the relations of technical, financial and social problems and to find integrated solutions. Decision makers are confused by the fundamental differences of engineers and environmentalists about the way in which a recognized problem should be solved.

●There is a tendency to deal ineffectively with risks. Unknown features of the planning process paralyse decision makers, limit innovations and result in stagnant technology and wrong solutions. Risk assessment and public discussion of the risks involved are needed.

●The political pressure, under which planning processes must progress, often blocks efficient planning.

●In general the planning process tends to be reactive rather than proactive. This unfortunately is observed the more, the higher the responsibility level is. Because of the obstacles listed above, science, technology, engineering design, ecological analysis, impact assessment and other factors all operate as reactive systems.

More severe is the ignorance of water laws and environmental protection requirements set out by government. In countries, where economic development receives the highest priority, corruption is observed in context with unpunished law offences. Frequent spills, accidents and related social and environmental disasters are difficult to be explained otherwise.

3 Principles and objectives for sustainable water management

Today sustainability i.e. the balance linking environmental, social and economic needs almost never is achieved, also because the specific characteristics of individual water systems make it impossible to have a universal method for sustainable water management, which could be applied everywhere like a recipe. Further, water management is linked to earlier development, social and political structures and geographic background and must account for this.

3.1 Definition and characteristics of sustainability

It is popular to reason with sustainability. The World Commission on Environment and Development defined sustainable development as "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (Brundtland report, 1987). According to the Commission of the European Community, criteria of sustainable development are to maintain quality of life, keep up continuing access to natural resources, and avoid lasting environmental damage. Sustainable water management has to ensure, that societies today and future can live without compromising the natural hydrological cycle and ecosystem integrity (UNESCO, 1996). In short: "sustainability avoids future regret for decisions made today" (Geiger et al., 2006). However, all of these definitions are too general in order to be of any help to decision makers in water management.

Towards the end of the last century it was realized, that development focusing on economic growth only will not remove poverty and secure future. It may make some people more rich, but the majority of people poorer. Instead, the three dimensions environment, society and economy must be equally addressed.

There are different opinions, which of the dimension should be dominant and if equal by which measure equity is expressed. In view of sustainability certainly environment is connected most to the development potential of future generations. Therefore the World Conservation Union, the United Nations Environment Program and the World Wildlife Fund for Nature defined sustainable development as a development that improves: "the quality of human life while living within the carrying capacity of supporting ecosystems." (IUCN,UNEP, WWF (1991) extracted from UNESCO N.D.)

This definition corresponds to the very old idea of sustainable forestry, developed by Hans Carl Carlowitz in 1713, an German forestry engineer from Freiberg. He defined a very simple balance which has to be fulfilled to reach a sustainable status for a given forest unit: "wood amount cut in one year ≤ wood amount growing up in one year." At last this is an excellent example of what is meant by the expression "carrying capacity of supporting ecosystem". For the assessment of sustainability it is essential if this principle is applied or not. The following distinction is important for the definition of indicator sets for sustainability evaluation:

- Strong sustainability. Strong sustainability means that preservation of natural capital is considered as not substitutable by any other form of capital and the imbalance is fulfilled for every case.
- Weak sustainability. Weak sustainability implies that the depletion of natural capital can be substituted by man-made capital, as long as the sum of both is not decreasing.

The different components which make water management sustainable did not receive the same priorities at all times. At different stages of societal development, different objectives are considered more important. In the pre-industrial society, emphasis was placed on drinking water supply and irrigation. In the industrial society, generation of hydropower and waste disposal and transport are prioritized. Finally, in the post-industrial society, high emphasis is placed on aesthetics and ecology. While the existence of changing priorities must be recognized, still lower priority uses cannot be neglected over a long run of time, because of the interdependency of various uses.

3.2 General requirements for integrative management

United Nations (UN, 1994) and UNESCO (UNESCO, 1987) through its International Hydrologic Programmes (IHP) in the 70ies of last century tried to gather meteorologists, hydrologists, biologists, social scientists, economists, agrarians, city planners and others to support integrated and holistic approaches. This has enhanced sustainability discussions and development of sustainability indicators especially on global issues. Until today, however, workable regulations to assess sustainability of different management options not exist.

Decisions in water management have to be done on different scales, local i.e. for an individual urban development, regional i.e. for the Shandong coastal area, for river catchments i.e. Huangshui river basin or Yellow river basin, maybe continental i.e. Australia or even global .

Integrated water management recognizes the system complexity. It equally involves local and regional authorities, environmentalists and decision makers, politicians of all parties, governing and in opposition, and especially the people affected. Sustainable water management ensures that no substances are accumulated or energy is lost by recovery and reuse techniques. This is easier said than done for the reasons discussed in chapter 2.

The creation of inter sector links, supporting cross-sector cooperation and integrated multi-disciplinary actions may bridge existing sectarian structures and the new goals for implementation of sustainable water management. Ultimately, sustainable and integrated water management needs novel administrative approaches and holistic education.

In Europe sustainable and integrative principles are included in the European Water Framework Directive (EUWFD), enforced since 2002. However, when applying the European regulations it was found, that conventional procedures for establishing water management plans and even more for selecting measures to implement the plans were not sufficiently taking into account sustainability aspects as requested.

In China on August 29, 2002, during the 27th meeting of ninth people's congress the "water law" was modified, which brought many breakthroughs in water management regulations. The new law is based on the destination of setting up a water saving and waste water prevention society and gave priority to water resources protection and optimization of the compromise between economy, society and ecology. Local governments began to focus on water management and many files were enacted. Currently a tough problem in China is how to overcome the sectarian division of responsibilities and political priorities influencing water management decisions. After all, in Europe like in China the legal background for sustainable water management is provided, but in both cases precise and workable regulations how to proceed with sustainability assessments are lacking.

3.3 Categorization of sustainable water management objectives

The identification of base-level objectives is a very demanding first step within an evaluation system. For a transparent evaluation system which represents all dimensions of sustainability it is necessary to define objectives in respect to one fact or process only and independent to each other. For example,for the environmental dimension the two objectives "minimizing phosphorous discharge" and "minimizing entropic status of lakes" theoretically could be identified. However, phosphorous concentration is the critical parameter for an entropic status of a lake. Therefore these parameters are not independent. If these two parameters would be both used as objectives the entropic status of the lake would be represented in excess within an evaluation. It is a laborious trial-and-error process to define a set of base-level objectives for each individual case, which is comprehensive on the one hand and independent on the other.

The next step is cataloging calculable objectives. To achieve this, indicators must be defined which finally have to be merged somehow for evaluation of sustainability. This suggests a thinking structure staging general, top-level and base-level objectives and related calculable indicators. Chapter 4 will elaborate on indicator systems and evaluation methods in detail.

Same principles as requested for the formulation of top-level objectives apply to indicators for base-level objectives. Neither two or more base-level objectives should be integrated into one indicator nor should more than one indicator be defined for one base-level objective. Otherwise an over- or under-representation of objectives would occur. The question may arise, if finally there should be only one indicator for one dimension permitted.

A problem in all societies is, how to deal with basic needs and with the poor. Social competence must guide new approaches for water supply and sanitation. In mega cities of developing countries infrastructural systems must be designed according to the needs and possibilities of the majority. Universally valid standards may be contra productive in some cases. Public participation prevents social conflicts whereby social development is not self-evident, but must be initiated and guided.

The ability to quantify, in monetary terms, the socio-economic dimension of a water project also does not determine its substance. Analysis should differentiate between price and value in situations where price is a current, transient factor, and not an accurate measure of ultimate value. The conventionally used monetary costs should be supplemented by resource and environmental costs, which consider positive environmental effects as well as environmental damage caused by implementation of environmental measures (UNESCO 1996).

Last not least it should be mentioned that setting objectives and planning by itself will not solve the problems, but helps to identify the most socio-economic compromise to achieve a good status in surface and groundwater. Water management planning is useless, if measures are not implemented and environmental laws are not enforced, i.e. controlling industrial or other emissions and sanction offences. One should think, what Winston Churchill meant, when he said: "At first we form our environment, then it forms us." This may lead to the true objective of water management: "An ounce of precaution is better than a pound of cure."

3.4 Variation of water management objectives in different planning phases

The chapter 3.1 illustrated, that overall objectives change with phases of development of whole societies. In addition one has to realize, that the potential to influence sustainability and thus planning goals are differ in the diverse planning stages(see Table 1).

Table 1 Goals of sustainability evaluation in different planning stages

Planning stage	Goals	Indicators	Comments
Pre-planning	To make the best choice of a system i.e. water supply, storm drainage, waste water treatment, flood protection, surface-groundwater protection	The choice of indicators strongly depends on natural and local conditional as well on stakeholder interests	Here most money can be saved, environment protected best and social concerns considered most. Aside from earlier layouts no data exist
Planning	System choice and environmental. protection ways largely are fixed, only technical solutions in more detail can be evaluated	Indicators may address cost efficiency and affordability for society	Still economic savings and environmental protection maybe optimized . Basic systems layout must exist
Design	The choice of material etc. still can be made	Indicator may address costs, durability etc.	Decided layouts are designed, the cost saving potential is quite small
Implementation	Different construction processes may be sequenced best	Different options can be compared for costs, in water sensitive areas for environ-mental impacts	Savings in any respect are marginal
Operation	Different operations scheme may be compared	Indicators cost and financial burden for the users	Economic saving and environ-mental issues can be influenced, but by far not as much as in the pre-planning phase

Obviously, sustainability can be influenced most in the pre-planning stage. Here most money can be saved and environmental and social concerns can be considered best. In planning and design stages still economic savings and environmental protection maybe optimized to some extend. During implementation savings in any respect become marginal, while during operation economic saving potential and environmental impacts again may be significant, but by far not as large as in the pre-planning phase.

4 Review of indicator systems

4.1 Review of general indicators on sustainable development

Many different indicators for sustainable development were suggested by various institutions in the past decades. Some were transformed into national criteria of sustainable development and eco-city development in China.

Water Poverty Index

Poverty is closely connected to water management. The Water Poverty Index is an integrated index, including five aspects: resource availability, access to water, capacity of people to manage water, use of water, environment. The main purpose of this index is concerned with water resources and related issues of human poverty.

4.2 Indicator systems for sustainability evaluation on river-basin level

4.2.1 Victorian Catchments' Indicators

Victoria located in the Murray-Darling Basin in Australia experienced consecutive droughts of eight years. The local government began to realize that exercised water management is not sustainable (Ayers, 2003). Relying on dams, reservoirs, seizing large quantities of water to secure human life, industrial development and agricultural irrigation and discharging raw wastewater, increasingly caused problems. Thus,local government has proposed a system to guide people to use water in a sustainable way after analyzing situation and history, five principles for water management were advocated: ①A healthy environment is the basis for social and economic development. ②Government departments should be the starting point for the interests of all the people of Victoria, to make efforts to protect all water resources. ③All people have ownership of water utilities. ④All water users must pay in proportion to their enjoyment the entire cost of water services, including investment in infrastructures. ⑤Victoria's water sector is in charge of the whole community water system.

4.2.2 Indicators applied to Yangtze River in China (China water, 2005)

Yangtze River with a length of 6,300 km, is the longest river in China and the third longest in the world. It's total runoff is $1,000\times10^9$ m^3/a. Its basin drains 1,808,500 km^2. The basin supports 36% of China's population and accounts for 40% of food supply, 33% of grain crops, 47% of freshwater products and 40% of GDP (China water, 2005).Due to the huge natural resources, especially the downstream region of Yangtze River Basin observed remarkable development in recent years. Ignorance of sustainability development produced many problems, i.e. deforestation in upstream reaches, provoking big losses of water and soil. The resulting mud silting frequency, floods and droughts in downstream reaches, unsound industrial development causing heavy pollution and subsequent damages on ecology decrease fish resources and increase incidences of schistosomiasis.

Now central government has established a "sustainable development strategy" as key strategy that always should be followed. The healthy Yangtze River indicator system is the first quantified river basin management indicator system in China. There are four levels in this system, general objective level, system level, status level, and factor level.

The general objective is to maintenance the health of Yangtze River and to balance human development and water resources. The system levels are ecological environment protection system, flood control and security system, and water resource development and utilize system. There are five status levels: status of water(soil) resource and water environment, status of the integrated stability of the river, status of aquatic biodiversity, status of flood retention capacity, and status of service capacity.

15 indicators were quantified:

(1)satisfaction degree of ecological water demand in river course.

(2)percentage of water up to par in water function area.

(3)percentage of soil and water loss.

(4)percentage of interdiction on schistosomiasis.

(5)wetland reservation.

(6)maintenance of river status.

(7)fish bio-integrality.

(8)completeness of flood control engineering and no-engineering measures.

(9)development and use of water resource per 10^4 RMB GDP.

(10)safety guarantee of drinking water.

(11)water supply guarantee in towns.

(12)irrigation guarantee.

(13)use of water energy resource.

(14)water depth guarantee for navigation.

(15)living status of rare aquatic animal species, and connectedness of the water system.

4.2.3 Indicators developed for Yellow River in China (Xinhua net, 2004)

Yellow River also spelled Hwang Ho, (Pinyin Huang He, with English Meaning Yellow River), River of China, often called the cradle of Chinese civilization. It is the second longest river of China with 5,464 km and drains the country's third largest basin with an area of 750,000 km^2. The river rises in Tsinghai province on Tibet Plateau and crosses six other provinces and two autonomous regions in its course to the Po Hai (Xinhua net, 2004).

Assessment of the Yellow River condition and research of possible indicators to define the health of the river are ongoing. The general objective is to maintenance life in Yellow River. There may be three pillars in an indicator system, which are: ecological indicators, human health and socio-economic indicators, and physical-chemical indicators.

4.3 Indicators for sustainability evaluation of urban developments

The wide-ranging indicators of chapters 4.2 and 4.3 may be sufficient to assess overall situations and to support government decisions on setting priorities towards sustainable development, but are not very helpful to assist the selection of management alternatives and structural or non-structural measures taken for the many individual developments especially in urban areas. Such indicators must be calculable with a certain precision and have to account for the specific local situation. Some examples are given for costs, water quantity and water quality.

4.3.1 Calculable index to reflect costs

The costs of different scenarios can be evaluated by the "Actual Cash Value" (*ACV*) of a scenario (MUNLV, 2005). The *ACV* of all measures belonging to a scenario is added. This method is used to compare measures with different durations of useful live and different ratios of investment and operational costs. The interest rates for loans and the price increase during the evaluation period are considered. The *ACV* is related to a baseline year, typically the beginning of the operation of the measure. The *ACV* is the monetary value of a measure corresponding to the purchasing power within this year. This value is much less than the sum of all expenses at the end of the evaluation period, because financing costs will not be calculated if the loan is paid out in the base year.

The following example compares two measures with different ratios of investment and operational