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## PREFACE

The Chinese National Committee of IAHS is glad to provide the national report from 2003 to 2006 on hydrological science to the members of IUGG. The main developments in hydrological science contributed by Chinese Scientists in the past four years are included in this report. It involves the following aspects: hydrological cycle and surface water, groundwater, land erosion, snow and ice, water quality, water resources system, application of RS in the management of hydrology and water resources, soil-vegetation-atmosphere system in hydrological process, and application of isotope technique in the management and assessment of hydrology and water resources etc.

This report can be considered as a contribution and authoritative record of the developments about the active fields in 2003-2006. It is available for reference to the scientists and professors engaged in these fields. I would like to express my appreciations to the Chinese National Committee for IUGG for the guidance and supports during my preparing the report, also to the authors, such as YANG Dawen, LIU Zhiyu (Chapter 1), WU Xiaofeng (Chapter 2), WANG Guangqian, FU Xudong (Chapter 3), DING Yongjian, YE Baisheng, LIU Shiyin (Chapter 4), ZHOU Huaidong, LI cong (Chapter 5), WANG Hao, JIA Yangwen (Chapter 6), LU Jingxuan, PAN Shibing (Chapter 7), YANG Dawen, CONG Zhentao (Chapter 8), SONG Xianfang (Chapter 9) particularly to Mr. ZHU Chuanbao and YANG Dawen, for their hard editing job.

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Chairman of Chinese National Committee for IAHS

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# CHAPTER 1 ADVANCES IN RESEARCH ON HYDROLOGICAL CYCLE AND SURFACE WATER

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## 1.1 INTRODUCTION

The researches on water science in China have continued to make new advances since 2003, promoted by the two major causes: (1) Participating in the international cooperative scientific research programmes, such as the International Geosphere and Biosphere Programme (IGBP), World Climate Research Program (WCRP), International Hydrological Program (IHP), Global Energy and Water Balance Experiment (GEWEX) etc. These scientific programmes face the common challenges of the human, such as climate warning, sea-level rising, aggravating hydrological and meteorological disasters and deteriorating ecological habitat etc., aiming at protection of living environment and sustainable development of the human. To develop international cooperation researches, China actively participates in those research activities organized by such international scientific organizations, as IHP, IAHS etc. Many aspects of current international scientific cooperation are involved in these research fields, to which China makes own contributions. (2) Conducting research activities to solve the important challenges encountered in sustainable development of the country, for instance, flood and drought, water resources scarcity and water environmental deterioration etc. This article will describe the progress made in these aspects respectively. The reference materials of the article are mainly from 30 open-publishing domestic and oversea scientific journals involved with the water field, e.g. “Journal of Geographical Sciences”, “Acta Meteorologica Sinica”, “Journal of Hydraulic Engineering”, “Advances in Water Science”, “Journal of Glaciology and Geocryology”, “Journal of Lake Sciences”, “Journal of Natural Resources”, “Advance in Earth Science” etc. The papers published in these journals in the past four years are reviewed. Simultaneously, the important national projects and project research reports of the Natural Scientific Foundation of China in the recent four years, such as “Study on ecological environmental change in the west China”, one of

national key scientific and technological projects during the Tenth National 5-plan, also are referred to. However, we are very regret that some excellent results cannot be introduced into this article due to limitation of the length as well as obtained materials.

## 1.2 STUDY ON HYDROLOGICAL CYCLE

### 1.2.1 *Study on Elements of Hydrological Cycle*

#### 1.2.1.1 *Study on Precipitation*

Some remarkable progresses in the study on precipitation are made in following several aspects in the last four years:

(1) Strengthening the study on macroscopic background of precipitation, i.e., exploring the physical climatic causes of generation and evolution of precipitation. Our meteorologists used the MM5 to simulate or predict the precipitation in some catchments in China, and made some analysis or improvement on the application (Liu et al. 2003, Guo et al. 2003).

Wei et al. (2004) reviewed the importance of applying the radar rainfall measurement to hydrology, analyses the key influence on the results of hydrological prediction and puts forward some proposals to improve its application to hydrology.

Using the method of the nonlinear cross-prediction error and the TBB (the cloud top black body temperature) nonlinear time series of data (GMS-5), Chen et al. computed and analyzed the characteristic of stationarity and nonstationarity of the extraordinary rain-storm in Wuhan. It is consistent with the variation trend of the actual rainfall (Chen et al., 2006).

(2) The inhomogeneous spatial and temporal distribution of precipitation has great influence on basin runoff.

Some study was done on the effects of spatial scale to runoff simulation, showed that using the distributed hydrological model based on the DEM saturation-excess runoff was sensitivity for the rainfall time and spatial variance (Wei et al., 2006).

The space-time variability of precipitation should be fully taken into consideration when the process of basin water cycle is simulated. A spatial interpolation method of daily precipitation in large-scale basin is introduced, according to the method, the reference rain gauges are selected with correlativity (Zhou et al., 2006).

A comparison was made on several spatial rainfall interpolation methods commonly used,



and a new Co2Kriging method was put forward, taking the elevation information as an influencing factor of the second class. It showed that the new Co2Kriging method was obviously superior to the Thiessen polygon method and the reverse distance weighting method (Shi et al. 2005).

The uncertainty in the spatial interpolation of rainfall data caused mainly by the number of stations, temporal scale, cell size of interpolation grid and different interpolation methods was analyzed, and the results indicated the basic way to reduce the uncertainty in rainfall data is to introduce other relative variations with high sample density and to integrate them in present interpolation methods (Zhu et al., 2004).

Considering it is hard to collect the complete long series short duration precipitation data, a model of temporal downscaling of daily rain is presented, and the approach of temporal downscaling of daily rain to acquire short-term rain data in lack-data watershed is studied (Zhou et al., 2005).

### *1.2.1.2 Study on Runoff*

In the aspect of study on the runoff, the great attention was given to the study on the transit curves in the 1960s to 1970s (such as study on Nash's hydrograph etc.) and to the study on hydrological models in the 1980s to middle 1990s. Since the next half of 1990s, studying response of river runoff to climate change, the effect of human activities on runoff and further on water resources, the runoff-generating mechanism in the northwest China, and the application of modern technology to the runoff computation etc is the emphasis during the period. In terms of study on response of river runoff to climate change, the study on possible change of runoff amount under various climate scenarios is mainly developed so as to expatiate the possible effect of climate changes on water resources.

In the last four years, Wang et al. pointed out the natural-artificial two-term evolvement theory of the annal runoff in terms of studying the influence of human activities on runoff generation, and applied the theory in the Wuding River basin (Wang et al. 2004). The effect of different factors on runoff was also studied, for example, Jia et al. studied the water the water budgets and spatial-temporal variations of hydrological cycle components in the Heihe river basin by using the distributed hydrological mode, and pointed out that the forest for water conservation made the runoff outcome from mountains slightly decreased (Jia et al., 2006).

In terms of the relationship of runoff and environment, Wang et al. did some research on the

evaluation method for river s' water requirements of the instream environmental flow: based on the analysis of the relationship among environmental flows of river requirements, the efficiency of water resource utilization and the consumption coefficient, and discharge concentration of waste water, the water quantity and water quality calculation method of environmental flows of river requirements in dualistic water cycle is developed, and the criteria for environmental flows of river requirements are established (Wang et al., 2006).

### *1.2.1.3 Study on Evaporation*

Different methods for evapotranspiration estimation were applied and compared in some basins.

Surface evapotranspiration has obvious spatial variability, but traditional measurement methods are based on point measurements. Remote sensing and the surface energy balance algorithm for land (SEBAL) model were developed to show the spatial variability of surface evapotranspiration. The remote sensing provides extensive surface information. The SEBAL model used the Landsat TM/ETM images as the main data source to calculate regional evapotranspiration. Liu et al. applied RS and SEBAL model to estimate evapotranspiration in arid regions, and improved the model by incorporating parameters for the specific study region. The example showed that the model can be applied extensively, especially in areas where data is scarce (Liu et al., 2004). Zhang et al. summarized and evaluated widely used models that were applied for predicting regional ET using satellite remotely sensed data and routine meteorological data, such as SEBAL and VITT, and showed the great prospect of quantitative ET retrieval with remotely sensed data at large scale (Zhang et al., 2006). In the ungauged Hulun Lake Basin, water evaporation was estimated by Penman-Monteith equation by using daily meteorological records at Manzhouli Station (Li et al., 2006).

Some research was done on the relationship between evaporation and agriculture. For example, Chen et al. analyzed the effects of different rowspaces on the soil evaporation and in winter wheat field (Chen et al., 2005).

Liu et al. estimated the evaporation rate from soil surface using stable isotopic composition of through fall and stream water in a tropical seasonal rain forest in Xishuangbanna, China (Liu et al., 2006).

### *1.2.2 Studies on Hydrological Cycle and Water Balance*

Some research was done on the hydrological cycle in northwest areas in China, and the study of the global hydrological cycle is paid more attention.

Gao et al. analyze the character of water cycle in Inland River in Hexi Region: formation of water resources in mountain areas, scatter and disappear of water resources in plain areas and duality composition in artificial area (Gao et al., 2004).

Gao et al. studied the coupling of enhanced land surface hydrology with atmospheric mesoscale model, and analyzed its implement in Heihe river basin (Gao et al., 2006).

A dynamic hierarchical assessment methodology of water resources is put forward in this paper, that is, according to the effective, controllable and renewable principle of water resources, the resources structure of precipitation is classified in order to realize the hierarchical assessment of water resources including general water resources, special water resources, water resources with runoff form and available water resources. The dualistic water resources assessment model combining distributed hydrological model with physical mechanism and centralized water resources allocation model is used. Furthermore, dynamic assessment of water resources is realized with changed underlying surface condition and water use condition (Wang et al., 2006).

The methods of deviation and accumulated difference and the Kendall's rank verification were used to analyze the observed data of temperature and river runoff in the Hotan oasis in the second half of last century. It showed that the annual average temperature had a clear and gradual trend of increasing, which means it fell into a warming period. The evaporation changed in accordance with temperature. The rainfall varied dramatically from year to year and it distributed concentrative within one year. Some unusual rainfall events happened. The atmosphere humidity changed little, because water vapor would diffuse rapidly to the desert around. The river runoff had a distinct trend of decreasing due to human activity, such as water diversion for irrigation (Shen et al., 2003).

## **1.3 STUDY ON SURFACE WATER**

### *1.3.1 Study on Potamology*

In the last four years, concerning aspects of studying potamology research results are as follows:

Zhou et al study the abnormal characteristics analysis of groundwater temperature field in canyon areas. The groundwater temperature field shows some abnormal phenomena due to special topographic and geomorphic conditions and geologic characteristics in canyon areas. Taking groundwater temperature field in canyon areas at Xiluodu hydroplant as an example, the groundwater temperature field is analyzed systematically through the numerical simulation, the analogy and the regression analysis method (Zhou et al., 2003).

Chen et al do experimental study on development of river pattern in the process of river reformation. The changing of flow condition caused by construction of hydro projects will result in river reformation and development of river pattern downstream of the reservoir. In this paper, the development of river pattern in the process of reformation is studied by means of flume experiment and the influences of river slope, angle between main flow and thalweg, discharge and grain size of river bed material are analyzed according to the experimental data and theory (Chen et al., 2003).

Wang et al study the water & sediment load variation and development at longitudinal & transversal profiles of the lower Yellow River. The study on the drainage system in the North Slope of the eastern Kunlun Mountains indicates that the E-W trending basin-mountain geomorphology was formed after the Kunlun-Yellow River tectonic movement. This tectonic movement established the early stage of drainage system in which the main river developed along the E2W direction valley. Another important tectonic event, Gonghe tectonic movement, occurred between the Middle Pleistocene and Late Pleistocene, caused the N-S Direction Rivers to erode quickly southward and capture the drainage system of early stage, when the framework of present drainage pattern was also formed. Then, there was a relatively stable stage during Late Pleistocene. A sequence of thick and large 2-scale sediments of T5 aged between 52. 4 ka and 18. 4 ka deposited along most of the rivers during this stage. Since 18. 4 ka , the tectonic events in the area have been frequent but with limited intensity. Besides, five terraces were developed after 18. 4 ka. The later terraces were upper-overlapping the fifth terrace and did not cut through the deposits of the fifth terrace (Wang et al., 2003).

In the past 30 years, the lower Yellow River has been watching obvious variation in water and sediment load, which has caused the readjustment of longitudinal & transversal river bed profiles. This article studies the characteristics of the water & sediment load from 1960 to 1997 and the longitudinal & transversal bed profile from 1977 to 2002 by employing statistic analysis (Wang et al., 2006).

### 1.3.2 *Study on Limnology*

#### 1.3.2.1 *Study on lakes*

Study on lakes is mainly on water environment. Yu et al study the evaluation of Oxygen Stable isotope Fractionation among Different Carbonate Minerals in the sediments of Lake Qinghai. Mineralogical examination and stable isotope analyses for the Lake Qinghai sediments indicate that authigenic carbonate minerals are present either in the form of one type or several types in the sediments, and those large differences in  $\delta^{18}\text{O}$  of up to 6.5‰ are shown for selected sediment samples. These  $\delta^{18}\text{O}$  values are highly and positively correlated with total carbonate contents (TCC) and are not affected by shifts in carbonate mineral composition. This indicates that oxygen stable isotope fractionation among co-existing carbonate minerals formed in natural environmental conditions are limited to 0-1‰ in  $\delta^{18}\text{O}$ . The  $\delta^{18}\text{O}$  proved to be a useful environmental proxy for the study of the past changes in P-E budget of closed-basin lakes (Yu et al., 2004).

The water environment has been tending to deterioration since 1990s, which promotes the study on lake water environment. Thereinto, these studies in the aspects of Lake Eutrophication, lake water chemistry, lake water movement and diffusion of pollutants etc have obtained better scientific results (Xie et al., 2004; Song et al., 2005; Wei et al., 2006). The studies on lake pollution, prediction and prevention as well as improvement will be sequentially taken as one of important topics in the field of lakes in China.

#### 1.3.2.2 *Study on marsh*

The highly effective studies have been made in the aspects of ecological diversity in marsh and protection of marshes in China in the last four years and a significant exploration is also conducted in the study aspects of palaeoclimate and disposal of contaminative water in marshes, using these marshes.

Tian et al investigated the ecological environment degradation and degradation mechanism of Napahai Karst Wetland in Southwestern Yunnan Plateau. Based on in-situ technique of locating experiment site, a two-year study on the degradation of Napahai Karst wetland, northwestern Yunnan Plateau was carried out. The results show that there are significantly ecological environment deteriorations that are destroying the wetland. Those deteriorations

include wetland shrinking, type of marsh alternation, aridity and sandification, retrogressive ecological succession, mesophytes and xerophytes instead of helophytes, biodiversity decline, soil subsidence, water quality decline and soil enzymes activities changes. The causes of natural water drainage from limestone geological structure and human interferences like over pasture, wetland reclamation and cultivation are discussed, among which the human interferences are the main driving factor that degrade the ecological environment of Napahai Karst wetland (Tian et al., 2004).

Liang et al study the seasonal variation of Macrophytes Root-zone microorganisms and Purification Effect in the constructed wetland system. Constructed wetland systems are increasingly used to treat domestic sewage, industrial wastewater and agricultural runoff in recent years. The wetland treatment process has been gaining international interests and applications due to its low maintenance and operational cost, and high removal capacity. Because environment has significant effects on the purification ability of constructed wetland systems, it is very necessary to study purification effects of constructed wetland systems in different seasons (Liang et al., 2004).

Xiong et al study the distribute on soil nutrients and correlation analysis in Lake Liangzi wetlands, Hubei Province. The wetlands in Lake Liangzi in the middle reaches of Yangtse River were investigated in autumn, after late rice harvest in 2003. Five typical paddy soils were identified, i.e. submersed, bleached, gleyed and swamp paddy soils. Soil profiles as well as samples from different horizons were collected for measuring organic matter, TN,TP, TK and available N, P,K etc (Xiong et al., 2005).

Liu et al study the primary study on the rule of removing Phosphorus in simulated wetland. The rule of removing phosphorus in small-scale simulated wetland system has been studied. Considering the influence of the environmental factors as dissolved oxygen, pH, etc, we chose not only the aquatic plants, but also rooted emergent macrophyte as the experimental macrophytes. By contrasted four kinds of macrophyte systems, we found out that the absorbency and functionary mode of removing phosphorus by macrophytes are different (Liu et al., 2005).

These studies provide scientific foundation for protecting and utilizing marshes.

### *1.3.3 Study on Glacial Snow Cover and Permafrost*

China is one of the countries where the mountainous glaciers are developed very much. In the recent years, the study on glacial snow cover and permafrost has made new progresses, driven

by the climatic change and the western development.

Concerning aspects of studying glacier and climatic change, the representative research results are as follows:

- (1) Yang et al study the response of the Climate records in the Guliya Ice Core to ENSO events. The period of ENSO is 2~10 a. In the lower and middle latitudes of the world, ENSO event is one of the very important factors for climate variation. Many scientists studied the impact of ENSO events on the climate in China. The studies of ENSO and precipitation variations in semi-arid regions in northern China showed that El Nino events corresponded with the deficit of precipitation in northern China and Southern Oscillation Index (SOI) significantly correlated with precipitation variations (Yang et al., 2003).
- (2) He et al study the modern changes of the climate and glaciers in China's monsoonal temperate-glacier region. Climatic data, ice core records, the tree ring index and recorded glacier variations have been used to reconstruct a history of climatic and glacial changes in the monsoonal temperate-glacier region of southwestern China during the last 400 years. All the results indicate that the temperature in the region increased in a fluctuating manner during the 20th century, after the two cold stages of the Little Ice Age during the 17th-19th centuries, with a corresponding retreat of most of the glaciers against a background of global warming. However, the amount, trend and amplitude of variation of precipitation have differed in different parts of the region (He et al., 2003).
- (3) Wei et al study the changes of glaciers and glacial lakes in the Pumqu Basin on RS and GIS. The glaciers are retreating year after year because of the global warming. As a result, the glacial lake outburst floods (GLOF) become frequent. So that more attention should be paid on them. But the study of glacial lakes with static and isolated means has not satisfied the need to monitor the glacial lake change. The basic data in this paper includes relief maps in 1970s and aster images in 2001 and 2002. The GIS tools are used to digitizing the spatial distribution of the glaciers and glacial lakes during these two periods. The results show that the glacier area decrease 9% and the glacial lake area increase 13%. Then 24 potential risk lakes are identified in Pumqu Basin. The results are vary important to monitor the GLOF and constructing an effective pre-alarm system of the GLOF hazards (Wei et al., 2004).

Zhou et al review the study on land surface process in soil freezing and thawing. Freezing soil is a natural phenomenon in cold and mountain areas, which has great impact on the regional climate, water cycle, and water balance. The land surface process in the condition of soil freezing

and thawing is one of the most important processes in the area. This paper firstly reviews the present study on land surface process in the condition of soil freezing and thawing, especially the development after the hydrological land surface model introduced into the study of General Circulation Model, then introduces the undergoing international research project, such as Project for Inter-comparison of Land-surface Parameterization Schemes and Cold Land Process Field Experiment by NASA, and finally analyses and puts forward the future research field and topics (Zhou et al., 2005).

Implementing the western development strategy will need to construct many works, such as roads, bridges and culverts etc., in the high cold permafrost region of the western China. Many permafrost problems have been raised in foundation treatment of these works and safety operations after completed. Accordingly, these studies on engineering problems of permafrost are promoted, e.g. the investigation and mechanism analysis of the major secondary harmful frozen-soil phenomena along Qinghai-Tibet railway (Yu et al. 2005) is a current representative result.

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# **CHAPTER 2 RESEARCH ON GROUNDWATER EXPLOITATION, UTILIZATION AND ANALYSIS**

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## **2.1 GROUNDWATER EXPLOITATION, UTILIZATION AND PROBLEMS**

The groundwater is not only an important component of water resources but also the major water supply source in many cities and northern country areas of China. It plays an important role in guarantying the people's life, promoting the economy development and improving the environment.

The mean annual amount of groundwater resources in China is 923.5 billion m<sup>3</sup>, in which 883.7 billion m<sup>3</sup> is freshwater, this is about 1/3 of the total amount of water resources in China. The mean annual amount of the fresh groundwater that could be exploited is 352.7 billion m<sup>3</sup>.<sup>[1]</sup>

According to the occurrence of groundwater in subsurface, the groundwater resources in China can be divided into four types: pore water in friable rock, fissured water in bedrock, karst water and suprapermafrost water. Among them, pore water in friable rock plays an important role in the exploitation and utilization of groundwater resources. This part of groundwater is mainly distributed in the plains and the basins; its amount is the largest and is explored and used widely. Fissured water in bedrock is mainly distributed in the fracture zone and weathering zone of bedrock or the pore of clastic rock. It is very difficult to form a concentrated water supply zone except a few developed areas of the bank water structure. Karst water mainly distributes in Karst region, in most of the karst region it is rich of groundwater and generally it's the source of water supply.

Precipitation and surface water are the main recharge sources of groundwater. The distribution of groundwater is very uneven in China. The area of the Yellow River, the Huai River, the Hai River, the Songliao River in north and the Inland occupy 61 percent of the total area of China, however, the annual groundwater resources amount distributed in these areas is only 255.1 billion m<sup>3</sup>, which is about 31 percent of the total groundwater resources amount of China. On the other hand, the area of the Changjiang River, Zhujiang River in south and some rivers in southeast and southwest occupies 39 percent of the total area of China, their annual average groundwater resources amount is 573.7 billion m<sup>3</sup>, which occupies 69 percent of the total annual groundwater resources amount of China.<sup>[2]</sup>

### *2.1.1 Exploitation and Utilization of Groundwater*

Compare to the other water resources, the groundwater has many advantages. Firstly, it has good quality because it is filtrated and cleaned in the unsaturated zone in the process of forming groundwater. Secondly, the investment of groundwater supply engineering is very little but the efficiency is very high.

It has a long history to exploit and use groundwater in China. However, large amount of groundwater exploitation happened in recent years. Before the mid of 1960's, the exploitation of the groundwater is relative little. From the mid of 1960's to the end of 1970's, it is the period of developing and utilizing groundwater in large scale in China. To the end of 1979, the total exploitation amount of groundwater in whole country reached 40 billion m<sup>3</sup>. Since 1980, with the rapid development of national economy and the sharp increasing of water consumption the exploitation amount of groundwater has been up to 102.6 billion m<sup>3</sup> in 2004.<sup>[3]</sup>

According to the statistics, in 2004, the total amount of water supply in whole country is 554.8 billion m<sup>3</sup>, among which 445.5 billion m<sup>3</sup> is from surface water sources, accounting for 82.1 percent of the total amount; while 102.6 billion m<sup>3</sup> is from groundwater sources, accounting for 18.5 percent; and 1.7 billion m<sup>3</sup> is from other water supply sources, accounting for 0.3%. Groundwater is very important water supply source in north part of China. In seven provinces Hebei, Beijing, Shanxi, Henan, Shandong, Liaoning, Neimenggu, the amount of groundwater supply occupies more than 50% of the total water supply amount.<sup>[4]</sup>

Up to now, nearly 400 cities in China develop groundwater as their water supply source. Accounting to the incompletely statistics, more than 60 cities regarded groundwater as their mainly water supply source, such as Shijiazhuang City, Taiyuan City, Hohhot City, Shenyang City, Jinan City, Haikou City, Xi'an City, Xining City, Yichuan City, Urumchi City, Lhasa City and so on. Other cities which regarded the groundwater and surface water as their water supply are as follow: Beijing City, Tianjin City, Dalian City, Harbin City, Nanjing City, Hangzhou City, Nanchang City, Qindao City, Zhengzhou City, Wuhan City, Chengdu City, Guiyang City, Kunming City, Lanzhou City, Changchun City, Shanghai City and so on.

### *2.1.2 Problems in the Process of Developing Groundwater*

The exploitation and utilization of the groundwater contributes a lot to the national economy development and increasing people's life level. On the other hand, because it is not controlled well the serious over exploitation in many regions caused many geological problems such as the groundwater depression continually, seawater intrusion, downward of salt-water interface, subsidence of land surface and desertification, etc. According to the statistics, more than 160 regions have the problem of over exploitation of groundwater up to now in China and the total

area of over exploitation regions is about 180,000km<sup>2</sup>, among which the area of severely over exploitation is up to 80,000km<sup>2</sup> occupies more than 40% of the total over exploitation area.

According to the publication of the administration, there are 24 provinces in China are facing the problem of groundwater over-exploitation, among them Hebei Province is the most serious one, where over-exploitation area has achieved 67,000 km<sup>2</sup>, occupies 90% of its total plain area.

A series environmental and geological problem appeared because of the groundwater over-exploitation, which can be summarized as follows:

(a) Regional groundwater depression continually.

Because of the over-exploitation of the groundwater continually and with high intensity in some regions, the groundwater resources can't be recharged in time and the depression cones have been enlarged, which even leads to the draining of the aquifers, the reduction of the water yield in a single well or discard of the wells and the depletion of the water resources. For instance, in Xi'an City of Shanxi province, because of the over exploitation of groundwater for a long time, the depression cone has been enlarged every year. [5]

(b) Subsidence of land surface

The over-exploitation of the groundwater not only cause the water level declined, but also lead to land surface subsidence in some areas mainly with the deep groundwater exploitation. Yangtze River Delta, North China Plane and Fenhe-Weihe Down-Faulted Basin Belt is three biggest areas of the subsidence of land surface in China. Subsidence of land surface has been a critical obstacle which slowed economic growth in these areas; the main inducement is over exploitation of ground water. [6]

(c) Seawater Intrusion

Seawater intrusion is mainly occurred in the coastal regions of China. The reason is that after the large scale exploitation of the groundwater, arisen the seawater circumfluence. The relatively severe areas are Dalian City in Liaoning Province, Qinghuangdao City in Hebei Province, Qingdao City in Shangdong Province and some other areas.

(d) Ground collapse

The over-exploitation of the groundwater in bed rock region (mainly in Karst area) will lead to some bad geological phenomena such as ground collapse, fissure and so on. Ground collapse is occurred widely in China, in the southern China, the occurring rate is higher than the north because of the distribution of karst water.

(e) Pollution of Groundwater

Over-exploitation of the groundwater not only quickened the infiltration of surface water but

also the pollutant in the surface water, which enhanced the groundwater contamination. Once the groundwater is been contaminated, it is very difficult to recover. Now the groundwater resources is polluted very severely in many cities. According to the statistics, there are more than 130 big and middle cities whose groundwater has been polluted in different degree and the main pollution source is industry and living pollution. The groundwater in local agricultural region is also been polluted, which is mainly caused by the sewage irrigation Up to now, there are over 20 million mu farms irrigated by sewage water, and this leads to the pollution of groundwater directly. Also in agricultural area, the groundwater is been threatened by the pollutants like the pesticide, the fertilizer etc..

(f) Soil desertification

The continuous decline of groundwater level will lead to the degeneration of vegetation and destroy the eco-environment, which is one reason of soil desertification. This phenomenon has occurred in Inner Mongolia, northwest of China and some parts of Heibei Province.

## **2.2 MONITORING AND MANAGEMENT OF GROUNDWATER**

### *2.2.1 Groundwater Monitoring*

The groundwater dynamic monitoring began from the 1960's in the departments of Ministry of Water Resources. After several years' hard work, a groundwater monitoring network with a certain scale which provides the evidence for water resources management and reasonable development and utilization of groundwater had been set up. The Monitoring items include groundwater level, water amount, water quality and water temperature and so on, which could collect, transmit store and analysis data at one time. Because of the promptitude, veracity, and scientificity, the Monitoring items have been used in several aspects instead of manual observation.<sup>[7]</sup>

A kind of new-type groundwater monitoring system has been developed to carry out the demand of remote observation of groundwater. The technique is based on PLC&GSM short message data transmission.<sup>[8]</sup>

But the work of groundwater monitor is still weak and it's difficult to meet the demand of water resources management and regulation. Many problems are still existed including the sparse density of observation wells, lack of monitoring wells in the funnel area and important

water sources, the old monitoring equipments, the laggard observation and transmission method which can't ensure the information will be transmitted in time and insufficient fund for groundwater monitor.

Because basins in China have special water resources characteristic, and based on scarcity and pollution actuality of water resources in many basins, researching and developing a real-time monitoring and management system is necessary. The system includes several aspects, such as rectification and improvement of current groundwater monitoring stations, modulation and examination of reservoir operational rules and technical parameters, regulation of flood resources and recharge of groundwater artificial, waste water treatment and eco-environmental water demand, unified operation of flood control and useful storage, monitoring and management of surface water and groundwater and the benefit, risk and standardization after the real-time monitoring and management project bring into effect.<sup>[9]</sup>

### *2.2.2 Management of Groundwater*

One side, water resources is seriously short in China and the over exploitation of groundwater leads to many environmental and geological disasters. On the other side, wasting of the water resources is very severe. Irrigation is the main water consumer, which occupies 70% of the total water consumption in China. Because the irrigation technology is out of date, most of the channels are soil channels and the facilities are very old, the traditional irrigation technology is used in most of the agricultural areas. In some irrigation areas farmers even still use the flooding irrigation method, which waste water very seriously. The utilization rate of industrial water consumption is not high either. The water loss through the water transportation pipe and water facilities has reached over 20 percent.

In order to develop and utilize groundwater more reasonably, reduce the water waste, optimize the distribution of water resources and improve the water utilization rate, in recent years a lot of work has been done on the groundwater planning and strengthening the legalization of groundwater management, which is useful for restricting the groundwater over exploitation.

Tianjin city integrated applied ArcGIS technique, Database technique, Model of water quality evaluation technique to develop its Groundwater environment quality evaluation system. The system has several functions, such as management and analysis of groundwater quality data and GIS data, integrated evaluation of groundwater quality and so on. This system can easily grip situation of dynamic pollution, special distribution, evolution tendency of groundwater.<sup>[10]</sup>

GIS technology and its application is the main focus in the development of water resources subject. Most of the developed countries have use this technique to manage their groundwater, and have got a lot of experience.<sup>[11]</sup> A groundwater resources management information system base on GIS technology has been developed.<sup>[12]</sup> The tendency and direction of groundwater



management model is founded multi-purpose dynamic planning model for groundwater management. While, it needs advanced intelligent optimization approach to solute the problem. [13]

Water Resources Demonstration & Management Rules of the Construction Project shows us for the new, rebuilding or expand construction projects that takes water from the rivers, lakes and underground directly, the owner of the construction projects must apply the water license, and should carry out the water resources demonstration and compile the report.

Besides the technical measures, administration management is also important to control the scarcity situation of groundwater. Reinforce the management and supervision of groundwater is imperative under the situation. [14]

## **2.3 RESEARCH ON GROUNDWATER ANALYSIS**

Strengthen the research on groundwater analysis is the basis of the scientific management of groundwater. Resent years a lot of work has been conducted on groundwater analysis, some details are given as follows:

### *2.3.1 Assessment of Groundwater*

The first national water resourcess assessment was carried out at the beginning of 1980's. During this period first national groundwater assessment were carried out, thid report provided important evidences for groundwater planning and management. But in the past 20 years, both of surface water and groundwater varied greatly because of human activities. Thus it is necessary to conduct the national water resources assessment again.

The Domenico model is used in combination with ASTM E 1739 in a Tier 2 risk assessment of chlorinated organic solvents contaminated groundwater sites to predict potential contaminant concentration in groundwater down-gradient from the point of exposure (POE). Knowledge of the dispersivity parameters is necessary for carrying out this calculation. A constant longitudinal dispersivity of 10 m is often used in analytical and numerical calculation. However, because of the scale effect of dispersion, two other main approaches are currently often used. From the viewpoint of conservative principle in risk assessment, it is necessary to determine which dispersivity data will give a higher predicted concentration, corresponding to a more conservative risk calculation. Generally, it is considered that a smaller dispersivity leads to a higher predicted concentration. This assumption is correct when dispersion is the only natural attenuation factor. However, degradation of commonly encountered chlorinated organic solvents in environment under natural condition has been widely reported. Calculations given in this paper of several

representative cases show that a general consideration of the influence of dispersivity on concentration prediction is not always correct when a degradation term is included in the calculation. To give a conservative risk calculation, the scale effect of dispersion is considered. Calculations also show that the dispersivity parameters need to be determined by considering the POE distance from the source, the groundwater velocity, and the degradation rate of the contaminant. <sup>[15]</sup>

### *2.3.2 Prediction of Groundwater Dynamic Analysis*

Many institutes and experts did a lot of work on the prediction of groundwater analysis. The prediction of groundwater level is important for the utilization and management of groundwater resources. At present there are many ways to do the dynamic prediction of groundwater level. The main method is to set up a model of groundwater movement and simulate the process of groundwater movement and predict the state. One groundwater dynamic prediction model is based on inversion models and self-memory formulation. Examples show that, this model is effective, and it also has satisfactory accuracy rate. <sup>[16][17]</sup> Another model use principle factor time as main factor of prediction model, and river course's replenishment and precipitation as modifying factors, which makes the physics model easy to understand, problem easy to solve. <sup>[18]</sup> A new model of groundwater table simulation is developed using the mass-lumped finite element method and is coupled with the land surface model of Variable Infiltration Capacity (VIC). The simulation results show that the new model not only can simulate the groundwater table dynamically, but also can evade the choice of water table depth scale in computation with a low computation cost. <sup>[19]</sup>

According to the research of prediction models, there are two way to increase the reliability and accuracy of prediction of groundwater dynamic analysis. One way is to found affirmatory stochastic coupled model, which could describe both inner characteristic and outer characteristic; the other is to found groundwater system's FBSDE model, and make the inner factor of the system as random variables, while it's outer circumstance factor is also be treat as random time series to solve fixed solution problems, and the solution is showed as probability distribution. <sup>[20]</sup>

### *2.3.3 Analysis and assessment of groundwater pollution*

In China groundwater pollution is quickly increasing every year because of the surface water pollution, irrigation with sewage water, unreasonable utilization of groundwater, leakage of harzadous substances from industrial factories and so on. Groundwater pollution has the characteristics of point, line and side distribution. The point pollution indicates the local severe pollution around the city and town or the farm because of the concentrated population, developed industry and feedlot with middle or large scale in rural areas. The line pollution indicates the groundwater pollution around the river caused by river pollution. The side pollution means the

irrigation with sewage water and the pollution of misusing fertilizer and pesticide in agriculture.

In recent years, we strengthened the work of water quality monitor and assessment in departments of water resources and achieved many analysis and assessment results. One of the difficulties frequently encountered in water quality assessment is that there are many factors and they cannot be assessed according to one factor, all the effect factors associated with water quality must be used. In order to overcome this issues the projection pursuit principle is introduced into water quality assessment, and projection pursuit cluster(PPC) model is developed in this study. The PPC model makes the transition from high dimension to one-dimension. In other words, based on the PPC model, multifactor problem can be converted to one factor problem. The application of PPC model can be divided into four parts: (1) to estimate projection index function ; (2) to find the right projection direction; (3) to calculate projection characteristic value of the sample , and (4) to draw comprehensive analysis on the basis of . On the other hand, the empirical formula of cutoff radius is developed, which is benefit for the model to be used in practice. Finally, a case study of water quality assessment is proposed in this paper. The results showed that the PPC model is reasonable, and it is more objective and less subjective in water quality assessment. It is a new method for multivariate problem comprehensive analysis.<sup>[21]</sup>

In 2005 according to analysis of groundwater quality done by Ministry of Land Resources in 158 cities and areas of China, it is concluded that totally groundwater quality in China is good, but in most of the cities the groundwater is suffering point and nonpoint pollution threaten, which results in exceeding standard of some elements in local regions. The main polluting elements are the degree of mineralization, the total degree of hardness, sulphate, nitrate, nitrite, ammonia, nitrogen, chlorid, fluorid, Ph value, iron and manganese, etc. Regarding on the pollution degree, generally, the pollution in northern cities is much higher than those southern cities.

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# CHAPTER 3 STUDY PROGRESS ON LAND EROSION

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In china, soil erosion is not only one of the most serious environmental problems, but also a natural process with complex mechanism. The soil erosion has multiple consequences : 1) Within the source area, soil resource and fertility will be washed away, which influences agricultural production and the ecosystem greatly; 2) In the downstream river channel, the sediment produced by erosion will accumulate on the river bed, which increases the frequency of flood. As a result, the safety of cities and countries will be threatened. It was reported that total soil erosion in china is estimated to be 50 billion tons per year. Classified by the climate zonation and erosion conformation, soil erosion can be divided into four categories: water erosion, wind erosion, freeze-thaw erosion and gravitational erosion. All of these erosions are distributed widely in different regions of china. Under these circumstances, for many years scientists in china have been studying the soil erosion intensively using different methods and approaches. Lots of research works have achieved important and valuable results. A brief summary of the research works on land erosion is presented as follow to shed some light on the future research projects.

## 3.1 POLICY BACKGROUND ON EROSION RESEARCH

Both the Chinese central government and the government departments always put emphasis on water and soil conservation. As early as in 1991, china has promulgated the law for water and soil conservation. This document pledges the conservation activities and the legal obligation for prevention, recovery and supervision on soil erosion. In the past four years, government departments have published several policies further supporting and strengthening of the erosion research. In 2003, the minister of the Ministry of Water Resources of P.R.C, Mr. Wang Shu-cheng ranked the check dam as the “bright point” project in recent years, and as a good start, much more investments will be put into this field to promote systematic research on optimization and stability of dam systems. With some key problems resolved, the construction of check dam systems will step into an advanced level. In 2004, the director of Yellow River Conservancy

Commission, Mr. Li Guoying revealed theoretic framework named “1493” for the first time, i.e., one ultimate target, four main indications, nine approaches and “Three yellow rivers”. “Three yellow rivers” consists of “Prototype yellow river”, “Model yellow river” and “Digital yellow river”. These three yellow rivers indicate three different measurements, which are prototype measurement, digital simulation and model experiment. The “three yellow rivers” cover nearly all aspects of the research works which may simulate and predict the activities of the yellow river more fully and accurately. Two new concepts, “Model loess plateau” and “Digital loess plateau” which are originated from the framework, will provide powerful means to support for the reformation of land erosion in loess plateau in particular and the water and soil conservation in general. In august, 2006, with the suggestion put forward by some academicians who are members of an inspection team of soil and water loss and environmental safety of china, the project named “Study on process of soil erosion and erosion control” is officially added to the “Plan 973”. This government policy will facilitate the critical projects of conservation and soil erosion researches greatly.

## 3.2 STUDY PROGRESS ON REGULARITY OF SOIL EROSION

The intention of research on the erosion regularity is to discover the qualitative or semi-quantitative relationship between external phenomenon and its internal influencing factors of the erosion processes. The basic approaches of regularity research are field data analysis and laboratory simulation. The results of this kind of research are always diagrams, simplex formulas which just indicate the regularity in a certain aspect. Although regularity research itself can not be applied directly to forecast the land erosion processes in river basin, the regularity discovered can provide proper directivity and verification data for further model construction.

### *3.2.1 Study on macroscopical regularity of Soil Erosion*

#### *3.2.1.1 Relationship between soil erosion and hyper-concentrated flow*

Wang and Qian have studied this regularity as early as in 1980's. By analyzing the data from runoff plot on sloping land in Tuan Shangou and Duan Chuan station, they found that hyper-concentrated flow can be observed in every erosion processes including splash erosion, flow erosion, gravitational erosion and channel erosion, at the same time, they also found that the fact the frequency which sediment concentration peak late than the flood peak goes from 13% on

slope area to 41.7% on gully area denote the gravitational erosion to be the most important sediment source for hyper-concentrated flow. Based on this research, Xu Jiongxin analyzed the relativity between measured sediment concentration and discharge which covers nearly all recorded flood in 1966 in Du Jiagou. He found out the frequency with which the sediment concentration peak late than the flood peak goes from 10% to 87% with the study area goes from sloping area to whole basin, and this fact shows clearly that with the dimension become larger, the influence by the gravitational erosion will become much more remarkable.

### *3.2.1.2 Scale effect and spatiotemporal variability of soil erosion*

From some kind of significance, soil erosion is a problem of geomorphology with multiple hierarchies and scales. Although in a certain circumstance soil erosion is produced by certain microcosmic mechanics, the integral regularity of erosion is produced by series of nonlinear actions in different hierarchies. As a result, the characteristic parameters for erosion in different hierarchies should be reconsidered.

Wang and Li analyzed the suitable degree between the influencing factors (rainfall, vegetation, soil and topographic) and their spatio-temporal scales. They found that some certain factors show quite sensitive to scales. i.e., Degree of slope is a main factor when the research scale is land slope, however, when the scale becomes larger, especially the whole basin, the effect this factor has greatly been weakened, so, we have to find some new factors to characterize erosion action at basin scale. Liu discussed the dynamic processes of runoff and erosion under different scales. The result shows that, with the scale increasing, the process of sediment concentration will be more skewed and last longer, at the same time, the discharge which causes the amplitude of sediment concentration lower increases with the scale. Zhang clarified the meaning of erosion modulus and its calculating method under different scales, and deduced six expressions of erosion modulus for different scales. Qiu calculated the erosion distribution of Nan Xiaogou basin for five different scales using LISEM model. The result shows that optimizing of the land use will increase the spatial variability of soil erosion, and the increasing variability will help to disperse the dangerous of erosion.

### *3.2.1.3 Influence on Erosion by Human Being Activities*

Human activities in modern society accelerate the process of erosion greatly. The influences include the mode of land use and the damage done to the ground vegetation by human agricultural production. Therefore, it becomes more important to study on the relationship

between production mode and soil erosion for establishing the sustainable development.

Wang collected the data of land use and soil erosion from Landsat TM Images by expert's interpretation for five years, then they built the digital environmental model and the relationship between land use and soil erosion were analyzed for recent five years. The result shows that the soil erosion is affected by the different land use ways, and the irrational land use will accelerate soil erosion. So the rational land use ways and optimized land use structure are significantly important for regional sustainable development.

Wang defined a new concept named vegetation dynamics which is a new interdisciplinary science, studying the law of evolution of watershed vegetation under the action of various kinds of ecological stresses, especially soil erosion. They found that the ecological stresses impacting the vegetation are: (1) natural stresses, such as the erosion storm. Eruption of volcano and the damages by animals as well pests and diseases; (2) human stresses, such as air pollution, grazing, logging, reclamation, mining and road construction. According this concept, they built a vegetation dynamics model and apply it to Xiaojiang basin on Yunnan plateau of south China. The results demonstrate that the vegetation-erosion dynamics is a powerful tool for prediction of the vegetation and soil erosion evolution. In addition, Li, Yu, Chen discussed respectively about the statistical relationship between vegetation and soil erosion by data from vegetation experiment and field collections.

### 3.2.2 *Laboratory simulation on Soil Erosion*

Because of the complexity of the mechanism of soil erosion, much more experiments are needed to discover the regularity. Laboratory simulation has two functions. The one is to summarize some laws which are helpful for the determination of the structure, parameters and tendency for erosion model. Another is the simulation result can always serves as verification data for the model.

Chen designed a series of miniature rills to analyze the dynamic process of rill. The result shows some tendency of the dynamic performance in the process, and there is also high randomness in it. Some empirical relations between the rill width or wet perimeter and discharge and slope are presented as follow:

$$B = 0.596Q^{0.316} S_0^{-0.23} \quad (1)$$

$$p = 1.512Q^{0.371} S_0^{-0.245} \quad (2)$$



Where:  $B$  is the rill width (m), and  $p$  is the wet perimeter (m). Correlation coefficient for (1) is 0.674, for (2) is 0.9011.

In order to conduct similarity experiment to utilize efficiently the results on small watershed of the loess plateau in China. Gao established a design means and experimentation technology based on similarity theory and hydrodynamic principles of rainfall, runoff and infiltration. The verifying experiment results indicated that the movements of rainfall, flow, production sediment and bed deformation agreed with the practical situation in Kangjiagou small watershed of the loess plateau of China. It can be used to control soil erosion, schedule farm operations and utilize water and soil resource effectively.

Zheng established an experiment with various combinations of rainfall intensities and slopes. They found that the flow pattern is always torrent turbulent on the steep slope. The relation between Reynolds number  $Re$  and resistance coefficient  $f$  is power function and both of them go with slope following parabolic equation, at the same time, the relation between Froude number  $Fr$  and resistance coefficient  $f$  is negative power function.

Sun simulated the soil erosion in laboratory with various combinations of rainfall intensities and slope lengths. The result indicated that the general regularity is the erosion increases along the slope, however, under different rainfall intensities, some exception appeared. e.g. when the rainfall intensity remains weak, erosion in 5~7 meter section increase fast, but when rainfall intensity become larger, the particular section will move to the upper direction.

In addition, Wu used a dual-box system to quantify effect of up-slope runoff and sediment on down-slope ephemeral gully erosion process under different sediment concentrations from up-slope runoff and rainfall intensities. Zhang established an experimental method for dam system in gully area of loess plateau based on the analysis of the characteristic of model experiment on erosion.

### 3.3 STUDY PROGRESS ON SOIL EROSION MODEL

The model for soil erosion and sediment yield is an effective tool to simulate the dynamics of flow and sediment in watershed. It uses theory from hydraulic and fluvial dynamics etc. to establish systematic method for fully simulating and prediction.

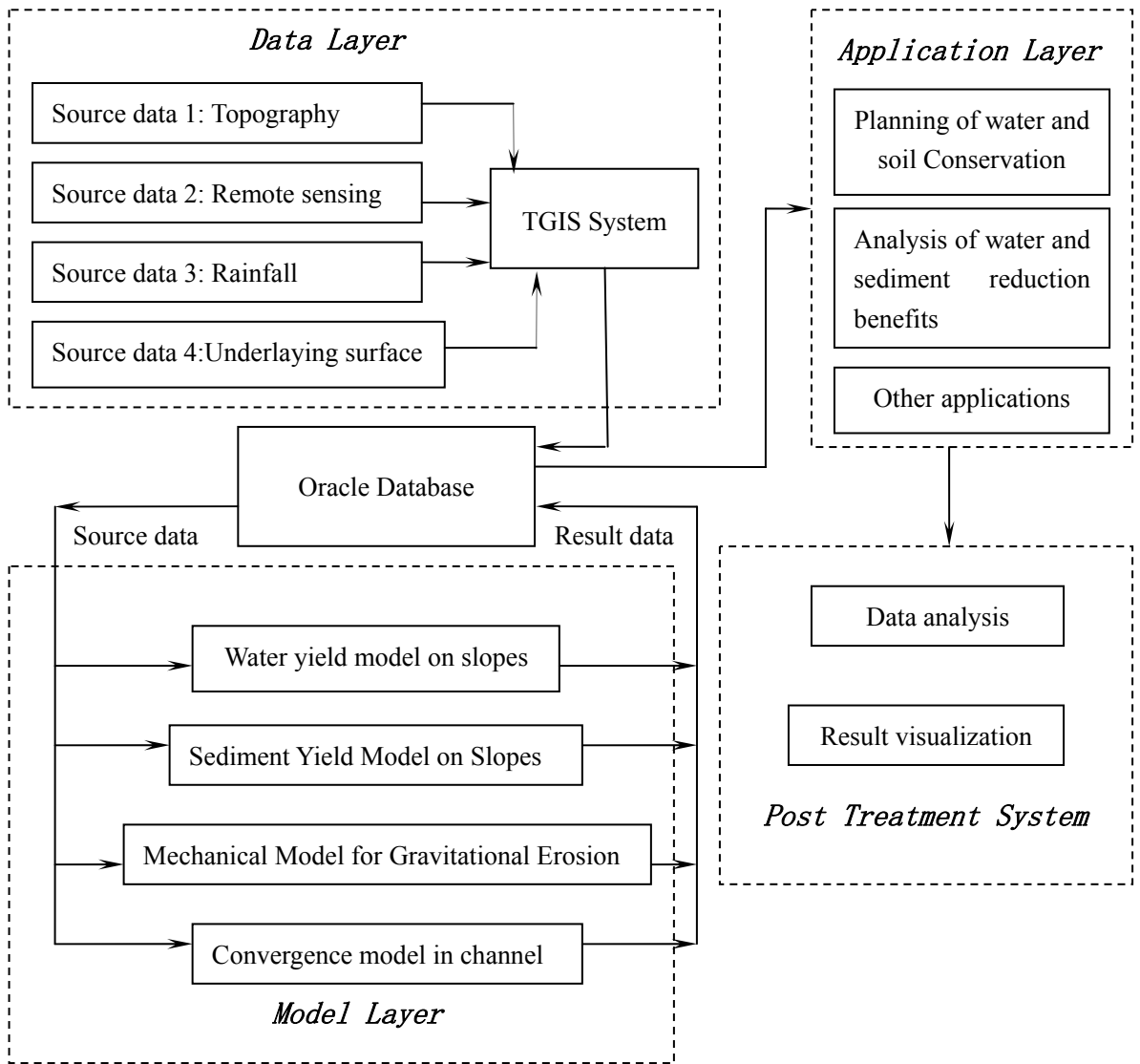
From 1980s on, some statistical models constructed from measured data emerge. These models make the best of information implied in measured data and are competent for general use. However, with the development of computer technique and the increasing demand for more

accurate simulation, the physically-based models which have the ability to simulate the temporal and spatial distribution of erosion become the main direction of research.

Qi divided watershed into multiple continuous grids and saved the information of natural factor and human activity influence into the grids. The next step is to solve the dispersed equation on each grid. The simulation result shows that the calculating data agrees well with the measured one, and the temporal and spatial distribution of the erosion can be simulated quite well for each grid cell.

Wang developed an integral model named digital watershed model which is based on digital elevation model and the classification theory of drainage network. The model structure is shown as Fig 1. It has four kinds of module, which are slope module, sub-basin module, region module and entire basin module. Several special models are built on the digital platform, including sediment yield model on slope and Mechanical Model for Gravitational Erosion in Gully Area. By simulating on watershed in different scales such as Chabagou watershed and areas with high and coarse sediment yield, the result shows that the model can give the temporal and spatial distribution and the nonlinear action of the erosion.

Jia established a distributed water erosion prediction model for small watershed in loess plateau based on the grid digital elevation model. The model is composed of hydrological component and erosion component. The erosion component includes the splash detachment, detachment rate formed by interrill flow, rill flow, ephemeral gully flow and channel flow, and the calculation of sediment yield is realized according to the principle of dynamic balance of mass. The simulation result of single rainfall event with rainfall intensity higher than medium grade shows that the accuracy of the prediction is acceptable.



**Figure 1.** Integral Structure of Digital Watershed Model

### 3.4 APPLICATION OF ADVANCED TECHNIQUE AND INTERDISCIPLINE ON EROSION RESEARCH

In recent years, some scholars introduced the advanced technique and newest research productions from other field into the study of erosion. The introduction not only broadens the eyereach for erosion research, but also obtains much information which is too difficult to get by

conventional methods.

Various radionuclides and magnetic tracing method have been tried in field of erosion measurement. Wei presented the fundamentals of the technique of cesium -137 tracing and summarized its advantages and limitations. Two key problems of  $^{137}\text{Cs}$  technique, namely acquiring the reference value  $^{137}\text{Cs}$  fallout in research area and selecting the quantitative model about the amount of  $^{137}\text{Cs}$  lost from the erosion site and soil erosion rate, were discussed. Based on the data of 39 soil profiles in different areas of red soil, Pu analyzed the relationship between  $^{137}\text{Cs}$  content and the composition of soil particles using statistical methods. The result showed that  $^{137}\text{Cs}$  had a positive correlation with sand and silt contents, and had a negative correlation with gravel and clay contents within 20 cm of the soil surface. They also found that in different layers, sand content was the main factor contributing to  $^{137}\text{Cs}$ . The quantitative model for the relationship between  $^{137}\text{Cs}$  and the composition of soil particles was constructed.

Due to the complexity and nonlinear characteristic of soil erosion, some scientists begin to study soil erosion by using the theory of nonlinear. Zhao built a three-layer feed-forward back-propagation network model for slope soil erosion in different tillage measures. The structure of the model has five input variables including rainfall intensity, gradient, length of slope, percentage of prophase soil moisture content and soil volume weight and one output variable for the sediment yield of secondary rainfall of slope soil erosion. The network model was trained and predicted by using the observed data of the field simulated rainfall experiment. The result shows that back-propagation network model is reasonable and can be referred as an effective method for studying slope soil erosion laws. Based on fractal theory and the general model of small watershed, Cui studied the quantitative coupling relationship between topographic fractal feature and sediment yield by simulation rainfall experiment, high precise photogrammetry and GIS technology. The result shows that during the different phase, the variation trend of fractal information dimension ( $D_i$ ) of watershed model topographic feature was similar to that of relative sediment transport rate ( $S_r$ ) of watershed model and their relationship presented positive correlation with power function. Therefore, the parameter  $D_i$  can be as the integrated index of quantifying topographic feature for soil erosion and sediment yield prediction of watershed model.

The study on soil erosion is a systematic project, which consists of theoretical analysis, field survey, laboratory experiment, model construction. Further more, the support by policy and laws is also important for erosion research. The success China achieved on erosion research is obvious

to all and the achievement will also lay stable foundation of soil erosion research.

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## CHAPTER 4 PROGRESS IN STUDIES OF SNOW AND ICE

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### 4.1 GLACIERS AND THEIR FLUCTUATION

After 24-year work from 1979, a 12-volume (22 issues) Chinese Glacier Inventory (Tab.1) has recently been finished by a group of Chinese glaciologists headed by Prof. Shi Yafeng from the Cold and Arid Regions Environmental and Engineering Research Institute under CAS.

The Chinese Glacier Inventory is surveyed and edited according to the Manual of Information Editing on World Permanent Ice Bodies (*Müller, 1977*) which is suggested by the Temporary Technical Secretariat (TTS) of international glacier inventory. The 2,699-page catalogue, containing more than 40 parameters (such as geographic location, area, orientation, elevation, and classification of morphological types) for glaciers throughout the country, is the result of a series of field surveys over 24 years with the help of more than 2,000 aerial maps, 342,000 aero-photographic pictures, and 200 satellite-relayed images. The survey reveals, for the first time in the history of similar studies, some fundamental data in this regard, including the precise numbers of glaciers in China. Furthermore, Concise Chinese Glacier Inventory (in Chinese and English) (*Shi et al., 2006; 2007*) summered main glacier statistical characteristics over China and some application results. Also the glacier information system databases is set up ([http://wcdcdgg.westgis.ac.cn/chinese/DATABASE/Glacier/glacier\\_inventory.htm](http://wcdcdgg.westgis.ac.cn/chinese/DATABASE/Glacier/glacier_inventory.htm)) (*Wu et al., 2004*)

**Tab. 1 Volumes and issues in the *Chinese Glacier Inventory***

Volume Title	Issue Title	Publishing Year	Authors
I Qilian Shan Region	Qilian Shan Region	1981	Wang Zongtai and Liu Chaohai, et al.
II Altai Mountains Region	Altay Shan Region	1982	Liu Chaohai et al.
III Tianshan Mountains	Eastern Interior River area with dispersed streams	1986	Wang Yinsheng and Liu Chaohai et al.



	Northwestern Zunggar interior River area	1986	Lai Zuming and Liu Chaohai et al.
	Southwestern Tarim inflow area	1987	Xie Weirong and Ding Liangfu et al.
	Ili river watershed	1987	Ding Liangfu and Xie Weirong et al.
IV Pamir Mountains	Pamir Mountains	1988	Luo Xiangrui and Mi Desheng et al.
	Kaxgar river watershed (revised edition)	2001	Liu Chaohai and Wang Zongtai et al.
V Kalakunlun Mountains	Drainage Basin of the Yarkant River	1989	Yang Hui'an and An Ruizhen
VI Kunlun Mountains	Drainage Area of Southern Qaidam Basin and Upper Reaches of Yellow River	1992	
	Interior Drainage Area of Hotan River	1992	
	Interior Drainage Area of Karamiran-Keriya River	1994	
	Interior Drainage Area of the Miran-Qarqan River	1994	
VII Interior Drainage Area of Qiangzang Plateau	Drainage Basins of the Ayakkum Lake and Hoh	1988	Jiao Keqin and Zhang Zhenshuan
	Drainage Basins of the Bangong Lake	1988	
	Drainage Basins of the Dogaioing and Yibuchaka Lakes	1988	
	Drainage Basins of The Siling Lake	1988	
	Drainage Basins of the Zharinam Lake	1988	
VIII The Changjiang River Drainage Basin	The Changjiang River Drainage Basin	1994	Pu Jianchen
IX The Lanangjiang River Drainage Basin	The Lanangjiang River	2001	
X The Nujiang River Drainage Basin	The Nujiang River	2001	

XI The Ganga Drainage Basin	The Nujiang River	2002	Mi Desheng and Xie Zichu
XII The Indus River Drainage Basin	The Indus River Drainage Basin	2002	Mi Desheng and Xie Zichu et.

The state project on the second Chinese glacier inventory has been started in 2006 because the glacier has changed rapidly in past decade due to climate warming and the first Chinese glacier inventory is mainly based on 1960-1970s aerial maps and aero-photographic pictures.

#### 4.1.1 *Glacier Resources*

The inventory for the first time accurately investigated the exact number of glaciers by river tributaries, mountains and administrative areas across the nation, providing basic information and scientific ground for reasonable utilization of water resources and carrying out global change researches. It shows there are a total of 46,377 glaciers throughout the country, covering a total of 59,425km<sup>2</sup> with 5,600 km<sup>3</sup> in ice storage, distributed in Xinjiang, Qinghai, Gansu, Sichuan, Yunnan and Tibet.

The scientists have discovered there are 33 glaciers with an area larger than 100 km<sup>2</sup>, including the largest valley glacier, Insukati, that covers 392.4 km<sup>2</sup>, the largest ice field, Puruogangri, totaling 423 km<sup>2</sup> in area and the largest ice cap, Chongce, covering 163 km<sup>2</sup> over China. In addition, the inventory records 34,700 small glaciers with less than 1 km<sup>2</sup> in area. They are vulnerable and sensitive to climatic changes and act as natural “barometers” for monitoring the ups and downs in water resources and weather forecasting in various localities.

The compilation of the inventory is of great significance for understanding glacier resources both in China and in the world.

Based on glacier inventory data, the melting water runoff of the glaciers on West China has been estimated. The estimated result indicated that the average melting water runoffs of the glaciers is about 61.6 km<sup>3</sup> per year (1 037mm). There are 36 km<sup>3</sup> (58.4%) in exterior river basins and 25.6 km<sup>3</sup> (42.6%) in interior river basins. However, the contribution from the melting water runoffs to river runoff is higher in interior rivers than in exterior rivers. The mean contribution in interior rivers is 24.3%, and can reach as high as 80% in some rivers like Muzate River in Tarim Basin.

#### 4.1.2 Glacier Changes since the Little Ice Age (LIA)

The “Little Ice Age” (LIA) is a period of three cold phases during the 15th -19th centuries, when glaciers advanced and formed about three fresh end moraines. The extent of the LIA glaciers can be determined based on the fresh end moraine using aerial photography in combination with 1:50,000/1:100,000 scale topographical maps. The extent of the LIA glaciers includes their glacier area, length and terminus altitude. Ice volume during the LIA can be estimated from the statistical relationship between the volume and area of model glaciers.

There are series of studies of glacier change since the LIA maximum began in the 1980s. These surveys concerned in over 800 glaciers in the Qilian Mountains, Tianshan Mountains, Altay Mountains, Kunlun Mountains and the interior of the Qinghai-Tibetan Plateau (*Wang Zongtai*, 1992), more than 1000 glaciers in southeast Tibet (*Su and Shi*, 2002), also in the eastern Tanggula Range, A’nyêmagên Range at the source of the Yellow River, Qilian Mountains, and Geladaindong area at the source of the Yangtze River (*Wang and Ding*, 2002; *Liu Shiyin et al.*, 2002; 2003; *Lu Anxin et al.*, 2002; *Pu et al.*, 2004).

The glacier changes between 1950s-80s and LIA over China have been summarized based on the above-mentioned result with additional 844 recently measured glaciers in the middle and western Himalayas and inner Qinghai-Tibetan Plateau (*Shi and et al.*, 2006a). There are over 3100 individual glaciers in western China to measure the glacier extents at LIA. The total glacier changes since LIA has been estimated in main mountains in west China using the more than 3100 glacier extents at LIA and Chinese glacier inventory data (**Tab.2**).

**Tab.2** shows that glacier area in western China has decreased by roughly 16 013 km<sup>2</sup>, 21.2% of the total glacier area since the LIA maximum, corresponding to a total ice volume decrease of 1 373 km<sup>3</sup> (12 494×10<sup>8</sup> m<sup>3</sup> water equivalent). However, the degree of glacier shrinkage since the LIA shows obvious regional disparity. Glacial shrinkage demonstrates a radial pattern with the degree of shrinkage increasing gradually moving away from the central Qinghai-Tibetan Plateau toward its surrounding mountains. For example, regions located far from the interior of the Qinghai-Tibetan Plateau, like the southern slopes of the Altay Mountains, Ili River basin, northwestern Tianshan Mountains, source areas of the Mekong River, Nujiang and Yangtze Rivers in the Hengduan Mountains, and lower reaches of the Yarlung Zangbo River, have lost much more glacier area and ice volume than the central part of the Plateau. Such a regional pattern of glacial shrinkage is closely related to the location of different glacier types and their response sensitivities to climate change.

The above estimation of glacial shrinkage did not include the ice loss resulting from the total disappearance of small glaciers since the LIA maximum. A study indicated that about 184 glaciers less than 0.6 km in length might have completely disappeared in the Bujia Kanri region of eastern Tanggula Range since the LIA, accounting for a total glacier area of 24 km<sup>2</sup>, roughly half of the regional decrease thus far identified. Approximately 82.8% of modern Chinese glaciers are less than or equal to 1 km<sup>2</sup>, suggesting that many glaciers smaller than 1 km<sup>2</sup> existed at the time of the LIA maximum and disappeared during the later warm period (*Wang and Ding, 2002*). As a result, the above estimation of glacial shrinkage could be considerably lower than the actual area and volume of glaciers since the LIA maximum.

**Tab.2** Statistics on the variation in glacier area since the Little Ice Age in western China (*Shi et al., 2006a*)

Water system	Glacier number	Area of modern glaciers	Area decrease since the LIA	Percentage of glacier area decrease	Ice volume of modern glaciers	Ice volume decrease since the LIA	Percentage of ice volume decrease
		(km <sup>2</sup> )	(km <sup>2</sup> )	(%)	(km <sup>3</sup> )	(km <sup>3</sup> )	(%)
Ob River	403	289.3	-137.4	-32.2	16.4	-11.6	-41.4
Yellow River	176	172.4	-60.8	-26.1	12.3	-5.1	-29.3
Yangtze River	1332	1895.0	-470.2	-19.9	147.3	-39.6	-21.2
Mekong R.	380	316.3	-130.3	-29.2	17.9	-10.9	-37.8
Salween River	2021	1730.2	-693.7	-28.6	115.0	-58.4	-33.7
Ganges R.	13008	18102.1	-4584.5	-20.2	1622.8	-389.6	-19.4
Indus River	2033	1451.3	-692.8	-32.3	93.9	-58.4	-38.3
Central Asian Region	2385	2048.2	-818.7	-28.6	143.7	-69.0	-32.4
East Asia Region	19298	25584.3	-6779.4	-20.9	2653.5	-582.4	-18.0
Qinghai-Tibetan Plateau Region	5341	7836.1	-1645.4	-17.4	777.5	-148.1	-16.0
Total	46377	59425.2	-16013.2	<b>-21.2</b>	5600.3	-1373.1	<b>-19.7</b>

#### 4.1.3 Glacier Change During Recent 50a

Using remote-sensing and Geographic Information System methods, the glacier change has been monitored in more than 5000 glaciers in main mountains in West China over the past 50

years (*Liu et al.*, 2004; 2005; *Shangguan et al.*, 2004a,b;2006; 2007). The glacier changes have been summered recently (*Ding et al.*, 2006, *Liu et al.*, 2006a, b). The results indicate that more than 80% of monitored glaciers in western China have retreated in past about 50a, losing 4.5% of their combined area coverage, although some glaciers have advanced. In addition, regional differences characterize glacier changes over the past few decades. For example, glaciers in the central and northwestern Tibet Plateau (TP) were relatively stable, while glaciers in the mountains surrounding the TP experienced extensive wastage. Mass-balance variations for some glaciers show accelerated ice shrinkage in the last two decades.

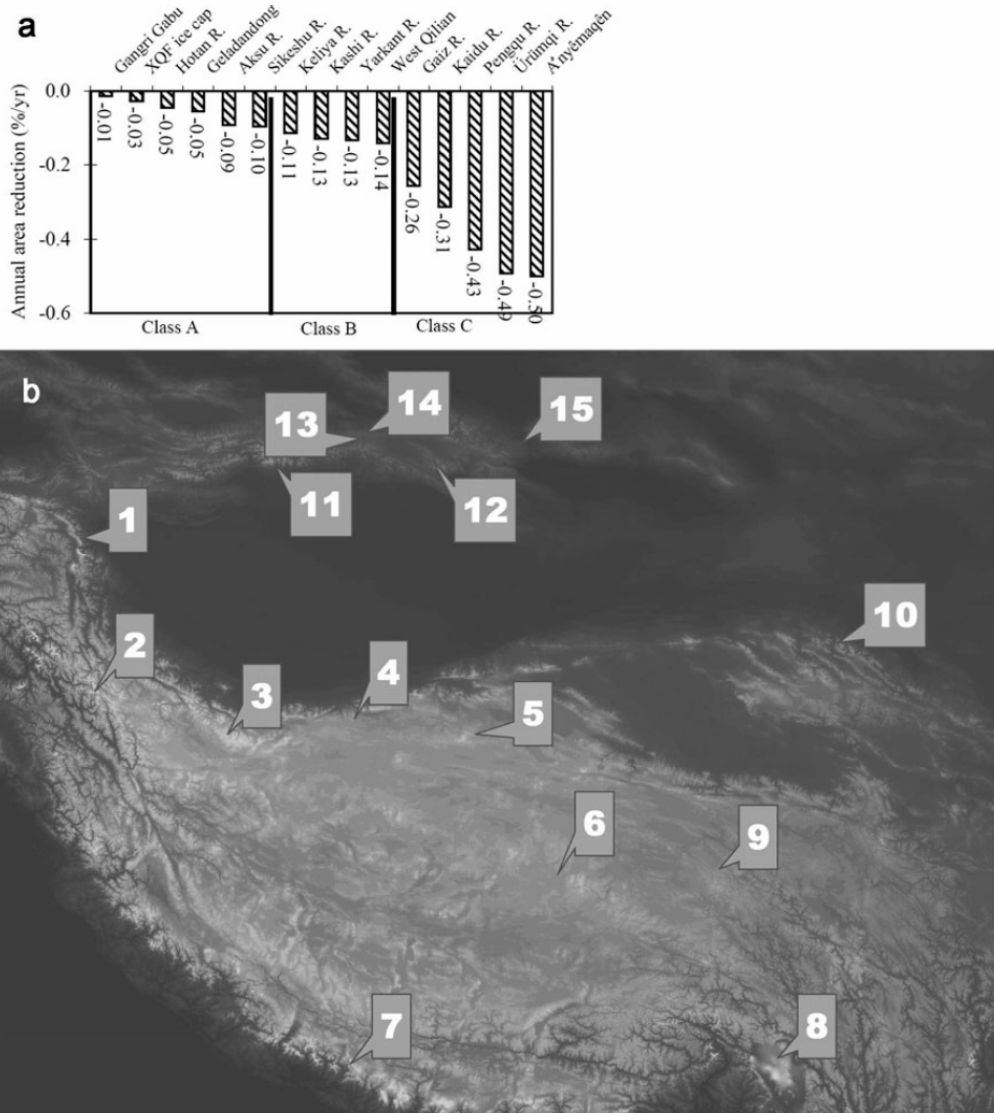
A comparison of glacier termini from Landsat Thematic Mapper (TM) images acquired in 2000 and 2001 and aerial photographs taken in 1956, 1966 and 1972 indicated that the 33 glaciers monitored on the northeastern slope of the eastern end of the mountains were all receding, with a mean length reduction of 11.5ma<sup>-1</sup>. Six glaciers completely disappeared during 1972 and 2001. In the western section of the mountains, 95% of the monitored glaciers retreated at a mean rate of 4.9ma<sup>-1</sup>, but we determined that ten glaciers advanced between 1956 and 2000/01. Our analysis indicated that about 170 glaciers monitored on the northwestern slope of the western section lost 4.8% of their total area during 1956–90, with a much more intensive area reduction (23%) for small glaciers (<1km<sup>2</sup>) (*Liu et al.*, 2003).

There are more than 9000 glaciers, with a total area of 9225km<sup>2</sup>, in the Chinese Tianshan. Repeat aerial photogrammetric mapping from two acquisitions of aerial photographs has been carried out for measurement of glacier variations in the Urumqi river basin (1962 and 1992) and source tributaries of the Yili river basin (1962 and 1989) on the north slope of the Tianshan. All of the 251 glaciers studied retreated during the periods indicated above, but the overall area reduction differed significantly between the two basins: 13.8% in the Urumqi river basin, but only 3.1% in the Yili river basin. However, the estimated ice-volume change indicates that the average thickness of glaciers after thinning is similar for the two basins: 5.8m for the Urumqi and 6.1m for the Yili (*Liu et al.*, 2002). As for glacier changes on the south slope of the Chinese Tianshan during 1960s-1999 or 2000 shows that 69.4% of the monitored glaciers have receded and 30.4% have advanced during the past 40 years. Subtracting the area increase from the advance of some monitored glaciers with a total area of 2093.8km<sup>2</sup> in the early 1960s, glaciers in the southern Tianshan still lost 4.6% of their area.

The north slope of Karakoram is one of the most highly glacierized areas in China, and the second highest mountain peak in the world, K2, is located there. Early research from in situ observations in 1937, topographic maps in 1968 and a Landsat Multispectral Scanner (MSS)

image in 1973 show that K2 (Qoger) Glacier retreated by 1.7km between 1937 and 1968 but the retreat slowed between 1968 and 1973. Similar changes occurred in two nearby glaciers, but two advancing glaciers were found in the region during the same period (Zhang, 1980). A careful analysis based on maps and Landsat Enhanced Thematic Mapper Plus (ETM+) imagery indicates that glacier changes in this region are complicated; some of the large glaciers were in a steady state (equilibrium) or have advanced or even surged during recent decades (Shangguan et al., 2004b).

Glaciers on the TP account for 84% and 81.6%, respectively, of the total area and volume of glaciers (including those in Karakoram and the Qilian Shan) in China. Due to the complex meteorological factors of the westerlies and south Asian monsoons, glaciers on the TP are of monsoonal maritime (temperate, southeast part and Hengduan Shan), subcontinental (Himalaya, central northeast part) and extremely continental (central and northwest part) types. Glacier changes in the TP reflect differing patterns of climate in different parts of this large region. Glaciers in the Kunlun Shan, a mountain range along the northern margin of the TP, which extends from west to east, have generally retreated during the past four decades, but the reduction in glacier area is larger (17%) than that in 1966 (*Liu et al.*, 2002) at the eastern end and smaller (0.3%) than that in 1970 (*Shangguan et al.*, 2004a) at the western end of the mountains, with intermediate changes in the central section (*Liu et al.*, 2004). In the central part of the TP, glaciers have been in relative equilibrium but with a trend toward a general retreat state during the past three decades (e.g. a decrease of 1.7% in glacier area in the basin that serves as the source of the Yangtze River) (*Lu et al.*, 2002). However, glaciers on the north slope of the Himalaya have experienced extensive wastage (*Jin et al.* 2004); many small glaciers may have actually disappeared during the last 20 years.



**Fig. 1.** (a) Annual percentage glacier area changes in each river basin or mountain range. (b) The monitored regions: 1. Gaiz river; 2. Yarkant river; 3. Hotan river; 4. Keliya river; 5. Xinqingfeng (XQF) ice cap; 6. Geladandong mountain; 7. Pengqu river; 8. Gangri Gabu range; 9. A'nye'maqen mountains; 10. west Qilian Shan; 11. Aksu river; 12. Kaidu river; 13. Kashi river; 14. Sikeshu river; 15. Urumqi river (from Ding et al., 2006).

Yao et al. (2004) estimated that the glacier volume in west China may reduce about 452.77-486.94km<sup>3</sup> in past 50a. The analysis of discharge in Tailan River, a branch of Aksu river in Xinjiang show that glacier runoff in 1980's and 1990's has increased by 4.5% and 6.9%. The increase of glacier runoff contributed to 1/3 of river runoff increase (Liu et al., 2006c). The measured glacier area and estimation of glacier ice volume change indicates that the glacier area and volume decreased by 1307.2 km<sup>2</sup> and 87.1 km<sup>3</sup> (about 3.8m glacier depth thinning),

respectively, about 6.6% and 3.8% of corresponding volume in 1963, respectively. The measured glacier mass balance in No.1 glacier in Urumqi river source in Tianshan during last 45a indicate the glacier mass loss can reach 480mm induced by 1°C summer air temperature increase (*Ye et al.*, 2005).

## 4.2 SNOW COVER VARIATION IN RECENT 50A OVER CHINA

The snow cover variation has been studied using the observation data in meteorological stations over during 1951-1997 China (*Qin et al.*, 2006; *Ren et al.*, 2005).

### 4.2.1 The Distribution of Snow Covers over China

The snow cover occurred in about  $9 \times 10^6 \text{km}^2$  over China (more than 90% area), extending south to 24°-25°N. However, the snow duration is short in most regions. The temporal or unstable snow cover (annual mean snow cover duration is less than 60 days) is dominated in most regions, about  $4.8 \times 10^6 \text{km}^2$ . The stable snow cover are existed in  $4.2 \times 10^6 \text{km}^2$  which are distributed in three regions: (1) Qinghai-Tibetan Plateau with  $2.3 \times 10^6 \text{km}^2$  including Pamir, Kalakunlun, Kunlun, Qilian Mountains and south Gansu province, west Sichuan and northeast Yunnan, but excluding valley in south Tibet, North Tibet Plateau and Chidamu Base; (2) Tianshan in Xinjiang with  $1.04 \times 10^6 \text{km}^2$ , (3) Northeast China and inner Mongolia with  $1.4 \times 10^6 \text{km}^2$ .

The thin and various distributions of snow covers are characterized. The snow covers are very thin in most regions. There is only 3.5cm daily snow average depth and 50% region has less than 3cm daily snow average depth. The most snow covers are concentrated in mountains in north China and northwest China. More than 50% snow is distributed only in mountains with less than 10% area. Usually, there is thin snow cover over the plain in north China. The snow depth is about 2-3cm in west region of northeast China and north China, and less than 1cm in the arid northwest China with 16% area. There is center rich in snow in Xinjiang. The snow depth is about 50-60cm in Altai, 40-50cm in Tianshan, Pamir and Kalakunlun mountains and 20-30cm in Kunlun mountains. However, there is no snow in most years, except for rich snow year in Tarim Basin. The rich snow cover also exist with 30-50cm depth in the mountains surrounding to Qinghai-Tibet Plateau, especially in Nyainqintanglha and Tanglha mountains in East region of Plateau and Karakunlun and west region of Himalaya in west region of Plateau. There is discontinuous and short-duration snow cover with less than 10cm in central Qinghai-Tibet Plateau.



There is nearly no snow cover in the valley in south Tibet and Qaidam Basin. The maximum snow cover depth is about 15cm averaged in whole Plateau. The deep snow covers with 20-30cm depth exist in mountains and thin snow cover occurred in plain in northwest China. The snow cover distribution is controlled main by air temperature, elevation and climatic system, also affected by surface sonditions.

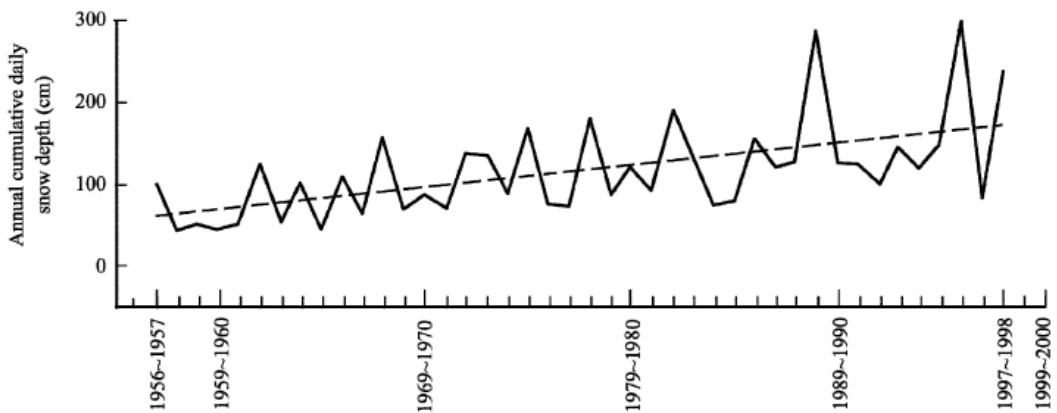
#### *4.2.2 Seasonal Variation in Ssnow Covers*

The snow cover duration is about half year over China. The snow cover formed in middle September, reach the maximum in early January and disappeared in June in Qinghai-Tibet Plateau. The snow storages are 45.2%, 28.0% and 21.2% in winter (December to February), spring (March to May) and fall (September to November). The annual maximums of snow storage has largely variation, the difference of annual snow storage can be  $30 \times 10^9 \text{ m}^3$  between years with rich and poor snow. The snow cover exists in middle November, then slowly extends to maximum in later February to early March, starts to melt in Spring and disappeared in middle April in Xinjiang. The annual maximum snow storages is about  $7 \times 10^9 \text{ m}^3$  water equivalent, have low variation, but its duration has large difference in the regions. The maximum snow storage duration is about 72 days in rich snow year and only about 30 days in poor snow year. The snow cover duration has long period, 5-7 months in Inner Mongolian and Northeast China. The snow cover duration exist from middle October to later April in most north regions (north of  $50^\circ\text{N}$ ), and from middle November to end of March in most south regions. The average snow depth is about 11cm over the region. The minimum average snow depth is only 4cm. the difference of snow storage between maximum and minimum is up to  $24 \times 10^9 \text{ m}^3$  water equivalent, very close to Qinghai-Tibet Plateau variation. The large variation can cause drought and waterlog in spring, and affect on local agriculture activities.

#### *4.2.3 The Fluctuation of Snow Covers during Recent 50a*

The geographical distribution and spatial and temporal variabilities of snow cover has been studied in the western China during the past 47 yr between 1951 and 1997 (Qin et al., 2006). The data used consist of Scanning Multichannel Microwave Radiometer (SMMR) 6-day snow-depth charts, NOAA weekly snow extent charts, and the daily snow depth and number of snow cover days from 106 selected meteorological stations across western China. Empirical orthogonal

function was performed on the SMMR dataset to better understand the spatial pattern and variability of the Qinghai–Xizang (Tibet) snow cover. A multiple linear regression analysis was conducted to show the association of interannual variations between snow cover and snow season temperature as well as precipitation. Further, the autoregressive moving average model was fitted to the snow and climate time series to test for their long-term trends. Results show that western China did not experience a continual decrease in snow cover during the great warming period of the 1980s and 1990s. It is of interest to note that no correlation was identified between temperature and precipitation in the snow cover season. However, year-to-year fluctuation of snow cover is caused by both snowfall and snow season air temperature. About one-half to two-thirds of the total variance in snow cover is explained by the linear variations of snowfall and snow season temperature. The long-term variability of western China snow cover is characterized by a large interannual variation superimposed on a small increase trend (Fig.2). The positive trend of the western China snow cover is consistent with increasing snowfall, but is in contradiction to regional warming.



**Fig.2** Variation of annual cumulative daily snow depth over the Qinghai–Xizang (Tibet) Plateau, 1957–98 (*Qin et al.*, 2006)

The trend of snow cover is insignificant positive in Xinjiang during last 50a. There is positive relationship between snow cover and winter precipitation in Xinjiang, however, negative relationship exist between snow cover and winter air temperature. The snow cover show slight decreased trend (1%/10a) in inner Mongolian and northeast China. The decreased snow cover is consistent with decrease of winter precipitation and increase of winter air temperature. These relationships imply that the change of snow cover mainly depend on winter precipitation change

over China. The reason may be the lower winter air temperature in China than in Europe and North America.

The snow covers in three main regions has inconsistent fluctuations in past 50a. The difference occurred not only in long-term trend, but also in period with maximum and minimum snow covers. For example, there is large snow cover in Xinjiang in 1959/1960 and 1958/1959, but there is low snow cover in inner Mongolian and northeast China. There is normal or low snow cover in inner Mongolian and northeast China when the heavy snow disaster occurred in 1985/1986 and 1995 /1996 in Qinghai-Tibet Plateau.

#### *4.2.4 Estimation of the Snow Covers Change in Future*

The analysis on the relationship between snow cover, winter air temperature and precipitation indicates the snow cover may increase in future in Qinghai-Tibet Plateau, North Xinjiang and some region in Inner Mongolian. Both the area and duration of unstable/temporal snow cover may decrease over China. This implies that snow change will enhance snow disaster in snow increased region and drought in decreased region in spring, and negatively affect on ecology and environments.

### 4.3 BIAS-CORRECTED PRECIPITATION CLIMATOLOGY FOR CHINA

There is systematic analysis on the bias corrections of Chinese standard precipitation gauge (CSPG) measurements for wind-induced undercatch, trace amount of precipitation and wetting loss (*Ye et al.*, 2004), based on experiment results in Urumqi River basin in 1980's-90's (*Yang et al.*, 1991, 1988). Long-term daily data of precipitation, temperature, and wind speed during 1951-98 at 710 meteorological stations in China were used for this analysis. It is found that wind-induced gauge undercatch is the greatest error in most regions, and wetting loss and trace amount of precipitation are important in the low precipitation regions in northwest China. Monthly correction factors (corrected / measured precipitation) differ by location and by type of precipitation. Considerable inter-annual variation of the corrections exists in China due to the fluctuations of wind speed and frequency of precipitation. More importantly, annual precipitation has been increased by 8 to 740 mm with an overall mean of 130mm at the 710 stations over china due to the bias corrections for the study period. This corresponds to 6-62% increases (overall mean of 19% at the 710 stations over China) in gauge-measured yearly total precipitation over China. This important finding clearly suggests that annual precipitation in China is much higher

than previously reported. The results of this study will be useful to hydrological and climatic studies in China. The bias correction also can affect on long trend of precipitation.

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# CHAPTER 5 THE PROGRESSES OF WATER QUALITY

## RESEARCH IN CHINA

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### 5.1 OVERVIEW

The continuously rapid growth of China's economy since the reform and opening up is rarely seen in the history of world economy. However, the process of China's economic development is still basically characterized by extensiveness and a considerable part of the growth has been obtained at the cost of sacrificing ecological environment and great consumption of resources. The continuously rapid economic growth has brought about a huge pressure on China's urban and rural ecological environments and led to even more serious damage to water environment and ecology.

According to the environmental bulletins published by the State Environmental Protection Administration (State Environmental Protection Administration of China, China Environmental Bulletins in 2002-2005), in recent years, the major rivers of China are generally confronted with organic pollution; the situation of surface-source pollution is becoming increasingly serious; and the proportion of rivers with Grade IV water or under in the major rivers is up to 53.7%--64 % (see Table 1). Dianchi Lake, Taihu Lake and Chaohu Lake have seen a rising trend of eutrophication (see Table 2).

**Table 1.** Water Quality of China's Major Rivers

Year	Grade I-III	Grade IV- V	under Grade V
2002	46.3%(main stream)	26.1%(main stream)	27.6%(main stream)
2003	53.4%(main stream)	37.3%(main stream)	9.3%(main stream)
2004	36.3%(main stream)	33.9%(main stream)	29.8%(main stream)
2005	36%(main stream)	40%(main stream)	24%(main stream)

**Table 2.** Water Quality of Dianchi Lake, Taihu Lake and Chaohu Lake

Lake	Year	Water quality assessment
Taihu	2002	In 20 water quality monitoring points, the proportion of sections with grade V or under was 60%. Major pollutants were TN and TP, and the lake was in a state of moderate eutrophication.
	2003	Compared with the previous year, the lake was polluted seriously, in which the proportion of sections with grade V or under was up to 85.7%, and without grade I ~III.
	2004	The contents of nitrogen and phosphorus in 21 water quality monitoring points were seriously excessive of the limits and the lake was in a state of moderate eutrophication.
	2005	Compared with the previous year, there was no significant change in Lake water. The permanganate indexes and the average of the TP reached the requirements of planning.
Dianchi	2002	The water quality was under grade V; nitrogen and phosphorus pollution was very striking; and eutrophication was serious. The permanganate indexes reached the requirements of planning.
	2003	The pollution was still serious. Compared with the previous year, the water quality declined slightly. The main polluted indexes were nitrogen and phosphorus. the lake was in a state of serious eutrophication.
	2004	Although the water quality of the lake had improved, the pollution was still serious. The permanganate indexes reached the requirements of the grade III and eutrophication was serious.
	2005	The water quality in 10 monitoring points was under grade V; Chaohai lake pollution was striking; and the Waihai lake was better in a state of moderate eutrophication. Compared with the previous year, there was no significant change in Lake water.
	2002	The water quality of the 12 monitoring points was of grade V or under entirely; and the water body is in a state of eutrophication.
	2003	The water quality in 50% of 12 monitoring point was under grade V; the contents of total nitrogen and total phosphorus exceeded the limits; and the water body was in a state of moderate eutrophication.



Chaohu	Compared with the previous year, there was no significant change in Lake water. The pollution of the western half of the lake was more serious than that of the eastern half; the western half was in a state of moderate eutrophication; the eastern half was in a state of moderate nutrition.
2004	
2005	The water quality of all of the 12 monitoring points was under grade V; The pollution of the western half of the lake was more serious than that of the eastern half, and the lake was in a state of moderate eutrophication.

Though the sewage treatment rate in China is continuously increasing, the volume of sewage discharged every year is still rising rapidly. The total volume of sewage discharged in whole China in 2005 was 8.5 billion ton more than that in 2002; and the total volume of COD discharged increased by 472 thousand ton (see Table 3).

**Table 3.** The Situation of Sewage and COD Discharge in China

Year	Volume of sewage discharged (million ton)			Volume of COD discharged (thousand ton)		
	Total	Industrial	Domestic	Total	Industrial	Domestic
2002	43950	20720	23230	13670	5840	7830
2003	46000	21240	24760	13336	5119	8217
2004	48240	22110	26130	13392	5097	8295
2005	52450	24310	28140	14142	5548	8594

The quality of ground water also allows no optimism. According to the circular from the Ministry of Land and Resources about the situations of ground water in the major cities and area of China in 2005, the statistical analysis of the quality of ground water in 160 cities and areas in all parts of the country shows that the overall quality of ground water is in a relatively stable situation, but the ground water in most cities has suffered point-sources and non-point sources pollution to a certain extent and the contents of some elements in some places have exceeded the limits. The main pollution elements include total solids, total hardness, sulfate, nitrate, nitrite, ammonia nitrogen, chloride, fluoride, pH value, iron and manganese.

The ground water pollution elements in the major cities of northeast China mainly include total hardness, total solids, nitrate, nitrite, iron and manganese and then sulfate and chloride. The ground water pollution elements in the major cities and areas of north China mainly include total hardness and total solids and then sulfate, nitrate, chloride and fluoride. The total hardness and total solids of ground water in this region are seriously excessive of the limits. Especially in Handan City and Tangshan City of Hebei Province, the total hardness is seriously excessive of the limit and the water quality is very poor. The total numbers of bacteria and bacillus coli

colonies are obviously excessive of the limits in Xuchang City of Henan Province. The ground water pollution elements in the major cities of Northwest China mainly include total solids, total hardness, nitrate and sulfate and then chloride, fluoride, nitrite and ammonia nitrogen. In addition, the pollution of chromium (VI) in Xi'an City and Hanzhong City of Shanxi Province is excessive of the limit. The ground water pollution elements in the major cities of south China mainly include nitrite, ammonia nitrogen, iron, manganese, total hardness and nitrate. In addition, the ground water of some cities is acidic and the pH value is seriously excessive of the limit. The excessive ground water pollution elements in the major cities and areas of central south mainly include nitrite, nitrate, ammonia nitrogen, iron and manganese and then total hardness, fluoride and pH value. The pollution of iron and manganese is mainly caused by the primitive environment and this pollution is very common. The ground water pollution elements in the major cities and areas of Southwest China mainly include total hardness, total solids, nitrite, ammonia nitrogen, iron and manganese and fluoride, sulfate, organic phenol, oxygen consumption and pH value. The pollution elements are mainly distributed in a point type and the limit-exceeding rate is low.

Generally speaking, the characteristics of ground water pollution in China are as follows: In terms of the degree of pollution, the pollution in the northern cities is generally more serious than that in the southern cities; the number of pollution elements is big and the limit-exceeding rate is high; and the pollution in North China is especially serious. In terms of pollution elements, the pollution of "three nitrogen components" is serious in all parts of China. The pollution of total solids and total hardness is mainly distributed in the northeast, north, northwest and southwest regions. The pollution of iron and manganese is mainly distributed in the south. In respect of the trend of change, the quality of ground water in most cities is becoming stable or rising slightly; the ground pollution in some cities and areas is aggravating, to which we should pay more attentions.

## 5.2 WATER PURIFICATION AND TREATMENT TECHNOLOGY

Super critical water oxidization (SCWO) is a new oxidization technology that can completely destroy the structure of organic pollutants and has unique advantages in wastewater treatment. However, China's research in this aspect has just broken the ice. In the treatment of wastewater containing aromatic compounds, Sun Yinghuang and some other experts have used this technology and studied the influence of temperature, pressure and retention period on the rate of phenol removal in intermittent and continuous reactors under sub-critical and critical conditions. They have found that the removal rate increases with the increase of temperature, pressure, and retention time. The removal rate of phenol can reach 96% or more during a short retention time, and the highest removal rate of acetic acid in wastewater is 99%. Yao Hua and

other persons have also made preliminary studies on phenol or nitrobenzene in different wastewater with SCWO method. The result of their studies indicates that SCWO may produce a very good effect for removing the phenol and nitrobenzene; and the rate of the degradation of organic components can reach more than 96% in a very short retention period. Qi Xinhua has studied the aniline wastewater Scwo reaction with hydrogen peroxide as an oxidant. The research indicates that the Scwo technology to deal with the high percentage aniline wastewater is effective (SUN Yinghuang, 2005).

Membrane biological reactor (MBR) is an efficient wastewater treatment technology that has been developed in recent years. Although membrane technique is of virtues as high quality filtrate, low lump-sum investment, taking up not much land, low motion cost, there is a problem of the membrane fouling pollutions and some pathogens in the filtrate, sometimes with water color, odor and other fly in the ointment. The technology of ultrasonic and ozone oxidation is a new technique to clean the biomembrane (MBR) element using membrane technique, ozone oxidation technique and modern ultrasonic wave cleaning technique based on the traditional technology of disposing and recovering of class biochemistry waste water. It can clean up the pollutants which stuck inside and outside the surface of the membrane, and can avoid the harm to membrane from the pollution to environment from the detergent, using modern ultrasonic technique. With strong oxidation of ozone, it can completely remove the possible harm to persons who use the recovery waste water from bacterium, peculiar sell, colority, etc, by using ozone oxidation technique, and make disposed waste water really safe and daily life water. The cleaning process of membrane components with the ultrasonic is that the use of ultrasonic energy in this special form, washing the pollutants attached to the outside wall of membrane components, peeling the pollutants, thus restoring the membrane flux and filtration. The procession can prolonged the life of membranes and increased the membrane replacement cycle, thereby achieved the purposes of increasing MBR economic (Zhao Kunyu, 2006).

Membrane filtration technique is a liquid separation technology, with high efficiency, low energy consumption and easy operation. Compared to traditional methods of wastewater treatment, membrane technology has many advantages, such as the circulatory use of wastewater and recovery of useful substances. The application of membrane separation process in wastewater treatment mainly includes several membrane filtration techniques, such as micro-filtration, electro dialysis, reverse osmosis, ultra-filtration, nano-filtration and so on. Membrane filtration techniques have been researched deeply in the treatment of wastewater containing oil, dye, heavy metal and organic compounds with high concentration. The treated water is transparent; Tang Yanhui et al. has used ultra filtration membrane to treat the oily wastewater. Experiments showed that COD<sub>Cr</sub> decreased from 728.64 mg / L to 87.8 mg / L, oil concentration from 5000 mg / L to 2.5 mg / L, the removal rates were respectively 87.95% and 99.95%. The treated sewage effluent has reached national emission standards. Yang gang et al. has used nano-filtration technology to treat the dye wastewater. When the pressure is 1.8 MPa,

the concentration of NaCl from 1.05 mol / L dropped to 0.049 mol / L and the NT concentration concentrated from 0.14 mol / L to 0.25 mol / L above. The average retention rate of NT components has reached to 99.8%. The Membrane filtration technique also has obtained impactful effect in the treatment of organic compounds wastewater with high concentration.. Wang et al. have used the IMBR to treat the beer wastewater. When the retention period of hydraulic force is 3.5—5 h and the COD load is 3.54 ~ 6.225 kg/(m<sup>3</sup>.d), the removal rates of COD, NH<sub>3</sub>-N, SS and turbidity in wastewater are respectively 96%,99%,90% and 100%(Xu Dezhi,2006).

According to the characteristic of heavy concentration municipal wastewater in cities in northern china, the treatment technique of sequencing batch reactor (SBR) is adopted to treat the wastewater. Xue Yingwen et al. have used the SBR method to treat the municipal waste water of ShiHeZi in XinJiang Province. Through this experiment, it proves that the SBR technique has a high effect on removing COD、TN、NH<sub>4</sub><sup>+</sup>、-N and TP. When COD, TN, NH<sub>4</sub><sup>+</sup>, -N, TP concentration are respectively 1231.2, 31.32, 20.67, 8.55mg/L in the raw sewage, the treated sewage effluent COD, TN, NH<sub>4</sub><sup>+</sup>, N, TP concentration dropped to 70.13, 12.81, 12.28, 0.85mg/L, respectively. The removal rates are respectively 94.3%, 59.09%, 40.6%, 90.02% and the wastewater reaches to the discharge standards of level 1(COD, NH<sub>4</sub><sup>+</sup>, -N )and level 2 (P). Based on the experiments including the enrichment culture of EM, the formation of biofilm and the application of biofilm technology in wastewater treatment, Tian Na et al. (2005) have obtained the following conclusions: 1 When the fillings and compound culture medium are cultivated together, EM can attach to the fillings and form biological films, and under the condition of 30°C or more and sufficient aeration rate, biological films come into being in 10 days or so after cultivation using attapulgitic clay and montmorillonite as fillings. 2 In sequence batch reactor (SBR), the removal rate of COD<sub>Cr</sub> in domestic sewage can reach 80%-90% when attapulgitic clay and montmorillonite a used as fillings (Xue Yingwen, 2005).

Luo et al. (2000) have combined magnetic treatment and artificial ecological system together for purifying organic wastewater. The result indicates that instantaneous magnetic treatment can directly remove about 20% of the COD in sewage; afterwards, the ecological effects caused by magnetization can promote the conversion of food chain and obviously improve the effects of purification. Xia Liqun et al. (2005) have used phyto-remediation technology to the treatment of wastewater in the coastal sea, such as Mariculture eutrophication, Oil and other organic pollution, red tide, heavy metal pollution of the coastal sea and so on. The advantages of the phyto-remediation technology in coastal pollution abatement includes: 1. it is acceptable to people because of its slight side effect for human and marine environment and its small ecological risk; 2. its post treatment is easy, and with little wastes, emissions, and problems left, it won't cause secondary pollutions; 3. it contributes to ecological landscaping; 4. its output is large (Xia Liqun, 2005).

Qi jian et al. (2006) has studied the TiO<sub>2</sub>photo-catalytic oxidation technique for treatment of

environmental pollutants. The mechanisms of TiO<sub>2</sub> photo-catalytic oxidation technique, preparation of catalyst and application of both suspended and immobilized TiO<sub>2</sub> to the treatment of organic pollutants were introduced. It is presented that suspended TiO<sub>2</sub> is mainly used in wastewater treatment, while immobilized TiO<sub>2</sub> can be used in the treatment of wastewater and leachate from landfill and the purification of environment. The development tendency of suspended TiO<sub>2</sub> is to improve its activity and application to the surface deposition of heavy metals, surface coupling, surface sensitization, and intermingle of transition metal. The research tendency of immobilized TiO<sub>2</sub> is to improve its catalytic activity, to choose suitable carrier and make the best of it, to strengthen the combination between photo-catalytic oxidation and other techniques, and to use solar energy as light source. Qi Qiaoyan et al. (2006) have used TiO<sub>2</sub>/AC in fluid bed reactor to degrade the Rhodamine B dye wastewater. The photocatalysis degradation reaction kinetics and degradation mechanisms of rhodamine B were studied. The results indicate that the degradation process conforms to the equation of first order kinetics. According to degradation mechanism, color group aniline and carbonyl of rhodamine B were destroyed, then the intermediary products were degraded gradually (Qi jian, 2006).

### 5.3 WATER QUALITY AND SAFETY

The quality of water environment is closely related to the people's life and water produces influences on human beings directly or indirectly through plants and animals. Many accidents arising out of water environment pollution have happened every year and consequently led to huge economic losses. The water environment in rural areas is worsening with every passing day and the water hygiene conditions in such areas are very poor. The overall situation of water environment in Shandong is worsening. The shortage of water resources and conflict between water supply and water demand are both serious, and it is difficult to ensure the water supply for ecological use. Large amount of industrial, agricultural, and sanitary wastewater discharged into rivers leads to serious water pollution and deteriorates ecological environment. With the development of economy, water environment safety of Shandong Province is facing great challenges. Comprehensive measures, including water diversion and water-saving measures should be adopted. Clean production should be put into practice actively and pollutant emission should be controlled strictly (Ren Lijun, 2005).

Nowadays almost all the countries are concerned of the exploitation and land harnessing along big river watershed. Industry clusters of high density and high intensity under the great exploitation in Jiangsu Province along the Yangtze River will bring pressure onto the water quality in the river. On the basis of the social, economical and investigated environmental monitoring data, the results revealed that the pollutant load of Yangtze River in Jiangsu province contains  $210\,997.80 \times 10^4$ t total waste water, 380 817.20 t CODCr and 28 391.36t of NH<sub>3</sub>-N

in 2002, and will be  $395\,977.10 \times 10^4$  t, 598 197.80 t and 42 381.56 t respectively in 2010 as predict, with the increase ratio being 87.7 %, 57.1 % and 49.3 % respectively. As for the polluted source treatment, more than 90% industrial waste water have met the discharge standard in China, but both domestic sewage disposal plant number and treatment depth can not meet the actual increase of domestic sewage treatment. On the purpose of the protection of ecological environment and the water source security, several principal countermeasures such as optimizing industrial structure, cutting down the pollutant load, strengthening the waste water treatment plant building and improving the main creeks treatment in the area are put forward(Yu Zhonghua, 2005).

At the same time, the pollution of non-point pollutant and sewage has been more serious with the expansion of towns in Jiangsu, China. The concentration of pollutant is high and its discharging is concentrated during urbanization, which was pushed by industrialization in Southern Jiangsu. River water quality has deteriorated rapidly that has been a new carrier of pollutant to decrease environmental capacity of water. The countermeasures to control water environment include implementing ecological engineering and environmental engineering, reinforcing environmental programming and management in the process of urbanization, and encouraging the population who are not peasantry to concentrate to the main towns nearby.(Li xin, 2005).

The major problems with drinking water in China's rural areas are caused by decentralized water supply and reflected in the aspects of seriously excessive microorganisms, poor states for sense organs (mainly including color, turbidity and excessive iron and manganese contents) and serious organic pollution. The microbial pollution of drinking water is still a very serious problem in rural areas at present. It's a long-term task for the public health and anti-epidemic workers to strengthen the sterilization and hygiene management of drinking water in rural areas and prevent the prevalence of hygrophilous epidemic diseases. Many places in the south use water from lakes and reservoirs as domestic drinking water, but most of these lakes and reservoirs are in a state of eutrophication. Therefore, studies on algal toxicants and antiphytes are an important link for improving the quality of municipal water supply. Furthermore, the halogenated hydrocarbon compounds resulted from the sterilization of city water with chlorine have become a new pollution source (Yin Jie, 2005).

Most of the water quality indexes of the drinking water sources in Anhui Province are problematic and the major problem is the seriously excessive content of bacteria caused by pollution. There is domestic pollution or industrial pollution around more than 70% of the water sources and hygiene protection facilities are very poor. Karst groundwater sources in Huaibei City, the coli was 3-18 个/L in general and the phenol content in some wells reached to 0.003mg/l. From 1968 to 2000, there were 66 people died of cancer because of drinking the groundwater including harmful substances 4.1-21.4 times more than the national standard of groundwater in Huaibei City District Shitai Duji Liu Village. Examination of the past five years, 13 were found

suffering from liver cancer and stomach cancer. The water supply facilities in most areas are simple and short of complete technological processes; and the quality of most of the water supplied to consumers cannot reach the national standard on the sanitation of drinking water (Zhang Xin, 2004).

The pollution of domestic drinking water sources in cities is even more serious. According to Xi'an City Water Company's investigation of the water quality of its ground water source (the Yellow River) and the upper stream, because of the discharge of domestic sewage near the water source, bacillus coli colony is the principal pollutant in all stream segments (Liu, 2006). The pollution of drinking water leads to the appearance of large amounts of algae. Some algae can produce algal toxicant, which is very harmful to human health. It's discovered in research that microcystin toxicant in Dianshan Lake, Taihu Lake and Chaohu Lake is probably a non-genetic toxic carcinogen or supplementary carcinogen and its pollution of water is possibly one of the important factors of drinking water-incurred cancer; and the traditional drinking water sterilization method can not entirely eliminate algal toxicants in water (China Environmental Bulletins, 2005).

Gao Jijun et al. (2004) had studied the concentrations distribution of the Cu, Hg, Cd, As in drinking water in the 8 city districts and 10 counties in Beijing based on a total of 120 random samples. Health risks associated with 4 metals in drinking water were assessed using USEPA health risk assessment model. The results showed that the concentrations of the heavy metals in drinking water in Beijing ranged from 0.81 to 6.96  $\mu\text{g}/\text{L}$  for Cu, 0.34~0.82  $\mu\text{g}/\text{L}$  for Cd, 0.10~0.74  $\mu\text{g}/\text{L}$  for Hg and 0.19~3.02  $\mu\text{g}/\text{L}$  for As. Among the health risks caused by the carcinogens in drinking water, the largest risk associated with As should be in Tongzhou county ( $2.0 \times 10^{-5}$  a-1) and that with Cd should be in Changping County ( $2.3 \times 10^{-6}$  a-1), while both were significantly lower than the maximum allowance levels recommended by ICRP ( $5 \times 10^{-5}$  a-1). Among the non-carcinogenic risks levels ranged from  $10^{-8}$  to  $10^{-9}$ , much lower than the maximum allowance levels recommended by ICRP (Gao Jijun, 2004). Yang Liujun (2006) had analyzed the water quality safety in source area of Honggang water plant in NanTong according to the influence of carrying capacity of environment, pollution sources, and spill accidents in the source area. It is concluded that the water environment capacity is large in the water function region. Pollution sources into the river have little impacts on water quality, while the oil spill accidents in the petrol products loading wharf are threatening the water quality safety. Emergency measures should be put forward and adopted to alleviate and avoid the harms caused by risk accidents.

There are also reports about ground water pollution. By the end of 1999, due to severe exploiting of underground water, the North China Plain had been the world's largest underground water landing funnel, with a total area of the  $5 \times 10^4 \text{km}^2$  above, and there had been linked together into one mass. Excessive exploitation of underground water resulted in the shortage of urban water resources and deterioration of groundwater quality. Yu Kaining (2003) discussed the

impact mechanisms and positive-negative effects of urbanization on groundwater quality based on a three-year study in Shijiazhuang by quantitative calculation and analysis of urbanization level and groundwater pollution. The results show that growth of urbanization is helpful to improve the groundwater quality, but may easily result in salt pollution.

The result of studies made by Zhu Zheng (2005) on the causes of the groundwater pollution of all big cities in Shanxi Province from the polluting paths of the groundwater indicates the polluting trend of the groundwater of Shanxi province, and points out that the groundwater pollution and its land-sourced pollution present the positive correlation. The major sources of groundwater pollution in Shanxi province are the following: 1. industrial sewage is a major one, especially the untreated industrial wastewater and the sewage under the discharge standards; 2. a large of sewage from life is one of the reasons for groundwater contamination. 3. An industrial solid wastes and life garbage pollute the groundwater certainly. 4. The sewage irrigation in agricultural production and an unreasonable application of fertilizers and pesticides result in pollution of groundwater by the water infiltration. 5. There are no measures to prevent the infiltration of the sewage drains. 6. The over-exploitation of groundwater makes the water level dropped sharply causes the hydraulic communication of the aquifer, so that pollution caused by the shallow water polluted the deep water. 7. The consecutive drought drier in recent years in Shanxi was resulted the increase of hardness in the shallow groundwater generally.

Liulin Well, as the biggest well in Luliang region, is one of the major protective wells, and the main water resources for the electric-coal zone and three counties (Lishi County, Zhongyang County, and Liuling County) of Luliang Region as well. Since 1990s, a lot of changes in the water source area have been taken place. A group of the pollution and harmful elements constantly increased, in which the harmful elements were various, such as coliform bacteria, sulfate, ammonia, fluoride, phenol, mercury, hexavalent Cadmium. From 1996 to 2003, the detection rate of these harmful elements and pollutants was 100% and in a gradual increasing trend, and some water overstepped the three GB groundwater quality standards. Water quality will be worsening further with the decrease of water and environmental changes (Kang Yinchang, 2003). Wang Yan'en (2005) has summed up the groundwater environment problems in Zaozhuang city and pointed out the countermeasures for its regulation. Shiliquan and Dingzhuang-Dongwangzhuang headwaters, the important water sources, have been over-exploited over a long period. The groundwater level had been continuously descending, which brought about hydrodynamic changes in groundwater. The groundwater undercuts the soil above, breaking the natural balance of rock and causing karst collapse. With the descending of groundwater level, the expansive clay formed in the Quaternary period in the rock formation of the Yicheng basin becomes desiccated and shrunk, forming fissures in the soil. The extraction of water from aquifer results in radially tensile zone of father wells, accelerating the desiccation fissure. The seepage of sanitary sewage and industrial wastewater into the aquifer causes serious groundwater pollution in Shiliquan.



## 5.4 WATER QUALITY STANDARD AND WATER QUALITY MONITORING METHOD

Water environment standard system is a complete management system for comprehensively planning the work of water environment standardization, coordinating the mutual relations and clarifying the functions and applicable scopes of the relevant standards. China's water environment standard system can be summed up in "five categories and three levels". The five categories include the standard of water environment quality, the standard of water pollutant discharge, the basic standard of water environment, the standard of water monitoring and analysis method and the standard of standard water environment samples; and the three levels including national level, industrial level and local level. However, the hygienic standard of water environment also contains a lot of information about water quality. By the end of July 2002, the State Environmental Protection Administration totally promulgated 370 national standards concerning water environment (exclusive of the hygienic standard of water environment), which account for 64.8% of the total national standards on environmental protection (Li Guibao, 2003).

China's water quality standard has been continuously improved since 1999. In 1999, the State Environmental Protection Administration approved the Standard of Environment Quality Standards for Surface Water (GHZB 1~1999), which was implemented as of Jan. 1, 2001. Because of the improperness of some selected indexes and values of indexes and for more effective coordination of interdepartmental relationship, in 2002, the State Environmental Protection Administration promulgated the amended Environment Quality Standards for Surface Water (GB 3838-2002), which has being implemented since June 1, 2002. One thing worth attention is that the index of oxygen consumption is added in the routine test items. The water conservancy system has built up 251 Water Environment Monitoring Center, 3228 types of surface water quality monitoring stations, and 11,620 groundwater monitoring stations. The national water quality monitoring network coverage all of the river and lake was established. The laboratory of 51 Water Environment Monitoring Center has achieved the national measurement certification, which accounted for 61.49% of the Water Quality Control Center System and included the Department of the provincial, regional and basin water environment monitoring center (Li and Zhou, 2003).

The Standard of Water Quality for Industrial Boilers (GB 1576-2001) was promulgated in 2001. The water quality-related standards promulgated by the other industries and departments include: Standard of Water Quality for Miscellaneous Domestic Water Consumptions (CJ/T 48-1999), Quality Standard for Reclaimed Wastewater Reused as Scenic Water (CJ/T 95-2000), Water Quality Standard for Fine Drinking Water (CJ 94-1999), Standard of Water Quality for Domestic Drinking Water Sources (CJ 3020-1999), Discharge Standard for Municipal

Wastewater (CJ 3082-1999), Foods without Public Nuisance--Quality of Drinking Water for Domestic Animals and Fowls (NY 5027-2001), Foods without Public Nuisance--Quality of Water for Livestock Product Processing (NY 5028-2001) and Standard of Water Quality for Petrochemical Water Supply and Drainage (SH 3099-2000) (Sun and Li, 2006).

The standards on water quality monitoring methods mainly include two categories, i.e. the standards of water sampling, sample keeping and management technology and the standards of experiment analysis and determination method. By the end of Sep. 2001, the State Environmental Protection Administration totally promulgated 134 national standards about water quality monitoring methods, which accounted for 58.5% of the total national standards on environmental protection. In the promulgated standards, there are 6 standards about water sampling (including the design of sampling, technical guidance, sample keeping, sampling of water in lakes and reservoirs, the general principles for rainfall sampling and the collection and keeping of samples), 3 standards about the determination of the physical properties of water (temperature, color and turbidity), 2 standards about industrial wastewater test method (test of total nitro-compounds), 4 standards about aquatic organisms and their toxicity (determination of microorganisms, determination of acute toxicity, determination of various substances' acute toxicity to algae and determination of various substances' acute toxicity to freshwater fish), 11 standards about rainfall test method, 13 standards about the method for determining radioactive substances in water (mainly including strontium, uranium, radium-226, thorium, kalium-40, plutonium, polonium and iodine-131); 25 standards about organic pollutant determination method and 70 standards about the determination of inorganic pollutants in water. However, all these standards were promulgated before 1998.

In the industrial standards promulgated by the State Environmental Protection Administration, there are 14 standards about water quality analysis and determination methods, all of which have been promulgated in recent years. These standards specify the methods for determining boron, trichloro-aldehyde, total salt, beryllium, sulfide, chemical oxygen demand of perchloric wastewater, total organic carbon, repeftal, dibutyl phthalate, vinyl cyanide, chlorobenzene, polychlorinated benzodioxole, polychlorinated benzofuran, absorbable organic halogen (AOX), inorganic negative ion and etc. The quality of water environmental monitoring stations is a problem at present. From 1998 to 2001, the Ministry of Water Resources made a measurement accreditation and changed the working permit. Based on the Statistical examination pass rate from the spot checks, checks 1st examination failure rate is 33% in 1999, 36% in 2000, and 42% in 2000. The quality of monitoring has seen a decline phenomenon. The quality of the staff also needs to be further improved (Gao Juan and Li Guibao, 2006).

## 5.5 WATER QUALITY PLANNING AND ASSESSMENT

Because of water deficiency, many cities and areas have made water resources planning in recent years. Water quality (water environment) is an important part of the planning. Hu Jinmin (2005) has studied the content of the overall water environment plan of Shijinghe city and the planning method. Yang Jie et al (2004) has comprehensively evaluated the water quality of the Wuhan reach in Hanjiang River with the artificial neural network (ANN) method. In the comprehensive evaluation of water quality, the results obtained by using those traditional methods for determining the weighting factors are normally quite subjective. ANN method now can effectively exclude the interference of some subjective factors in determining the weighting factors. A three-layer back-propagation (BP) ANN model is constructed for the comprehensive evaluation of the multi-factor water quality. Taking BOD<sub>5</sub>, NH<sub>3</sub>-N and TP as the evaluation factors, the application of this ANN method indeed are more objective than those obtained by the traditional methods and are very consistent with the observation.

The water bodies with different environmental functions in the areas crisscrossed by waterways have different requirements on water quality. Xu and Chen (2005) have assessed the water quality of one reach of the Cache River with the synthetic index method and grey clustering method. The monitoring sites of water quality were arranged according to the water quality characteristics of wastewater, and the pollution sources and hydrogeology were investigated comprehensively. Based on the water quality assessment on main factors selected, it is concluded that the results of the two methods are almost the same, but the result from synthetic index method is more suitable and correct. In view of the uncertainty of indexes for evaluating water quality, Zhang and Liang (2005) applied the entropy value theory to combine with fuzzy matter-element method to establish an entropy fuzzy matter-element model. The coefficients of weight in this model are derived from the avail value of data reflecting the information entropy, by this method the problem of weight allocation can be avoided. The calculation result for an example is compared with those by integrated evaluating method and attribute recognition model. It indicates that the proposed method is reasonable and practical.

Many articles have published in respect of water environment quality appraisal, but few substantial breakthroughs have been made. Li and Zhao (2004) have discussed the model of the appraisal and the forecast for the Chaniang River's water quality, carried through qualitative and quantitative analysis on the recapitulative situation and inter local distributing of the Changjiang river's water quality for near two years. Based on the mainly statistic datum for near ten years (hydrology years), some compounding models in consisting of several kinds of excessive functions, and trendlines of relatively statistic datum have given, in which developing trend of the percentage of every kind of water quality I -V, in ferior V and the trend of the quantity of pollution water (wastewater) have shown, At the same time the state of water pollution of the Changjiang river's water for future 7 years have been forecasted. In the end some suggestion to solve the problem of water pollution of Changjiang River has been listed. Combined with the project of Comprehensive Assessment for River Water Quality and Quantity,

Xu Yeping (2005) reviewed sampling interval, water quality simulation and prediction, water quality evaluation for different quantities, dynamic water environment capacity evaluation. Methods, technique line, and available conclusions of the research were introduced, and suggestions for further study were also made.

Based on water resources survey and evaluation in China, Tang et al. (2006) analyzed the groundwater quality systematically. The assessment of the hydrochemical of groundwater shows that most groundwater is of bicarbonate type with high hardness and TDS (Total Suspended Solids). The PH of groundwater is mostly neutral and alkaline. As the groundwater quality is poor naturally, the recognition of hydrogeochemical characteristics of natural groundwater is important for the groundwater quality protection. Through analyzing the comparison of the consistency of over-standard parameters with the evaluation results and statistical analyses of the distribution features in the groundwater samples, Zhang and Yan (2005) adopted the fuzzy evaluation method as a suitable method to evaluate the groundwater quality in Tianjin. The evaluation results show that phreatic water in Tianjin is of bad quality, and the area of water in Class V of national surface water quality standard accounts for 70 percent of the total plain area, and the quality of deep confined groundwater is also bad, with the V class water accounting for 40 to 50 percent of the total area.

In accordance with the characteristics of the organic pollution on the groundwater, Yin and He (2006) established a graded comprehensive index model, with clarified levels and explicit physical significance, is established herein based on both the limit of detection and the single contaminated factor standardized in the secondary standard given in the relevant EPA water quality standard; with which the problems from the range produced from the primary evaluation standard concerned are avoided. The case study demonstrates that better applicability to evaluate the organic pollution on the quality of the groundwater can be obtained from the model. Recently, as economy is rapidly thriving in Urumqi-Chanji region and a new economic development area in the east of Miquan is quickly extending, more and more water supply is urgently needed. On the other hand, because of the especially geographic position of the city, surface water in the region has been polluted, resulting in contamination of groundwater at some degree. Zeng (2006) have collected and analyzed several groundwater samples in the rural region in the city. Based on investigation, the quality of groundwater in country area of Miquan was evaluated and some suggestions on protecting and managing the water environment in the region were introduced.

## 5.6 WATER QUALITY SIMULATION AND CALCULATION

The establishment of water quality simulation model and calculation is indispensable for water quality planning and appraisal. The field of water quality simulation and calculation is very

active. Chen Shouyu et al. (2005) have put forward a new model in comprehensive evaluation of water quality. Under systematic view, a comprehensive evaluation model for water quality was established based on variable fuzzy sets method, and the water quality evaluation was converted from the qualitative assessment to a quantitative one. The method can scientifically and reasonably determine membership degrees and relative membership functions of water quality indexes at level interval. Weights of indexes can be obtained binary comparison and quantification based on the importance of indexes. By calculating the characteristic value of each level, water quality of the Yongding River in Beijing was evaluated using the variable fuzzy sets method, which showed that the proposed method was feasible. The result of calculation indicates that this plan is effective and universal and applicable to various comprehensive environmental quality appraisals (Chen Shouyu, 2005).

Fan Li-ping and Yu Haibin et al. (2005) introduced the river water quality model No.1 (RWQM1) developed by the International Water Association (IWA). It is an effective approach to improve river water quality and to protect ecological environment by integrated management of urban wastewater with the view of better water quality. This model was described like the standard Activated Sludge Model (ASM) and the organic matter and nutrients were characterized by COD. Water quality constituents and model state variables characterizing circling of carbon, hydrogen, oxygen, nitrogen, and phosphorous were selected in the model to describe the cycling process under aerobic and anaerobic conditions. Connected directly with Activated Sludge Model (ASM), the model can be used in the decision, planning, monitoring of the integrated urban wastewater system (Fan and Yu, 2005).

WASP6 is an enhanced Windows version of the USEPA Water Quality Analysis Simulation Program (WASP). WASP 6 includes 4 dynamic equilibrium calculation processes, such as dissolved oxygen, eutrophication, toxic and organic compounds. The main features of WASP 6 are as follows: ① the development of user-friendly Windows-based interface; ② include the WASP identifiable conversion data format; ③ eutrophication and organic contaminants with the efficient processing module; ④ the results of WASP with the measured one can be directly compared in curve. Yang and Xiao et al (2005) have used WASP6 to simulate the present water quality for Xiangfan Reach of the Hanjiang River. Water quality indices, including BOD<sub>5</sub>, NH<sub>3</sub>-N, and DO, were studied. The simulation results were verified using the field data in 2001. It is showed that the averaged relative error of BOD<sub>5</sub>, NH<sub>3</sub>-N, and DO are 10.7%, 11.0%, and 5.6% respectively. Results indicated that the application of WASP6 to the water quality simulation in Hanjiang River is satisfactory.

Zhang Xingnan and Geng Qingzhai et al (2004) have developed a software system for simulating water quality based on the platform of GIS. It possesses the functions of input data processing, real-time modeling calculation and visualized output of calculation result. The interface of this system is friendly and the display of the output is directly perceivable. Water quality model coupled with the GIS have the advantages in some aspects : 1、 the use of digital

devices and GIS to sum and mesh the study area, will significantly reduce the preparatory work for the model, reduce human error and improve the accuracy; 2、 the grid vector function of GIS can be used to produce high-quality color filled concentration distribution graph; 3、 the spatial data processing functions of GIS calculated the real-time concentrations, the average concentration of the time and space and showed that output. Query Module can visit the results of inquiries. This can provide an effective and scientific instruments for the decision makers to monitor and manage the regional pollution; 4、 the model results are more directly and explicitly with the visual language system; 5、 in combination with computer technology to achieve a centralized data management and information sharing. The system is applied to the information management system of aquatic environment capacity of Jiangsu Province, China.

Gong ChunSheng and Yaoqi et al (2006) have developed 2-D plane flow-water quality-bed sediment pollutant coupled model. The control equation of water quality considering the bed sediment pollutant is deduced according to the characteristics of turbulent disturbance. The equation is coupled with shallow flow equation to establish the depth averaged 2-D plane flow-water quality-sediment pollutant transport model. Under the framework of finite volume method, the Riemann approximate solver is applied to obtain the numerical solution of the equation. The model is used to simulate the total phosphorus transport in the Xuanwu Lake, Nanjing. The result is in good agreement with observation data.

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# CHAPTER 6 WATER RESOURCES SYSTEM

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## 6.1 RESEARCH OF HYDROLOGY AND HYDROLOGICAL CYCLE

### *6.1.1 Research of Water Resources Evaluation*

The evaluation on water Resources in China has developed during 2002~2004, since the first time performed in 1980. According to the uniform technologic demand, and adopted the working means as three classes linkage of country-River Basin-province and cooperation of industries, departments, and subjects, the results of the evaluation was summed up after several harmonizing, testing and auditing step by step. The results, including quantity evaluation of water Resources, quality evaluation of water Resources, investigation and analysis of water Resources exploitation, and survey and analysis of water environment, which reflected external condition of the water Resources in our country and problems in the process of exploitation in the round and by the numbers.

### *6.1.2 Research of Hydrological cycle under Nature-Manpower-Dualistic-Driver*

The more people interfere in water Resources during hydrological cycle progress, the more critical social property of water Resources has, meanwhile, the exploitation, utilization and management of water Resources is faced with more crisis and challenge. Academician Wang Hao, professor in Institute of Water Resources and Hydropower Research, founded Nature-Manpower dualistic water circulated theory, and established Nature-Manpower dualistic water circulated model based on the theory, coupled with WEP-L distributed hydrological model worked out by Jia Yangwen and River Basin water Resources ration model. The model, not only reappeared the exchange process among atmosphere, vegetation, surface, soil and subbase under the interfere of people in Huanghe River Basin genuine, also revealed water Resources evolving mechanism and rule under changing environment in Huanghe River Basin quantificational, at one time, it evaluated the effect to water Resources by decades' changing climate and several kinds of human influences dynamically and separately.

### 6.1.3 New Techniques Used in Water Resources Evaluation

Water Resources evaluating technology is the core technology in hydrology and hydrological cycle technical system. Conventional evaluating technology is guided by influx water Resources circulated theory, and the primary object is runoff cycle. Conventional evaluating technology and rules cannot suit the demand in order to exert the integrated benefit under new condition any longer as a result of embedment in exploitation of water Resources. Under this situation, Wang Hao pointed out a dynamic full aperture layering evaluating method, and reformed water resources evaluating technical system. This method analyzes the resources' structure of precipitation based on validity, controllability, and renews ability, and actualizes layering evaluation of broad sense water resources, narrow sense water resources, runoff kind of water resources, and available national economy mobilization. This method can be achieved by dualistic water resources evaluating model, which is coupled with distributed simulated model and adjustment model. Variable underlying surfaces and manual water intake is the variable of model in order to achieve water resources dynamic evaluation.

## 6.2 CONTINUABLE UTILIZATION OF WATER RESOURCE

### 6.2.1 Scheme of Water Resources

As the economy is developing day by day, water resources optimal allocation is developing in the area of water resources basic research. The main achievements are as follows:

In order to satisfied the demand of water resources' unified management and allocation in river basins, the research of *Index system and method for assessing water resources renewability of the Yellow River Basin* has started up, which is an example of north semi-arid river basin in the research of water resources unified management and allocation. This project has two significant harvests in the basic theory and research in water resources, enumerated as follow: 1. it is the first time to figure out and practice four-layer-controlled-structure in river basin's water resources allocation which based on simulation-allocation-evaluation-scheduling, and provide an intact system in the research of river basin's water resources allocation. 2. it is the first time to couple and nest water resources macroscopically allocated scheme and real-time scheduling scheme, which provide a effective measure to unified manage river basin water resources.

The project of *Studies on Rationally Water Resources Allocation under Economic and Ecological System of Ningxia* figured out a new theory and its research method of broad sense water resources rational allocation. This project starts from the rational allocation of broad sense

water resources, and its aim is to satisfy the demand of water supply in society and eco-environment, which prodigiously maintains the sustainable development of regional society-economy-ecosystem. In the content of allocation, this project can not only allocate controllable surface water and ground water, but also can allocate semi-controllable groundwater and even un-controllable precipitation, which vary the contents of allocation.

### *6.2.2 Construction of Water-Saving Society*

Since the 16th National Party Congress to propose ways to implement the scientific concept of development and building a resource-saving and environment-friendly society, the strategic approach, by the idea of building a water-saving society in China to develop pilot projects to be deeper and broader. Our country established Zhangye City in Gansu Province, Mianyang City in Sichuan Province. Dalian City in Liaoning Province, etc. 12 national pilot project for a water-saving society and achieved initial success. Zhangye success as a pilot representative, a series of basic experience in building a water-saving society in China has formed, and that preliminary answer the question of what is a water-saving society, should it be able to build a water-saving society, and how to build a water-saving society; This experimental plot laid the foundation in building a water-saving society under Chinese characteristics. In March, 2005, the replication of *plan of structure of water-saving society in Ningxia* made Ningxia the first provincial pilot project.

In recent years, a large number of cities and regions have drafted plans for the construction of a water-saving society and measures followed these pilot cities, which has great significant in perfecting our aim, mode, measure and content of the construction in building a water-saving society. On this basis, in 2005, Hydraulic Ministry launched the "National" 11th Five-Year "plan for construction of a water-saving society" in the preparation. The plans clarify the strategic plan of building a water-saving society; clear the goal in building a water-saving society during "11th Five-year Plan" period; figure out countermeasures and emphases of development, and develop social systems and the construction of major water-saving plans for the implementation of the project. This plan is a program of action in this period for the construction of water-saving society. As one of the special plans, Hydraulic Ministry launched project in constructing a water-saving society in Yellow River Basin.

Considering the Chinese characteristic of water scarce condition, an advanced theory, construction of water-saving society, which is advanced in international water-saving area, has

been figured out. However, construction of a water-saving society is a complex, comprehensive and long-term systems engineering, which involves water conservation projects, technology, and many other aspects of economic management. The complexity and chronicity in building a water-saving society decides that the project should be done steady by continuously review and exploration.

### *6.2.3 Efficiency of Water Reuse*

Agriculture is the principle part in economy water supply. In our country, efficient use of irrigation, precipitation, crop moisture is the focus in improving agriculture water resources efficient. On the aspect of basic theories on the efficient use of water resources in agriculture, some scholars figured out some concepts, such as Limited irrigation, No-full irrigation, Regulated deficit irrigation, etc. The emphases of water-saving is changing from saving in supplying and irrigating to bio-water-saving, precise control, and scientific management, and the real amount saving water is calculating the decreasing amount of evapotranspiration. In the past 20 years, China's basic research in the efficient use of water resources in agriculture has achieved important progress, and not only introduce the concept and calculation of the actual saving, but also make a number of independent innovation, such as Natural Science Foundation of major projects, "the North China Plain water-saving agriculture in basic research". The study made a breakthrough in many aspects, such as regulation of water recycling and water saving farmland law, SPAC water and farmland into a typical operation and regulation, and Regulating the biology and water-saving agriculture. NSFC fund nearly 50 studies on the basis of efficient use of water resources in agriculture in the past five years, and made great progress in the law of moisture transferring, simulation of water nutrient transport, crop water requirement and the calculate model in mechanism of drought. Judging the trend of development, irrigation is transformed form traditional abundant irrigation to water-saving high-yield absent irrigation, and the experiment is changing from normal state test to inferior state test accordingly, and water supply is changing from simple distribution by time to special allocation.

In China, industry water is developing toward water-saving techniques integration and water system optimization. Besides, the circulated economy has gradually introduced into water-saving areas in cities, and renewable water technique and policy has gained much attention. In 2005, five ministries in the State Development and Reform Commission jointly issued *China Policy Commitment Saving Technologies*, and this covered relative water-saving technology and the

current domestic economic policies comprehensively. Generally speaking, urban water micro-efficient water supply's technology has been developed by leaps and bounds, while urban water circulation, water efficiency evaluation, theoretical conversion and safety standards and mechanisms of efficient use of water and other basic research is rather weak.

#### *6.2.4 Reproducibility of Water Resources*

As the problem of water resources scarcity is more and more grievously, the research of water resources renewable capacity in China has received much attention in recent years. In Yellow River 973 research project, we solve the evaluation problem of renew ability in natural resources and urban cities' resources. The main characteristic of water resources renews ability is it needs considering natural renew ability, social renew ability, and artificial composite renew ability in water resources.

### 6.3 THE RESEARCH OF ZOOLOGY EVOLVEMENT UNDER THE CONTROL OF THE EVOLVEMENT OF HYDROLOGICAL CYCLE

By the influence of human activities, kinds of ecosystems are degrading in an unprecedented speed. The research on the protection and restoration of ecological system is attached many Chinese scholars. Studies on eco-hydrology progress can seek academic support in constructing rational eco-hydrology pattern and sustainable use of water resources. As some international projects, such as BAHC in water circulation and International auspices of UNESCO's international hydrological program (UNES CO/IHP2.3~2.4), etc. are carried out, research on eco-hydrology progress has developed rapidly and gained extensive attention.

Ecological protection, restoration and water accounting relies on the mechanism of eco-hydrology interaction. Domestically, water driven ecological succession theory, Layered Structure Theory was constructed by the comparison with water succession and ecological succession in the program of the research in north-west; mean while, a correspondence between groundwater and vegetation was also established in the rolling project. In the special study in Heihe River Basin, in addition to the use of ecosystem model to forecast downstream oasis' change, model of the relationship between vegetation coverage and water-salt was also established.

## 6.4 RESEARCHES ON OTHER ASPECT

### *6.4.1 Research of Edaphic Water*

The water cycle is the process of transforming the dynamic expression. With the changing of the water cycle research, the existence and evolution of forms of water change, resulting in the further expansion of the concept of water resources. As for the water cycle, the maintenance of the ecological environment and the vegetation growth, holard plays an important role in them. People gradually pay attention to the evaluation of it. Falkenmark and other scholars in 1995 published the concept of green and blue water. Precipitation stored in the river, lakes or aquifers is called the "blue water", precipitation stored in unsaturated soils, which back into the atmosphere by the evaporation of forests, grasslands and farmland is called the "green water." With the publishing of the concept of "green water", the evaluation of the "green water" resource caused widespread concern in the world. Stockholm International Water Research Center consider that the green water is an important resources of human well-being, and draw the outline of a new management strategies of water cycle with a concise water sysle chart; International Fund for Agricultural Development (IFAD) and the Global Water System Project (GWSP) also committed themselves to the research of "green water". Nevertheless, the relevant research is still in its infancy stage with no systemic theory. In China, academician Chen Guodong and academician Liu Changming have "green water" explained a connotation of resources; Academician Wang Hao brings up the concept of generalized water against the validity of the geometrical shape in the water cycle process[23], included the "green water" resources and "blue water" resources, and apply them in the Yellow River Basin. Not only evaluates the "Blue Water" ,a narrow assessment of water resources, but also completely evaluates different forms of the evapotranspiration of holard. To some extent, he achieves a coupling and comprehensive evaluation about "blue water" and "green water". Meanwhile, the "green water" essentially consumes quantity of holard of the vegetation evapotranspiration. He further evaluates the efficient and inefficient, the ineffective and effective of evapotranspiration in the Yellow River valley. This lays the groundwork of making a transit of an ET overall control of the region, rational use of "green water" resources, coordination of the "blue water" and "green water" to the rational allocation and effective utilization of resource.

### *6.4.2 Initiatory Distribute Theory of Water Resources Usufruct*



In China, due to the water resources belong to the state, and not be allocate the initial water rights adopted some general principles through legislation, while contradiction between the supply of and demand for water have increased, making the initial allocation of water rights research developed gradually since the end of last century. Not only many scholars devote into the research and debate on the meaning of the water rights and the principle of water distribution, initial water rights distribution is attempted in some valley. In 1987, a water divide indicator in the provincial Administrative Regions at the Yellow River Basin is approved and promulgated by the State Council. This is the earliest byelaw of initial allocation of water use rights. The allocation and scheduling in the work of exploitation and utilization the water resources in the Yellow River valley is still based on *Yellow River for water distribution program*; Zhangye in Heihe River Vally established two indicators management systems on total control and Quota Management. The volume of water was strictly controlled, the cities total water rights gradually allocated to counties, townships, villages, even to households. This makes the efficiency of water use increase greatly. Dalinghe introduced "water rights allocation of the initial work program in Dalinghe Vally", called for the establishment of initial water rights distribution system, and worked out the initial water rights allocation program.

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# **CHAPTER 7 APPLICATION OF REMOTE SENSING IN THE MANAGEMENT OF HYDROLOGY AND WATER RESOURCES**

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## **7.1 INTRODUCTION**

Remote sensing has been defined as the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by sensor that is not in direct contact with the target of investigation. During the period of year 2003 to 2006, the remote sensing technique and its application is rapidly developed in both the world and China. More and more sensors with higher spatial and temporal resolution were developed and put in optional use or research works in various fields. In China, Meteorology Satellite FY/1D and FY/2C were respectively launched in May of 2002 and in October of 2004. The Earth Resources Satellite CBERS/02 was successfully launched in October of 2003. The Ocean Satellite HY-1 was successfully launched in May of 2002. Miniature Satellite BJ-1 was successfully launched in October of 2005, and put in operation in June of 2006. These satellites have provided rich information for almost all of the departments all over the country. Also, the remotely sensed data play very important roles in the field of water resources. Compared to conventional hydrological measurements, remote sensing has certain significant advantages, but also some disadvantages. In this chapter, remote sensing application to hydrologic monitoring and modeling, as well as water management in recent years are discussed with emphases on water cycle research, flood and drought hazard monitoring and evaluation, irrigation and drainage management, monitoring of ecologic environment related to water resources development and utilization.

## **7.2 REMOTE SENSING APPLICATION TO HYDROLOGIC MONITORING AND MODELING**

### *7.2.1 Remote Sensing in Hydrologic Modeling*

For hydrologic modeling, the time series of runoff and possibly precipitation, and a climatological estimate of monthly evapo-transpiration are very important, which may be obtained by the station-based observation system. The model development based on surface station for a large river basin is almost impossible due to the scarcity of land surface observations and difficulties in representing hydrological processes at large scales. Remote sensing may provide the required data, such as information on land surface/cover, soil texture, initial soil moisture and topography, for hydrological modeling at regional to global scales. For modeling land-atmospheric hydrologic interactions, remote sensing provides both model parameters and meteorological data, like surface air temperature, humidity, precipitation and radiation.

Liu S.C. and Zhang W.C. (2004) gave a review of application of remote sensing to retrieval of precipitation, land use/ cover classification, leaf area index, albedo, land surface heat flux and some indirect parameters in distributed hydrological model, and proposed a framework for developing a distributed hydrological model by integrating GIS and remote sensing. Wu J.F. and Liu C.M. (2002) considered that the data obtained from remote sensing is still hard to use in hydrological model directly, and the hydrological scale problem is the important aspect for hydrological modeling using remote sensing. Li D.F. et al. (2005) developed a physical-based distributed hydrological model to simulate the watershed runoff response process under climate and land-cover changes in the head area of Yellow River by using remote sensing and GIS. Liu C.M. et al. (2004) developed distributed hydrological model for Yellow River basin, which is a part of National Key Project “Yellow River Water Resources Evolution Law and Renewability Maintaining Mechanism”. The area precipitation data obtained from meteorology satellite image was treated as an input for the model.

### *7.2.2 Remote Sensing in Water Cycle*

Remote sensing plays important roles in water cycle research especially for regional scale or watershed scale, and the hydrological cycle components may involve precipitation, evapotranspiration, soil moisture, surface water as well as groundwater.

**Precipitation** is of primary importance in hydrology. It shows large and frequent spatial and rapid temporal variations. The scales over which precipitation occurs are so large that methods of measurement are wide ranging and usually complementary. Point measurements are insufficiently representative of catchment scales. So remote sensing becomes a very powerful tool for obtain the precipitation information for water cycle research. Currently, the emphases are

put on the application of radar, ground-based or space-borne radar, as well as passive microwave data. The approaches based on visible and infrared satellite data were also developed. Two basic approaches namely the “life-history” and the “cloud-indexing” are widely used. Wang J.H. (2003) developed the area precipitation model according to the regression relationship between cloud and point precipitation by using GMS image and surface rain gage. The model prediction precision reached to 90% in Yellow River Basin. Huang Y. (2006) developed the Flood-Causing Torrential Rain Forecasting and Warning System for Huaihe River. Rainfall was estimated by using of satellite and CIN RAD-radar data. Furthermore, from GMS-5 multi-channel data, the empirical formula of rainfall measurement was developed by using statistic method in Huaihe River field. The model was tested verified by the application of flood season in year 2003.

**Evapotranspiration** plays an important role in earth-atmosphere interaction process, and has attracted a rather considerable amount of attention and research work. The researches are related to the use of thermal infrared observations and the land surface heat balance, as well as spectrum of multi-spectral measurements by space- and airborne instruments to estimate potential evaporation and crop water requirements for the purpose of water management especially in irrigation regions. Wang J.M. (2003), Guo X.Y. (2004) and Sun M.Z. (2005) et.al. gave a review of advances in the monitoring approaches of evapo-transpiration with remote sensing data and its application in water resources management. Sun M.Z. (2005) et al. developed SEBAL model by using spectral radiances recorded by satellite-based sensors, plus ordinary meteorological data, to solve the energy balance at the earth's surface, and to evaluate evapo-transpiration in the Haihe River Basin. Hu M.G. (2006) considered ET technique of remote sensing monitoring to realize the sustainable management of agricultural water supply in Beijing City. Pang Z.G. et. al. (2004) developed the evapo-transpiration estimation model based on energy balance by using remote sensing, and the approaches were demonstrated in Heilongjiang province.

**Soil moisture** is the interface between the solid earth surface and the atmosphere, and is very important to understand the hydrological cycle process in both smaller and larger scales. However, soil moisture is a very difficult variable to measure, not at a point in time, but at a consistent and spatially comprehensive basis. It has been shown the soil moisture can be measured to some extent by a variety of the electromagnetic spectrum. Successful measurement of soil moisture by remote sensing depends on the type of reflected or emitted electromagnetic radiation, and only the microwave region of the spectrum can provide a quantitative approach to estimate soil moisture under a variety of topographic and vegetation cover condition (E.T. Engman, 2000). Zhang H.M. and Sha J.M. (2005), Zhang C.L. (2006) summarized the theories

and methods of soil moisture monitoring by remote sensing, including microwave remote sensing monitoring, thermal inertia, the composite index of crop vegetation and brightness index, as well as hot infrared monitoring. Bao Y.S. et al. (2005) discussed the estimation approaches of soil water content and wheat coverage with ASAR image. The authors concluded backscattering, which was greatly affected by land surface roughness and soil texture, is a key problem which must be considered in the retrieval of soil water content, and the vertical polarization backscattering coefficient is significantly correlated to soil water content while the horizontal polarization backscattering coefficient is significantly correlated to both soil water content and wheat cover.

**Surface water** may occur as lakes, reservoirs, rivers as well as snow and ice. Remote sensing can be used to estimate the area extent and water content of these surface water-bodies, as well as the changes in water regimes. One of the main obscurations to remote sensing application is the limitation of relatively cloud-free and daylight conditions. Microwave satellites offer the potential all-weather application and the synergistic application of combined SAR and optical remote sensing for surface water estimates needs to be examined more closely (G. Kite and A. Pietroniro, 2000). Yang G.D. et al. (2003) presented a method for analyzing the surface water system in plain areas with the help of GIS, DEM and remote sensing. Hong Z.G. et al. (2006) utilized the various sources of remote sensing images combined with DEM and DOM data to analyze the characteristics of surface water system including springs, lakes, water resources of head regions in Tsinghai and Tibet plateau. Wang Y.J. and Zhang Y. (2005) developed a momentum BP neural network model to retrieve the water depth information for the South Channel of the Yangtze River Estuary using the relationship between reflectance derived from Landsat ETM+ satellite data and water depth.

**Groundwater** is essentially a subsurface phenomenon, so the common current remote sensing, mainly recording features on the surface, can only provide information to indirectly help qualitative or semi-quantitative analysis of groundwater system with simple geological conditions and shallow groundwater tables. The application of remote sensing involves two aspects, i.e. the conceptualization of the hydrogeology and water budget (Allard M.J. Meijerink, 2000). Abduwasit and Qin Q.M. (2004) presented a review of the development and progress of remote sensing application research on groundwater exploration, as well as the methods of regional groundwater monitoring, delineation and detection. Tashpolat Tiyp et al. (2005) developed a quantitative model for deriving groundwater level in oasis-desert ecotone in arid area by using Landsat-7 ETM+ data.

### *7.2.3 Soil Erosion*

Soil erosion, as a natural process caused by water, wind, and ice, has been accelerated by human activities. The consequence from soil erosion on loss of productivity, land degradation, and off-site, downstream damages from eroded soil particles on water quality become major concerns around the world. Soil erosion is characterized by spatially and temporally distribution on the landscape, it is difficult, time consuming, and expensive to use the classical soil erosion measurement techniques. The remote sensing techniques that measure the spectral properties of landscape are most commonly applied to soil erosion management and research. The data sources of remote sensing involve optical sensors like LandSat/TM, SPOT, IRS, AVHRR, ground-based and airborne laser system, as well as Synthetic Aperture Radar (SAR) for evaluating large-scale soil erosion patterns and rates. The application of remote sensing techniques to study and monitor soil erosion may include the following general approaches: photointerpretation /photogrammetry, model/GIS input, spectral properties, and topographic measurements. Xue L.H. and Yang L.Z. (2004) Zhou W.F. et al. (2005) gave a brief introduction to the theory, technique and methods of soil erosion with remote sensing, and discussed the future development trends and prospect of soil erosion with remote sensing. Bu Z.H. et al. (200) introduced the advance of quantitative remote sensing for monitoring annual soil erosion and its application in Taihu Lake basin. Tan B.X. et al. (2005) presented a method for extracting vegetation coverage and estimating soil erosion by remote sensing data combined with surface investigation information and DEM, and applied in Guishuihe river basin of Beijing City. Jiang H. et al. (2005) utilized remote sensing to establish the Universal Soil Loss Equation (USLE) for the dynamic monitoring of soil erosion in Changding County of Fujian province.

### *7.2.4 Water Quality*

Monitoring and assessing the quality of waters in rivers, lakes, reservoirs, estuaries, and oceans are critical for managing and improving water resources and environment. Classical techniques for measuring indicators of water, in situ measures or laboratory analysis, are time consuming and expensive, although they can give accurate measurements. Remote sensing of indicators of water quality offers the potential of relatively inexpensive, frequent, and synoptic measurements. The indicators like suspended sediments (turbidity), chlorophylls, dissolved organic matter, thermal release and oils produce visible and/or thermal changes in surface waters that can change the energy spectra of reflected solar and/or emitted thermal radiation from



surface waters. This fact is the basis for using remote sensing to estimate water quality of an individual water body or multiple water bodies across the landscape. Most chemicals do not directly affect or change the spectral or thermal properties of surface waters. Measuring water properties affected by chemicals can only be inferred indirectly from remotely sensed measurement of other water quality parameters affected by these chemicals (J.C.Ritchie and F.R.Schiebe 2000). With the coming availability of hyper spectral data, more parameters can be quantified using remote sensing technique. Yang Y. P. et al. (2004) Zhou Y. et al. (2004) Liu C.D.et al. (2005) presented a review of the current situation of application of remote sensing techniques to inland water quality monitoring and its development process, and explored the principles and methods of applying different kinds of remote sensed images. Lu H. et al. (2005) discussed three common methods of water quality inversion algorithm including empirical model, bio-optical model and artificial neural network model and their application limitation. The authors also discussed the main factors determining water quality retrieve accuracy, and pointed out the atmosphere correction models need to be developed for water quality remote sensing. Lei K. et al. (2004) proposed the models for the estimation of concentration of chlorophyll and total nitrogen in Taihu Lake based on the regression analysis between the CBERS-1 CCD data and semi-synchronous ground referenced data, with the consideration of the spectral characteristics of water components. He L.H. and Yang J.G. (2005) utilized NOAA/AVHRR images to measure hue, temperature, and transparency, in order to discern the different pollution level of water bodies in Yangtze River delta region by remote sensing. Yin Q. et.al.(2005) developed the optimal channel combination models for retrieving chlorophyll and suspended sediment concentration from remote sensing data of FY-01C multi-channel scanning radiometer, Landsat TM, SeaWiFS of Seasat and a supposed set of remote sensing channels. The models were used to estimate the eutrophic degree, its spatial distribution and its variation with time in Taihu Lake and Dianchi Lake. Wan Y. (2003) studied the possibility of using hyper spectral remote sensing to detect the degree of pollution. The water spectra can not only reflect the relative pollution degree but also determine the types and characteristics of water pollution.

### *7.2.5 Snow and Ice*

Ice and snow, storing most of the Earth's freshwater, are important components of the hydrological cycle. The ice and snow cover, also called as cryosphere, carry information on the other system components like climate system. Moreover, about one billion people depend on

water resources originating from snowmelt runoff. Melt-water runoff is extensively used for hydropower generation, irrigation or freshwater supply. The positive aspects of ice and snow, particularly as freshwater, go in hand with a large number of natural hazards like floods (the outburst of subglacial lakes), slushflows, ice fall and so on. The investigation and monitoring of ice and snow cover is essentially important. However, the presence of ice and snow is confined to cold climates either at high altitudes or high latitude (or a combination of both). In many cases, ground-based observations of ice and snow properties are difficult to obtain in the respective regions due to lacking infrastructure and complex topography, harsh climates. Remote sensing has received increasing significance over last two decades, since it is the only feasible way for acquisition of ice and snow information. The EOS Science Plan (NASA, 1999) comprehensively describes the current state of knowledge, the unsolved problems and new possibilities and strategies of ice and snow research by remote sensing system. The recent researches focus on radiative transfer models suitable to correct high-resolution VNIR and SWIR images for topographic adjacency and bi-directional reflectance distribution function (BRDF) effects, accurate retrieval of ice and snow properties from remote sensing data in particular snow water equivalent at high spatial and temporal resolution to develop the snowmelt runoff model, as well as the subpixel analysis algorithms such as the retrieval of snow properties in forested areas or detection of cloud contaminated pixels. Huang X.Y. (2004) presented a review of the application of microwave remote sensing in monitoring the snow and ice and its future directions. Che T. et al. (2004) used the SSM/I brightness temperature data to estimate the snow water equivalent (SWE) in Tibetan Plateau. The authors established an improved algorithm to retrieve the snow depth from the difference of 19 and 37 GHz brightness temperatures in horizontal polarization, and developed a statistical algorithm to estimate the snow water equivalent from the differences of 19 and 37 GHz in vertical polarization. Zhang Z.J. et al.(2004) put forward an effective method of distinguishing snowpack, probability combined with threshold, by using NOAA-16/AVHRR3 and FY-1D/MVIRS, and established the operational system of snow cover monitoring. The features of winter snow cover distribution in China, from 1996 to 2003 were discussed. Liu Y.J. et al. (2003) calculated the percent of snow cover in west of China by the multi-spectral analysis of AVHRR data.

### 7.3 WATER MANAGEMENT WITH THE AID OF REMOTE SENSING TECHNOLOGY

### *7.3.1 Flood Hazard Monitoring and Assessment*

Flood severely affects the life and environment at different places over the country each year. It causes considerable damage to buildings, roads, villages, towns and agriculture. Often floods cause also a high loss of human or animal life. Heavy rains, snow smelts or typhoons are reasons for the generation of floods. Rapid identification and response to flooded areas can help to safe life and to protect some important areas. Real-time flood monitoring with high resolution images in the optical wavelength range are desirable but usually not possible because of the cloudy and rainy weather conditions at this time. Because of their independency of weather and light conditions, Synthetic Aperture Radar data are used for these purposes. After the floods a precise assessment of the damaged areas can help local authorities in planning and organizing the reconstruction and future protection measures. Data from optical instruments in different spectral channels of satellites like SPOT or LandSat are very helpful in precise assessment of the situation and damages. Liu Y.L. et al. (2003) put forward the concept of normal water extent (NWE) to define the minimal values for the assessment of flood losses, referring to some special areas around the river, lake, reservoir and dyke and to the land use etc., which are easy to suffer the flood during the rain season. The basic data for NWE are TM or NOAA/AVHRR images. The authors set up the NWE database for seven large river basins of China, which were used to monitor and assess the floods in China since 1999. Yi Y.H. et al. (2005) put forward an algorithm to calculate the depth distribution within the inundated region extracted from the satellite imagery, which can be applied in the flood monitoring and loss evaluation. The algorithm combines the flood region with DEM and acquires a smooth elevation distribution in the flood borderlines after efficient error control due to inadequate precision in the satellite imagery processing. Li D.K. (2005) used MODIS data to identify the flood areas with high bedload content in Weihe river flood of 2003 and concluded that the method of vegetation and the false color composition of channel 2, 5 and 6 were effective to pick up the areas of a flood with high bedload content. Yu T.S. et al. (2003) discussed the monitoring and prediction approaches of drought and flood disasters using meteorological satellite, numerical prediction and field data in Changjiang and Huaihe river basins.

### *7.3.2 Drought Hazard Monitoring and Evaluation*

Droughts, both natural or meteorological droughts and human-induced or agricultural droughts are frequent hazards which cause considerable economic loss in China. The monitoring

and assessment of drought are essentially important for hazard alleviation and agriculture management. Remote sensing technique has superiority in drought monitoring compared with conventional means like ground-based measurement. The approaches by VIS/NIR/FIR bands of remote sensing include the methods based on soil thermal inertia, calculation of regional evapo-transpiration, vegetative cover index and temperature, and feature of soil water contents spectrum and so on. For regional drought monitoring and assessment, the polar orbit meteorology satellite like NOAA or FY, as well as Earth Observation System (EOS/MODIS) are the feasible sources because of the appropriate spatial and temporal resolution. Sun L. et al. (2004) Xia H. et al. (2005) presented a review of the approaches of remote sensing based drought hazard monitoring and their applications. Zhang S.Y. et al. (2006) established the regional drought monitoring model, i.e. the thermal inertia model and vegetation supply water index (VSWI) model, using MODIS data and the work flow to process the remote sensing data, and the severe spring drought in Shaanxi province was successfully monitored in 2005. Mo W.H. et al. (2006) discussed the application of the vegetation supply water index (VSWI), the ratio of normalized difference vegetation index to land surface temperature, in the assessment of farmland drought with the NOAA satellite data from 1995 to 2000 and the digital information of land use in Guigang City of Guangxi Province. Qin Z.H. et al. (2005) described the methodology to retrieve land surface temperature from MODIS data for agricultural drought monitoring in China, and concluded that the band 31 and 32, of the 8 thermal bands, could be especially suitable for land surface temperature estimation. Zhang J.Y. et al. (2005) introduced the principles of the surface energy balance system (SEBS) and an arithmetic for quantitative survey of surface drought characters based on SEBS using NOAA satellite images and weather observations, discussed the application of the arithmetic, including the data processing, model parameter initialization, result evaluation and error analysis, on drought monitoring at large scale in China.

### *7.3.3 Irrigation and Drainage Management*

The complexity of sustainable land and water management leads to a need for improved monitoring, understanding and modeling of spatial processes related to irrigation and drainage. The remote sensing technique pays a significant role for this purpose. The applications may include the high resolution mapping of irrigated lands, crop water requirement, crop water stress, detection of saline areas, catchment hydrology, and irrigation management. Liu X.L. et al. (2005) discussed the approach to assistant extraction of winter wheat cropping area using the time series

of MODIS vegetation indicator. Bao Y.S. (2006) described the method for retrieving soil water content and winter wheat planted field from ENVISAT ASAR, by analyzing the relationship between winter wheat field's backscattering coefficient and soil water content or wheat coverage. Kang Q. et al. (2005) Fu Q.H. et al. (2005) presented a review of current major methods for soil salinization monitoring by remote sensing and its prospective. Kang Q. et al. (2005) discussed the remote sensing application in studying soil salinization in arid areas based on ASTER images. A remote sensing dataset comprised of 9-band multi-spectral images of ASTER was used, and the accuracy of the method reached to 79.1%. Pan S.B. et al. (2004) discussed the impact of water resources development on the environment system in Shule River basin located in Hexi Corridor, Gansu province of China. The numerical groundwater simulation models for three irrigation commands was developed with the aid of remote sensing and GIS in order to analyze the ecological environment changes after the implementing of the agriculture development project.

#### *7.3.4 Land Cover Changes and Water Resources Development*

The production and use of information on land cover and land use has dramatically increased during the last 50 years in relation with the development of spatial planning policies on one hand and of remote sensing and GIS techniques on the other hand. Land cover i.e. the cover of the earth's surface with soil, water, vegetation, cities etc. depends on natural factors and human activities. The anthropogenic influence on land cover is related to land use and for agriculture, forestry and urbanization. Changes in land cover include changes in the hydrological cycle and in most of the mass and energy fluxes that sustain the biosphere and geosphere. As a result the amount of runoff, the soil moisture and groundwater recharge are strongly affected by land use changes. On the other hand, unreasonable water resources development, especially in arid or semi-arid regions, may also cause the land cover changes such as the degradation of vegetation and desertification. Chen H.L. et al. (2005) presented a review of remote sensing application in land use/cover change (LUCC) monitoring and assessment with emphasis on the composite application of multi-source data and numerical experiment. Yan Z.L. and Tang G.A. (2004) employed remote sensing to investigate the variation of vegetation after emergent water transferring in Tarim River basin in year 2000. Cui W.G. and Mu G.J. (2004) introduced the evaluation of Manas oasis, and the method using RS technology and the theory of physiognomy and geology to study oasis spatial and temporal change process. Wang Y.Y. and Li J. (2004) described new methods aiming at improving the conventional computer classifiers, such as statistic based classification, artificial neural network classification, knowledge based, support vector machine classification. Cao Yu, et al (2006) discussed the landscape ecological classification using vegetation indices based on remote sensing data, and demonstrated the method for natural oasis landscape analysis at Ejina of Inner Mongolia of China.

## 7.4 CONCLUSIONS AND FUTURE PERSPECTIVE

### 7.4.1 Conclusions

Remote sensing, particularly from various satellites in various spectral bands, can provide information on watershed characteristics for the spatial estimation of regional parameters for hydrological research and water resources management at various scales. Another important facet of remote sensing is the fact, that such data can be acquired in remote areas or under very difficult circumstances.

Many of the advances in the application of remote sensing technique in hydrology and water resources management have come from various fields including flood and drought hazard monitoring and evaluation, irrigation and drainage management, monitoring of ecologic environment, as well as water cycle research in catchment, watershed and global scale. The advantages of using remote sensing are as followings (E.T. Engman and G.A.Schultz 2000):

- The ability to provide spatial data, rather than point data,
- The potential to provide measurements of hydrological variables, such as soil moisture and snow water content, which are not available through traditional techniques.
- The ability, through satellite sensors, to provide long-term, global-wide data, even for remote and generally inaccessible regions of the earth.

### 7.4.2 Future Perspective

The future development of remote sensing application in hydrology and water resources is likely to be great for several reasons such as:

- The convergence of data acquisition and data visualization technologies,
- The integration and fusion of data from all available sources and the development of models related to hydrology and water resources, as well as disaster and environment.
- The possibility, to acquire data for large areas with a high resolution in space and time at one spot and in real-time, which may serve as basis for water management decisions in real-time.

In China, the Miniature Environmental Disaster Satellite Constellation, which is composed of four optical satellites and four radar satellites, is planned to be launched in recent years. The CBERS -03/04, the succession of CBERS- 01/02, are also planned to be launched before 2010. The spatial resolution and the quality of image of the satellites will be considerably improved.

FY-3 and FY-4, respectively the polar orbit and geostationary orbit of the second generation of meteorology satellites, are also put in planning. The applications of remote sensing in hydrology and water resources management could be expected to be greatly developed with more and more sources of satellites.

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# CHAPTER 8 RESEARCH PROGRESS ON WATER CYCLE OF SOIL-VEGETATION-ATMOSPHERE SYSTEM

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Water transfer through Soil-Vegetation-Atmosphere system is one of the most important multi-interface processes of land surface. A good understanding of those interface processes and their mechanism is helpful to determine and regulate the water requirements of an ecosystem.

Toward these ends, more attentions have been paid by the Chinese scientists; however, most researches focus on production and application in agriculture and forestry. From the mid 1970s to the mid 1980s, researches were mainly focused on soil moisture holding capacity, dynamics and numerical simulation of moisture movement. In the mid 1980s, the conception of Soil-Plant-Atmosphere Continuum (SPAC) was introduced into China, a series of research, with focus on farmland's ecosystem, on reciprocity among soil, plants and atmosphere, laws of moisture movement inside SPAC and fluxes' evaluation model have been conducted. Coming into 21 century, the above researches were deepened while much more attentions were paid to researches on laws of crop water consumption and water-saving agricultural technology. Meantime, the mechanism of water transfer through interface was enhanced and exciting outcomes were achieved, such as the transformation rule, micro-ecosystems of plant root ends and simulation of water movement across the leaf-atmosphere interface. Other significant progress has been achieved in the study of changing flow resistance in micro-ecosystems of plant root ends and leaf-atmosphere systems, including resistance due to soil, soil-root interfaces, root systems, and air. Exploration of such resistance factors must consider their changing relationship with organisms of different genetic makeup, variable root system structure, soil-root interface clearance and changing conductivity under natural conditions.

The main activities of research on water transfer in Soil-Vegetation-Atmosphere can be outlined as two following aspects: (1) numerical simulation on water/heat transfer and modeling coupled water/heat and carbon transfer process, which verified by field observation data; (2) water cycle of Soil-Vegetation-Atmosphere System at watershed/regional level. More details as follows:

## 8.1 PROCESS ON WATER CYCLE OF SOIL-VEGETATION-ATMOSPHERE SYSTEM

### *8.1.1 Numerical Simulation of Water/Heat Transfer in SPAC*

The conception of Soil-Plant-Atmosphere Continuum (SPAC) was introduced into China in the mid 1980s. By the end of the 20<sup>th</sup> century, this theory had made great progress and was come into use in many areas. While, in resent years, researches are continued and many new evolvments have been made to make the theory more perfect.

Neoteric research of moisture circling is inclined to regard soil-vegetation-atmosphere as continuity in physics, which is called SPAC system. Meng and Xia (2005) founded crop growth period's water&heat transport model of SPAC system, and designed numerical analysis program to simulate water&heat state. The result shows that, the model factually reflect water&heat state of soil and dynamic progress of evapotranspiration in the progress of crop growth. This model could use to forecast soil moisture and frame appropriate water norms. <sup>[1]</sup>

Cong et al (2004) raised a calculating pattern to estimate evapotranspiration based on SPAC according to meteorological condition, crop condition, and temperature & humidity on the surface of the soil. By this method, we can get crop transpiration, soil evaporation, and evapotranspiration. This method is authenticated as credible according to the result of soil water numerical calculation. Cong et al (2004) also compared this pattern with Penman pattern, Shuttleworh-Wallance pattern, and found the relations between these patterns. Because the input of this pattern can be gained by regular observation, this pattern has some applicable value in production and scientific research. <sup>[2]</sup>

Ji et al (2006) founded transportation of soil water's sub model of irrigated farmland in inland oasis SPAC system based on soil water dynamic theory. They did simulating research on soil section moisture content, evaporation, and foliage transpiration, and confirmed by measured value. After forecasting field moisture, soil evaporation, foliage transpiration of spring wheat growing season under the same plant and manage condition, we gained satisfactory result. Sensitivity analysis to the main factors of the model shows that these factors have great effect to soil water transport. <sup>[3]</sup>

Three models were constructed by Zhang et al (2004) for estimating water and heat transfer in the Soil-Plant-Atmosphere Continuum (SPAC) in different spatial and temporal scales. Three kinds of experiments have been conducted for the models at two Ago-ecosystem Stations, Chinese Academy of Sciences in the North China Plain, since 1998. The first model is the Coupled canopy Photosynthesis-Conductance-Evapotranspiration (ET) Model (CPCEM), which was applied to simulate CO<sub>2</sub> and water fluxes above plant canopies well, compared with the measurement. The second one is the one-dimension and three-layer Soil Water Balance (SWB) model, which was successfully used to simulate soil water deep percolation and ET under different irrigation schedules in 1998-2003. The third one is the regional energy fluxes and daily ET model, which is based on remotely sensed and synchronous surface data. It was successfully used to estimate surface energy fluxes and daily ET in a regional scale. <sup>[4]</sup>

### *8.1.2 Numerical Simulation of Land Surface Processes in MSPAS*

Liu et al (2004) uses a Modified Soil-Plant-Atmosphere Scheme (MSPAS) to study the interaction between land surface and atmospheric boundary layer processes. The scheme is composed of two main parts: atmospheric boundary layer processes and land surface processes. Compared with SiB and BATS, which are famous for their detailed parameterizations of physical variables, this simplified model is more convenient and saves much more computation time. Though simple, the feasibility of the model is well proved in this paper. The numerical simulation results from MSPAS show good agreement with reality. The scheme is used to obtain reasonable simulations for diurnal variations of heat balance, potential temperature of boundary layer, and wind field, and spatial distributions of temperature, specific humidity, vertical velocity, turbulence kinetic energy, and turbulence exchange coefficient over desert and oasis. In addition, MSPAS is used to simulate the interaction between desert and oasis at night, and again it obtains reasonable results. This indicates that MSPAS can be used to study the interaction between land surface processes and the atmospheric boundary layer over various underlying surfaces and can be extended for regional climate and numerical weather prediction study. <sup>[5]</sup>

A series of sensitivity tests are performed to test the stability and sensibility of the Modified Soil-Plant Atmosphere Scheme (MSPAS), which was wholly introduced by Liu (2004) in the previous paper. The numerical simulation results from the experiments show good agreement with physical reality. Besides, some of the results are illuminating. Together with the first paper, it is concluded that MSPAS is a simple but effective model, and it is practically valuable in the research work of desertification control and reforestation in China. <sup>[6]</sup>

### *8.1.3 Other Numerical Simulations of Water/Heat Transfer*

- 1) Cong et al (2004) figured out ThuSPAC model, including Soil model, Canopy model, SPAC model, Wheat model and WheatSpac five separated models. ThuSPAC model can simulate distribution law of moisture temperature in soil and canopy, growing progress and final yield of winter wheat, based on soil condition, breeds of winter wheat, atmosphere condition and irrigation condition etc. The programming language of this model is Visual Basic, and it has broad foreground in relative field's research. <sup>[7]</sup>
- 2) Based on the physical analysis that the soil moisture and vegetation depend mainly on the precipitation and evaporation as well as the growth, decay and consumption of vegetation a nonlinear dynamic coupled system of soil moisture-vegetation is established. Using this model, the stabilities of the steady states of vegetation are analyzed. This paper focuses on the research of the vegetation catastrophe point which represents the transition between aridness and wetness to a great extent. It is shown that

the catastrophe point of steady states of vegetation depends mainly on the rainfall  $P$  and saturation value  $v_0$ , which is selected to balance the growth and decay of vegetation. In addition, when the consumption of the vegetation remains constant, the analytic solution of the vegetation equation is obtained. [8]

- 3) Yao et al (2006) studied integration of DHSVM and GIS based on the new ArcObjects fetched by ESRI. They analyzed the ways of model integration between DHSVM and GIS, and treated Luohe Lushi hydraulic station as a case. The result showed that integration system strengthened function of DHSVM model in automated extraction of model factors, management of data, visualization of progress and special analysis, and provided powerful support in the simulation of river basin land-surface hydrological progress. [9]

## 8.2 EXPERIMENTS AND APPLICATIONS ON WATER CYCLE OF SOIL-VEGETATION-ATMOSPHERE SYSTEM

Scientists did a lot of experiments to study the water cycle of soil-vegetation-atmosphere system, in order to apply in different kinds of landforms and physiognomies. More details as follows:

### 8.2.1 *Oasis-Desert Ecotone*

Zhang et al (2006) treated oasis-desert ecotone as research object, and founded water & heat conduction mode in unconfinedgroundwater-soil-vegetation-atmosphere system. They pointed out numerical simulated disaggregating-coordination method to solve unconfinedgroundwater-soil-vegetation-atmosphere system. The experiment was held in Sanjianghe river basin's oasis-desert ecotone, and the experiment data validated the reliability in water & heat transfer model. This model has high precision in simulating unconfinedgroundwater-soil-vegetation-atmosphere continuity's dynamic transferring progress, plant transpiration, soil evaporation and hydraulic conductivity of plant root in oasis-desert ecotone. [10]

### 8.2.2 *Mountain Region*

In the mountain area of inland Heihe River Basin at Hexi Corridor of northwest China during the vegetation growing season from May to September, the Simultaneous Heat and Water (SHAW) model of Soil-Vegetation-Atmosphere Transfer (SVAT) system is applied to simulating and studying energy and water balance of the soil-residue-plant canopy layers in the *Picea crassifolia* forest and the grassland by the forest at the shaded slope and the grassland at the

sun-facing slope. The simulation of energy balance indicates that net radiation of the grassland at the sun-facing slope is more than that of the *Picea crassifolia* forest and the grassland by the forest at the shaded slope. The energy outgoing components are the first latent heat and next sensible heat from the grassland both at the shaded slope and the sun-facing slope, but those at the former are less. The energy outgoing components are the first sensible heat and next latent heat from the *Picea crassifolia* forest. The composition and distribution of energy in the soil-residue-plant canopy layers in the *Picea crassifolia* forest and the grassland by the forest at the shaded slope make the soil layer receive less energy, which therefore, especially the forest possesses the energy conditions for soil water conservation. The simulation of water balance indicates that the water loss of the grassland at the sun-facing slope is mainly caused by soil evaporation, while evapotranspiration of the *Picea crassifolia* forest and the grassland by the forest at the shaded slope is less than that of the grassland at the sun-facing slope. Half of the evapotranspiration of the *Picea crassifolia* forest and the grassland by the forest at the shaded slope is consumed by transpiration. After precipitation, the soil water storage is increased much more for the *Picea crassifolia* forest and also more for the grassland by the forest at the shaded slope. Therefore the shaded slope vegetation, especially the forest is favorable for soil water storage. <sup>[11]</sup>

### *8.2.3 Plane & Plateau Region*

Mo et al (2005) simulated Huabei Plane winter wheat and summer corn evapotranspiration progress in growing time continually during 1981 to 2001. <sup>[12]</sup> The result showed high consistency compared with other observation result done by other researcher's field experiments and Lysimeter observation. Many researches have done in Yellow River Delta. In order to study evaporation progress, Pan et al (2003) decided use remote sensing method in the study of evapotranspiration because of its merits such as speediness, nicety, large scale and topographical visualization. They used SEBAL model and ETM+ image to study Huanghe River Delta, and analyze the evapotranspiration characteristic of Huanghe River Delta. This research has potential instructional meaning in reasonably use water resources. <sup>[13]</sup> Start from the same intention, Shao et al (2005) founded soil moisture transfer numerical simulation model on Huanghe River Delta with shallow water area based on field experiment and indoor analysis. <sup>[14]</sup> They did a lot of experiments and did numerical simulating calculation based on the result of numerical simulating experiments. The research shows that soil water transfer model is an effective tool in estimating evapotranspiration in complicated situation.

Loess Plateau is also a research hotspot, and many researchers focus on this area. Such as Huang et al (2003), their keystone was hydro-ecological effect of the soil dry layer <sup>[15]</sup>, and Xu et al (2003), which spent his time on the research of effect and influence factors of vegetation construction on soil water in semi-arid area on Loess Plateau. <sup>[16]</sup>

#### *8.2.4 Desert & Semi-Arid Region*

Ren et al (2006) discussed relationship on sand land's GSPAC natural plant-water system by the numbers based on the relationship between groundwater and soil-vegetation-atmosphere continuity GSPAC. <sup>[17]</sup> The result shows that the deeper water table is, the more depressed underground biomass has. This result has some instruction in protecting sand land zoology protection. Wei et al (2004) analyzed characteristic of soil water, farm evapotranspiration, etc. during extremely high temperature and drought term 2003 in Jiangxi Province, and did some researches. <sup>[18]</sup> Wang et al (2005) introduced main methods in the research of sand land region's soil-hydraulic progress and basic soil moisture balancing equation. They also analyzed relationship between specifically regions' soil moisture dynamic and plants structure in order to inspire other researchers and supervisors. <sup>[19]</sup>

Many studies on dune fixation shrubs development at semi-arid region had been done to prevent desertification. <sup>[20]</sup> And doing experiment on farm land in semi-arid region to study evapotranspiration can help constitute irrigation law. <sup>[21]</sup>

#### *8.2.5 Wetland Region*

Wetlands, one of the most productive systems in the biosphere are a unique ecosystem. They occur in landscapes that favor the ponding or slow runoff of surface water, discharge of ground water, or both. Wetlands are not only important for maintaining plant and animal diversity, but also for balancing global carbon budget via sequestering or releasing CO<sub>2</sub> from/into atmosphere depending on their management. Therefore, it is imperative to understand how wetlands form and function, and then we can better manage, utilize, and protect these unique ecosystems. Hydric soils, hydrophytic vegetation, and wetland hydrology are the three main parameters of wetlands. These parameters are interrelated with each other which jointly influence the development and functions of wetland ecosystems. The objective of this paper was to report the current understanding of wetlands and provide future research directions. The paper will first focus on aspects of hydrology research in wetlands, and then shift to soil hydrosequence and wetland vegetation to better understand processes, structure, and function of wetlands, and conclude with some possible future research directions. <sup>[22]</sup>

#### *8.2.6 Red Soil Region*

Red soil region is very common in South-eastern China. The effect of different vegetation systems including bamboo plantation (BP), forest ecosystem (CF), citrus orchard (Ctr) and farmland (FL) on erosion and nutrients of red soil were investigated in hilly region of southeastern China to find effective control measures for soil erosion. The results showed that all

the vegetation systems could significantly reduce soil erosion and nutrient losses compared to bare land (Br). The ability of different vegetation systems to conserve soil and water was in the order of Ctr > BP > CF > FL > Br. Vegetation could also improve soil fertility. The soil organic matter, total N and total P contents were much higher in all the vegetation systems than in bare land, especially for the top soils. Vegetation systems improved soil physical properties remarkably. Compared to the bare land, soil organic matter, TP, TK and available K, especially soil microbial biomass C, N and P, increased under all the vegetation covers. However, they were still much lower than expected, thus these biological measurements are still needed to be carried out continuously. <sup>[23]</sup>

### 8.2.7 Alpine Meadow Region

Wang et al (2003) researched the influence to soil moisture circulation by the change of alpine meadow vegetation fractional cover. <sup>[24]</sup> The result showed that on alpine meadow, widely spread in Tibet Plateau headstream of river, vegetation fractional cover had notable correlations to soil moisture. This result has great significance in protecting headstream's alpine meadow. Chen et al (2006) founded A Distributed Water-Heat Coupled (DWHC) Model for Mountainous Watershed of An Inland River Basin. <sup>[25]</sup>

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# CHAPTER 9 RESEARCH ON THE APPLICATION OF ISOTOPE TECHNIQUE IN THE MANAGEMENT AND ASSESSMENT OF HYDROLOGY AND WATER RESOURCES

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Environmental isotopes refer to isotopes that generate in natural conditions or by nuclear explosion and can transfer in water cycle. They can be divided into stable and radioactive isotopes by their radioactivity. Among them, oxygen and hydrogen isotopes are widely used in water cycle related study. In nature, there are two different stable isotopes for hydrogen and three for oxygen,  $^1\text{H}$ ,  $^2\text{H}$  and  $^{16}\text{O}$ ,  $^{17}\text{O}$ ,  $^{18}\text{O}$ , respectively, and there exists totally nine different molecular forms of  $\text{H}_2\text{O}$ , with only three of them, i.e.  $\text{H}_2^{16}\text{O}$ ,  $\text{H}_2^{18}\text{O}$ ,  $^1\text{H}^2\text{H}^{16}\text{O}$  can be easily detected. Meanwhile, about 97% of water in the world is seawater, and the isotopic ratios of  $^2\text{H}/^1\text{H}$  and  $^{18}\text{O}/^{16}\text{O}$  are very small (in magnitude of  $10^{-4}$  and  $10^{-3}$ ) and variable. In order for the ratios to be easily calculated and expressed, relative deviation of heavy isotopes relative to some standard was introduced and  $\delta$  values are usually given in ‰ (per mil). At present, the most widely used standard is the Vienna Standard Mean Ocean Water, whose  $\delta$  values ( $\delta\text{D}$ ,  $\delta^{18}\text{O}$ ) are both defined as 0 (‰). And isotopic ratios of water are calculated using equation:

$$\delta = \frac{R_{\text{Sample}} - R_{\text{VSMOW}}}{R_{\text{VSMOW}}} \times 1000\text{‰}$$

Here,  $R_{\text{Sample}}$  and  $R_{\text{VSMOW}}$  stand for ratios  $^2\text{H}/^1\text{H}$  and  $^{18}\text{O}/^{16}\text{O}$  in water samples, respectively. Different waters in water cycle are characterized by different isotopic composition with different temporal and spatial variation. For precipitations worldwide, isotopic compositions are mainly controlled by the temperature when they experience evaporation, from which a series of isotopic effects are derived. They are such:

**Latitude Effect:** Isotopic composition of precipitation decreases with a higher latitude, and some call this to be annual temperature effect by some experts.

**Altitude Effect:** As heavy isotopes in water vapor masses may sink prior to light isotopes and so  $\delta$  values of precipitations are usually depleted with altitude increases.

**Continental Effect:** Similar to the altitude effect, when water vapor evaporated from seawater surface or other origins moves across a continent, heavy isotopes tends to penetrate more easily.

So coastal precipitations have heavier isotopic compositions and the inner ones are lighter.

**Seasonal Effect:** Isotopic composition varies with local temperature, especially for the monthly mean temperature. Generally, rains have heavier isotopic composition in high temperature months.

**Amount Effect:** Isotopic compositions usually correlate with the amount of each rain event, and it often takes on a lighter isotopic composition for heavy rains and heavier for rains with long duration and small intensity.

Based on the effects above and other characteristics, isotopic composition can help to study the origin and movement of water vapor. Since 1950s, a series of isotopic studies have been carried out worldwide, and by far, a series of accomplishments have been achieved in distinguished aspects of water cycle based on environmental isotopes worldwide.

## 9.1. APPLICATION OF ENVIRONMENTAL ISOTOPES IN METEORIC WATER STUDY

As the most important input for water cycle, isotopic analysis of precipitation is the foundation for systematic study of other outputs and median hydrological processes in integrated water cycle research in a watershed.

Due to parallel isotopic fractionation, isotopic compositions for  $\delta D$  and  $\delta^{18}O$  vary in similar modes, and so there is a good relationship between them. In 1961, Harmon Craig found the linear relationship between  $\delta D$  and  $\delta^{18}O$ , which was called Global Meteoric Water Line (GMWL). The GMWL defines the relationship of  $\delta D$ - $\delta^{18}O$  in worldwide fresh surface waters:

$$\delta D = 8\delta^{18}O + 10 \text{ SMOW}$$

Here all the results used SMOW as reference. Through subsequent monitoring of isotopic compositions for precipitations by Global Network for Isotopes in Precipitation (Rozanski et al., 1993), the relationship was refined to be:

$$\delta D = 8.13\delta^{18}O + 10.8 \text{ VSMOW}$$

And here, the analysis results have been changed to VSMOW standard.

As  $\delta$  value is integrated reflection of geographic and meteoric information, relationships between  $\delta D$  and  $\delta^{18}O$  in different regions may vary in some degree, and in this sense they are usually called Local Meteoric Water Line. For example, for rainwater samples in 27 stations of China, the meteoric water line is  $\delta D = 7.82\delta^{18}O + 8.48$ ,  $R^2 = 0.97$ . The relationship can be expressed to be  $\delta D = A * \delta^{18}O + D_{excess}$ , here  $A$  means slope of the water line, relating to the evaporation process water experienced, and  $D_{excess}$  is the intercept, indicating the moisture when water experiencing evaporation.

There have been many studies referring to isotopic composition for precipitation, and from these, a series of new domains are developed, such as water origin, vapor transport, paleoclimate reconstruction and so on. Since 1961, IAEA and WMO has been observing isotopic composition of rain water in more than 500 meteoric stations worldwide and studying their spatial and temporal distribution in global or regional scale (Araguas-Araguas et al., 2000). Craig et al firstly analyzed the isotopic composition of vapor above the sea surface. Schoch-Fischer et al (1984), Jacob et al (1991) and White et al (1984) systematically studied the isotopic ratios of water vapor near the surface, and found there is good relationship between  $\delta D$  and relative humidity of vapor when water evaporates.

In China, many isotopic studies for meteoric water have been performed, and problems such as local water origin have been discussed based on several years' observation, especially in the Tibetan Plateau (Zhang Xinping et al., 1996; Tian Lide et al., 1998; Yao Tandong et al., 2000). In international scientific cooperation aspects, there are still some advances for studies performed in Tibetan Plateau and North China (Tsutomu et al., 2004).

In glacier research, environmental isotopes of snow in different depth are usually used to perform climate reconstruction. Hou Shugui et al (1999) compared  $\delta^{18}O$  of the NO.1 glacier in the headwaters of Urumchi with the meteoric information observed in Daxigou station, discussed the significance of  $\delta^{18}O$  in climate study and spread the applicability for using  $\delta^{18}O$  as a temperature index. Zhang Xinping et al (2002) also analyzed  $\delta^{18}O$  values for the surface and superficial firn in the east branch of NO.1 glacier, and discussed its relationship with local temperature, as well as effect of melting and evaporation on isotopic evolution. Also many other studies have been performed in paleoclimate reconstruction, paleo-hydrogeology reconstruction and so on.

In water origin study, some latest significant results have been obtained. Liu Xiangchao et al (2005) identified the movement of summer vapor in Dongtaigou catchment using the changing mode for  $\delta^{18}O$  and relationships between  $\delta^{18}O$  and rainfall, elevation, air humidity in the catchment. So far, the Chinese Network of Isotopes in Precipitation is observing precipitation in 31 stations of the Chinese Ecosystem Research Network to study the vapor origin in China, and provide information for ecosystem related study. And precipitation sampling are still continued in many meteoric stations or experimental catchments, such as Niujiashuang watershed in Taihang mountain area, Chongling watershed in Hebei province, and Chabaogu catchment in Loess Plateau Breck Revine region, North of Shaanxi Province.

## 9.2. APPLICATION OF ENVIRONMENTAL ISOTOPES IN SURFACE WATER STUDY

Using environmental isotopes such as D,  $^{18}O$  can help perform hydrological separation (Dincer et

al., 1970; Martinec et al., 1974), evaluate isotopic composition of local precipitation, on the basis of which paleoclimate reconstruction can be discussed. Surface water study can also provide useful information for problems such as precipitation infiltration, groundwater drainage. Many studies have been performed for different rivers in the world, and surface water related issues such as evaporation when surface water flows downstream, relationships between surface water and groundwater were discussed (Simpson et al., 1991; Mckenna et al., 1992; Vrbka et al., 1993; Gremillion et al., 2000).

Since 1990s, studies of surface water isotopic composition have been performed gradually. Gu Weizu et al (1995) studied surface and subsurface responses to rainfall events based on tritium and oxygen-18 isotopes in three specially designed catchments. From the daily variation of stable isotopes for surface water and in combination with that of local precipitation in Naqu River basin, Tibet Plateau, Tian Lide et al (2002) analyzed the characteristic of runoff, and found the isotopic evidence for lake water's role in regulating runoff of mainstream. In other regions, some studies about surface water are more likely to be related to groundwater for a integrated study for both surface water and groundwater.

On the whole, China is still lack of systematic study for surface water, while some special projects for water in several main rivers have been performed in the recent years. In the Yangtze River basin, in order to study carbon cycle and hydrochemistry, surface water samples are collected every 10 days in 8 sections (Pingshan, Beibei, Cuntan, Wanxian, Wuxiangmiao, Yichang, Hankou, and Datong) for carbon, hydrogen and oxygen isotopic analysis, with suspended matter collected in situ. In the Yellow River basin, three sections, i.e. Qingtongxia, Tongguan, Luokou station, were chosen to collect surface water samples every 10 days for stable isotopes and hydrochemical analysis, also with hydrological processes observed and suspended matters filtrated to analyze carbon cycle related items.

### 9.3. APPLICATION OF ENVIRONMENTAL ISOTOPES IN SOIL WATER STUDY

As a media process in water cycle, the movement of soil water is very important to the water content distribution in soil interface and significant to evaporation. Through isotopic study of soil water in different depths, we can get the vertical profile of isotopes (Barnes et al., 1984), reveal the process of soil water recharging shallow groundwater, evaluate drainage of groundwater through upward diffusion from water table (Fontes et al., 1986), describe the evaporation process of soil water (Sonntag et al., 1985), and identify evapotranspiration effect (Allison et al., 1982, 1983a, 1983b) of vegetation.

Until recent years, isotopic studies for soil water have begun to be widely developed in China. Former studies mainly focus on arid and semi-arid regions and use T (Tritium) isotope in vertical profile as an indicator, e.g. Liu Ruifen et al (2001) found that the vertical infiltration of precipitation only accounts to about 12~13% of the total annual rainfall, and put forward that precipitation infiltration may not be the main mechanism for groundwater recharge. The changing

mode both in different depths under different vegetation may provide some useful information for groundwater study and evapotranspiration process. At present, there are systematical observations for soil water in several experimental fields constructed by Key Laboratory of Water Cycle and Related Land Surface Processes, CAS. In the Taihang mountain area, Li Fadong (2005) systematically analyzed isotopic composition of soil water in three different vegetations, i.e. vitex, robinia and wild grass, and studied the different processes precipitation experiencing after infiltration from a series of linear relationships between  $\delta D$  and  $\delta^{18}O$ . Yang Cong (2006) analyzed the isotopic composition of soil water in several depths for different parts of the watershed, and studied the evaporating process in combination with soil water and corresponding meteorological observation in Dongtaitou experimental watershed, Beijing. Soil water under typical vegetations in Chongling experimental watershed, Hebei province, and soil water under different land coverage in Chabagou catchment, Loess Plateau are also collected for environmental isotopes studies. In combination with soil water content observation and normal meteoric observation, advanced long-term study of isotopic composition for soil water can help identify the process of soil water infiltration, evaporation and vegetation transpiration in these regions, on the basis of which an integrated study of water cycle can be obtained.

#### 9.4. APPLICATION OF ENVIRONMENTAL ISOTOPES IN GROUNDWATER STUDY

In groundwater related study, environmental tracers, such as T, D,  $^{18}O$ ,  $^{14}C$ ,  $SF_6$ , CFCs and etc., have been widely used successfully in many fields since 1950s. Many problems including dating, renewability and recharging origin of groundwater, as well as other related processes can be solved using these techniques, among which D and  $^{18}O$  played an important role. Integrated isotopic studies for precipitation, surface water and groundwater have been performed, with many valuable conclusions obtained internationally (Song Xianfang et al., 1999a, 1999b; Tang Changyuan et al., 2001; Rademacher et al., 2003; Chen Zongyu et al., 2005), and also a Geological Survey Ground-Water Resources Program was carried by USGS in 2001. These successful applications of environmental isotopes for groundwater have provided varieties of examples for domestic studies, and many conclusions gained from these are providing useful information for water resources exploitation and management.

So far, most isotopic studies in China focus on Tibetan Plateau and North China, mainly including the Heihe River, North China Plain, and Northeast of China. Until today, lots of studies have been performed in the Heihe River basin, northwest of China. Through environmental isotopes, hydrograph separation method and correlation analysis, Zhang Guanghui et al (2005) found that the rain, groundwater and snowmelt from the Qilian mountain area are the main sources to recharge groundwater in the middle reach of Heihe River basin in the Northwest internal region, and the recharge varies dynamically both during seasons and years. They also

concluded that variation of rainfall in Qilian mountain area is the main factor to variation of groundwater recharge in the middle reaches, and human activities have been related to the decrease of groundwater recharge in the middle reaches since 1980. Zhang Yinghua et al (2005) found that irrigation water greatly influenced the relationship between surface water and groundwater in the oases of the middle Heihe River, and identified the transfer amount of the two features. Qian Yunping et al (2005, 2006) studied the recharge sources of deep groundwater in Ejina basin in lower reaches of Heihe River basin by 3 years hydrochemistry and isotopic information, and concluded that deep groundwater has multi-recharge sources and most formed before nuclear bombing period, and should be used with caution. Wu Xuanmin et al (2002a, 2002b) divided the groundwater system of the Ejina basin by field investigation, hydrochemistry, environmental analysis of T,  $^{18}\text{O}$  and  $^{14}\text{C}$ . Chen Jiansheng et al (2004) also discussed the hydrogeological conditions of deep confined aquifer in Ejina basin using environmental isotopes, artificial methods and hydrochemical information, and put forward a possible recharging source for lower reaches of the Heihe River. And this conclusion is still in discussion (Research group of Heihe Project, 2005).

In the aspect of relationships between precipitation and groundwater, relatively more studies were carried out in Southwest of China. Yin Guan et al (2000) studied the water cycle in Jiuzhaigou scenic spot, Sichuan province, and found that precipitation is the main water source, and different waters have different  $\delta$  values due to many factors, such as time lag for rainwater recharging waters, elevation of recharging area, recharging mode, volume of groundwater water bank, residence time and etc. The author (Yin Guan et al., 2001) also discussed the variability of deuterium excess ( $D_{\text{excess}}$ ) both in precipitation and groundwater of Jiuzhaigou and Yele, identified their isotopic meaning and controlling factors, and then compared the  $D_{\text{excess}}$  both in karst and local normal waters. Li Hongye et al (2005) and Wu Gang et al (2006) studied the hydrochemical characteristic and recharge-drainage conditions of groundwater in Jinshajiang Valley in Mounigou and Leijiawan, Sichuan province, respectively, and discussed the effect of precipitation recharging groundwater.

As an important water-scarce region in China, North China Plain still has many isotopic related researches for groundwater. Liu Cunfu et al (1997) discussed the isotopic meaning of D,  $^3\text{H}$ ,  $^{18}\text{O}$ ,  $^{14}\text{C}$  and  $^{36}\text{Cl}$ ,  $^{37}\text{Cl}$  in groundwater of Hebei Plain and compared their effect in identifying groundwater recharge and paleoclimate reconstruction. Chen Zongyu et al (1998, 2005) analyzed the paleo-environmental meaning of local groundwater by isotopic (D,  $^{18}\text{O}$ ,  $^{14}\text{C}$ ) and hydrochemical data, on the basis of which the effect of paleoclimate change on formation and evolution of groundwater were discussed, and deemed that ground water in the central and littoral part of the North China Plain is being mined under non-steady state conditions.

Still some researches were performed in other regions. Zhang Guangxin et al (2005) studied the mechanism of water salinization in western part of the Songnen Plain of Northeast China based on the isotopic and hydrochemical information, and found that the process of groundwater salinization is mainly attribute to water soil interaction, not only to the evaporative process. Gui

Herong et al (2005) observed the drift features of oxygen and hydrogen isotopes in deep groundwater in mining area of northern Anhui province, and discussed different water-rock interactions in distinguished aquifer systems. Still there are already some researches discussing groundwater isotopic stratification and their implications in groundwater related problems such as paleoclimate change and paleo-water recharge. Wang Yuan et al (2005) discussed the possibility to use environmental isotopes and hydrochemical information to study the distribution and forming factors of fracture confined water along west route of South-to-North water transfer Project.

In engineering domain, environmental isotopes can be used to identify the leakage of water through dams or other water-blocking facilities (Chen Jiansheng et al., 2004; Li Feng et al., 2005). By analyzing the environmental isotopes and artificial tracers in Beijiang Dyke Shijiao section, Chen Jiansheng et al (2003) approved the piping water origin in the dyke according to isotopic analysis of D and  $^{18}\text{O}$  from water samples during flood season, and determined the leakage passage in the bedrock fault combining with the artificial tracer NaCl. Fan Zhechao et al (2006) analyzed the leakage of Gaoshuihe embankment using D,  $^{18}\text{O}$  and fuzzy clustering method, and found that the conclusion is identical with that from environmental isotopic and hydrochemical analysis.

Wholly speaking, isotopic studies in groundwater related domains are the most extensive, and nowadays, the current studies tend to identify the integrated processes between precipitation, surface water, soil water and groundwater from water cycle view. The main program being processed about isotopic composition for groundwater in China will be referred in the next part (water cycle related studies).

## 9.5. APPLICATION OF ENVIRONMENTAL ISOTOPES IN WATER CYCLE RESEARCH

The technique of environmental isotopes has become an important tool to study the water cycle problems. This is a more complicated process and should be based on detailed study of isotopic characteristic of different waters. Many experts have attempted to interpret  $D_{\text{excess}}$  for precipitation, surface water and groundwater from isotopic view. Chao Nianying et al (2004) interpreted the characteristic of  $D_{\text{excess}}$  in Hebei Plain and concluded that results will be better if  $D_{\text{excess}}$  parameter be used together with  $^3\text{H}$ ,  $^{14}\text{C}$ ,  $^{36}\text{Cl}$ , and etc. By far, water cycle studies based on environmental isotopes are on the increase.

In Chabagou watershed of Loess Plateau Breck Revine Region, isotopic compositions of precipitation, surface water, soil water and groundwater in different seasons were observed both in the whole catchment and in a small watershed, to study relationships between the four waters. Also, water vapor origin, origin and renewability of groundwater can be discussed in detail. In the Dongtaitou experimental basin, Beijing city, rain water, soil water, surface water and



groundwater were collected for isotopic composition, which can provide some information for water cycle study in the catchment. While in the Chongling experimental basin, Yixian county of Hebei province, a whole observation and isotopic sampling system of four waters is working to study water cycle problems both in 10 km<sup>2</sup> and watershed scales. Through studying variation of isotopic composition for soil water in different depths (10cm, 20cm, 30cm, 50cm) comparing with that of precipitation, process of precipitation infiltration and recharging groundwater can be identified. Li Fadong et al (2005) performed water cycle study based on environmental isotopes and hydrological observations in the Taihang mountain area both for precipitation, surface water, soil water under different vegetation and groundwater, and got the water consuming mechanism for vegetation, and mechanism of hydrological and lateral recharge.

From the whole point, hydrogen and oxygen isotopes are being widely used in water cycle studies, which are playing a more and more important role in national water related studies. It tends to study complicated relationships between different waters in water cycle view, including precipitation, surface water, soil water, groundwater, and also vegetation water, vapor water near the land surface. And on such basis, more detailed hydrological features will be studied.

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