PROPOSAL FOR INCLUSION OF THE HEIHE RIVER BASIN, CHINA TO THE G-WADI PILOT BASIN PROGRAM

PART-1

1.1 Name of the proposed G-WADI pilot basin:
Heihe River Basin (HRB), China

1.2 Name(s) of Investigators (Key Organization/Contact Persons):
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1.3 Brief Resume of the Organization and Bio-data of Investigators (Key/Contact Persons):

Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences (CAREERI,CAS) is a newly re-organized institute in June 1999 from three former institutes of Chinese Academy of Sciences in Lanzhou. The new institute aims at disciplinary integration and scientific synthesis, based on retaining the former unique and distinguished disciplines. Now there are 260 full-time employees, with 55 titled as professors, in the new institute.

The research activities of the institute focus on glaciology, geocryology, desert, plateau atmospheric science, hydrology and water resources as well as restoration ecology and ecological agriculture. With these scientific concerns, the institute can respond rapidly to the requirements of national objectives in the development in the western China and can be a producer of fundamental theory and key technology for the rational development and utilization of land and other natural resources, environmental protection and ecological construction.

The institute will be an internationally predominant research center by the integrated studies on the interaction mechanism among cryosphere, atmosphere, hydrosphere, biosphere and lithosphere within the disciplinary studies of cryosphere and global change, especially, when such an integrated multidisciplinary fusion is characterized by the studies of extreme environment, and by the research on the chemical and physical processes on ice and snow surface in the polar ice sheets.

Aiming at important scientific issues within the sustainable development in the west China, the institute will be in full involvement in the theoretical studies about optimization model for the resource utilization, ecological construction and social-economic sustainable development.

The hydrology research is one major research area of CAREERI of CAS, focusing primarily on hydrological processes and water resources in cold and arid regions, capacity of water-land resources, as well as their optimization and utilization.

More details can be obtained through the official website at http://www.casnw.net .

Professor Xin Li's curriculum vitae can be found in attached sheet.

1.4 Name and address of the Nodal Agency

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1.5 Name(s) of Sponsoring organization(s), if any :

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http://www.yellowriver.gov.cn/vh/heihe/

1.6 Program or project supporting partners:

Supporting partners include as following:

- CAREERI, CAS
- Gansu Bureau of Hydrology and Water resources Survey
- Heihe River Administration Bureau of Yellow River Conservancy Committee
- Chinese Academy of Sciences
- National Natural Science Foundation Committee, China (NSFC)
- Dept. of Hydraulic Engineer, Tsinghua University
- College of Geography Science, Nanjing Normal University
- College of Resource and Environmental Science, Lanzhou University
- School of Geography and Environmental Science, Northwest Normal University
- Zhangye Water Authority
- Government of Zhangye City
- Water Authority of Ejina Banner
- Jiuquan Water Authority
- Jiayuguan Water Authority
- Government of the League of Alxa, Inner Mongolia

We have tight ties to those above mentioned institutions or governmental agencies during the process of projects completed. During the implementation of the pilot basin program, we are committed to work together to reach the proposed purpose, improving hydrology research level and basin management in arid regions.

1.7 Provision of resources:

With 20 years of hydrological and water resources research in the HRB, CAREERI has grouped experienced and young scientists to form a competitive hydrology professional team focusing on cold and arid regions. Those studies range from water resources surveying at the very beginning, to hydrological modeling and model integration research in recent years. A number of popular models such as PRMS, SVAT, SWAT, SHE, and VIC have been run and evaluated in the HRB. Based on the migration of existing models, we started to construct new models which suit for the HRB, by considering the special watershed characteristics as well as actual data and parameter conditions. Data assimilation, hydrological parameter estimation, decision support system for water management, and hydrological modeling environment are carried out by the support from funding agencies, like CAS and NSFC.

Precious scientific data and parameters necessary for driving hydrological models have been archived. Tens of observation stations with advance observing instruments have been established inside the proposed watershed, performing normal hydrological and meteorological monitoring tasks, as well as ecological experiments and remote sensing experiments. There is also a state-level integrated observation station (the Linze station) in the HRB. The Linze station can provide logistics supports to field practice ranging from accommodation arrangement and vehicles provision to carrying on long-term observation for specified project.

There have been close academic connections between CAREERI and other institutes and universities of common interest to the HRB. Their cooperation has been witnessed by existing joint research projects. Since the aims of water resources in the HRB are in accordance with the general purposes of “West China Development Strategy” and “Water Saving Society”, strong support from local government and water authorities are available.

Current undergoing projects can support pilot basin program by their partial funds. The director of CAREERI has promised the institute would financially support any G-WADI training programs and local or global workshop in Lanzhou. The hydrology and water resources research in the HRB is always the most important research area in CAREERI. NSFC proposed to launch a large program “Basin Science Plan” in coming year, where we possibly seek funding from this plan.

<u>PART-2</u> (start with a separate page)

2.1 Description of the G-WADI proposal:

The Heihe River Basin (HRB) is the second largest inland river basin, with an area of 140 thousand km^2, in arid and semi-arid area of Northwest China. There are diverse landform units, complex water resources transformation mechanism, vulnerable ecological environment and serious water problems in the HRB. To understand the water resources transforming processes, to rationally and effectively utilize and allocate water resources, and to harmonize economic development and environmental protection, are some of main challenges in front of local hydrologists. From the inception of over 20 years ago, the research in the HRB has begun to incorporate more fields, e.g., hydrological modeling, integrated basin research, and development of decision support system, etc. A broad range of data have been collected during past research activities. Due to its specific location in the developing West part of China as well as the deterioration of ecological environment in the downstream area, the HRB has been a concern of the national Chinese government. Under the supervision of the national government, the water diversion from the upstream and midstream areas of the Heihe River to the downstream area has been carried out once a year to satisfy the need of ecological demand in tail region. The Zhangye city located in the midstream area has been selected to be a pilot city of “water saving society”, where the measures proposed to address the water shortage issues would be evaluated. As a result, water allocation between sectors has been adjusted, waste water has got completely controlled, and the water exchange system has been preliminarily established. A spatially explicit decision support system for water resources management and optimized allocation has been constructed. We also see those scientists are active in the international stage, working together with international colleagues in an easier-than-ever and more effective way. When the startup of G-WADI program, we found we were in consistence with the objectives of G-WADI. Hydrologists in CAREERI have actively attended G-WADI workshops. This proposal will introduce the basic information of the proposed pilot basin and existing issues in terms of water resources and basin management, following by introduction of existing research activities, and finally expressing our commitment of inclusion to the G-WADI framework. We are willing to share experiences and data with other G-WADI pilot basins, to improve the understanding of hydrology, water resources and basin management by helping each other.

2.2 Baseline conditions in the basin:

(a) Geographical Characteristics:

The HRB (figure 1) is the second largest inland river basin, with an area of 140 000 km^2, in arid and semi-arid areas in Northwest China, while the first is Tarim River Basin in the Xinjiang Autonomous Region, China. HRB is located between 96°42′~102°00′E, 37°41′~42°42′N.

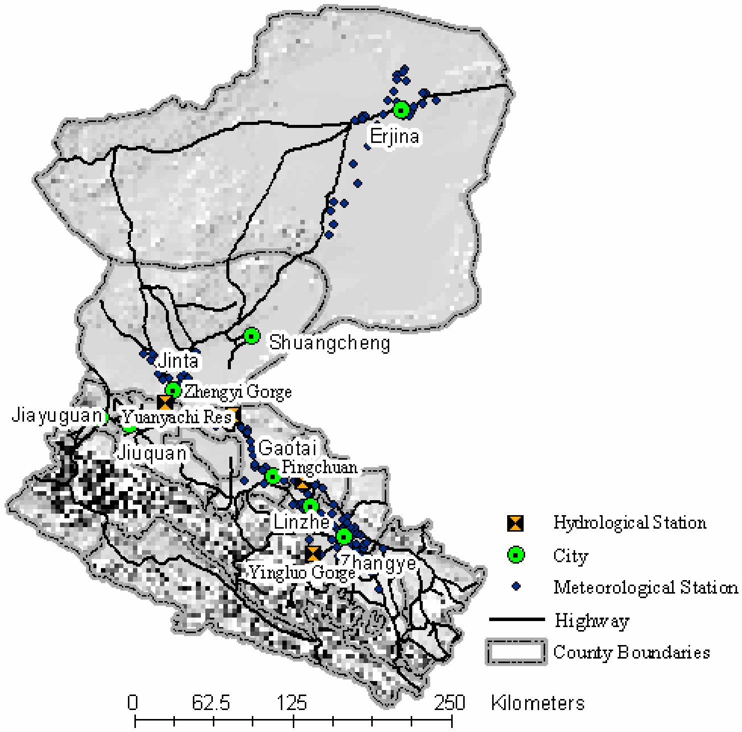

Figure 1, general picture of the Heihe River basin

The HRB lies in the zone between the Qinghai-Tibet plateau and Mongolia plateau. The elevation is falling down from south to north as well as from west to east. There are high mountain, oasis, gobi and desert in the basin. Based on the elevation distribution, the land forms can be classified into alpine glacier-snow-frozen-soil zone in Qilian Mountains, hilly grassland-forest zone in Qilian Mountains, plain agricultural zone in corridor oasis and desert-grassland zone in the downstream area. The elevation of alpine glacier-snow-frozen-soil zone ranges from 2 500 to 4 000 m; there are snow and glaciers in the zone above 4 000 m all the year around. The hilly grassland-forest zone distributes in the elevation between 2 300 to 3 400 m in the Qilian Mountains area; there are dense forest composed of shrubs and arbors. With the distribution of forest for conservation of water supply, hilly grassland-forest zone is also the runoff generating area of the HRB. With the elevation ranging from 1 000 to 2 000 m, the agricultural zone is the main runoff-consuming area. The elevation of desert-grassland zone ranges from 1 000 to 1500 m.

From the perspective of geotectonics, HRB is divided into three basic units, Qilian geosyncline fold belt, Alxa anticlise and Beishan fault block belt, and Hexi Corridor depression basin. The local deposition, construction, formation, and movement of groundwater from Cenozoic were controlled by late geological tectogenesis, rather than strong fault block movement since Mesozoic Era.

Qilian Mountains are the result of remarkable uplift in the late geological time. The terrain is so high that it has become the source of loose materials in the middle or lower basins. It is rich in precipitation to be the source of various water systems in Qilian Mountains. The southern part of HRB is controlled by the Qilian structure belt. Separated by Longshou-Heli ranges, there are two geological neighboring basins in the midstream area aligning from south to north. The south basin, namely Zhangye-Jiuquan Basin, with an elevation of 1 400~2 200 m higher than the north one, has some properties of depressions or intermountain depressions, and is composed of alluvial fan style clinoplain and fine soil plain. It joins the Qilian faults on the south, which helps to build a water-proof barrier preventing groundwater from supplying the basin. The basin base was formed in the late Tertiary or Cretaceous. Quarternary loose sediments of several hundreds to a thousand meters in thickness, with rich groundwater stored, have been formed. The north basin, namely Jinta Basin, is in a relatively lower elevation of 1 100~1 450 m. It is of edge faulted type, with a base of Neogene Tertiary. The thickness of Quarternary sediment is smaller than that of the south one, normally less than 400 m and controlled by the up and down movement of the base. Erjina Basin is located within the Alxa anticlise, which is partitioned by north-east, north-west and north-north structures to varying scales of checkerboard patches, with a pattern of depression and upheaval interval. The lithosphere has been in stable mode since the Quarternary Period. The Erjina plain is the depression area in the slowly uplift zone, with features of small magnitude of relative subsidence and disparity.

The upstream and midstream areas differ from the downstream area in formation and types of landform, by which, the landform of upstream and midstream areas are classified into 3 basic units, namely, 1) mountains comprising of strongly folded fault uplift high mountain, fault uplift medium high mountain, and folded fault block low mountain, 2) high plains formed by vibrating uplift and further shaped by water flows, and peneplain formed under construction-denudation forces, and 3) corridor plain consisting of alluvial-diluvial, diluvial gobi plain, alluvial-diluvial fine soil plain and aeolian deposit plain, etc. On the other side, the Mesozoic geologic structure established a frame for the landform of the downstream, which was shaped through the wind-erosion forces under the late dry climate scenario. It can be divided into 3 types in the formation as well, i.e., 1) structured denudation landform comprising of peneplains and lower mountains, 2) deposition landform comprising of alluvial-diluvial plains, alluvial-lacustrine plains, and diluvial clinoplain, etc, and 3) wind-formed landform comprising of various types of sand dunes and other wind-eroded landforms.

The precipitation in the HRB can be grouped into three categories by amount: mountain area with annual precipitation greater than 300 mm, the middle reach area with annual precipitation between 100 and 200 mm and the downstream Alxa desert with lower than 50 mm. Precipitation decreases from southeast to northwest gradually. The precipitation of middle reach area is generally smaller than 200 mm, increasing to 300 mm in the piedmont, and over 800 mm in the alpine ice and snow zone.

There is spatial and temporal heterogeneity of precipitation distribution, primarily concentrating on May to September, accounting for 75.9% - 97.2% of the overall annual amount.

Heihe main river starts from Corridor South Mountains in the area of Qilian Mountains of Qilian County, Qinghai Province, with an elevation of 4 300 km. The entire length of Heihe River is 821 km. Two branches, i.e., the eastern and the western, make up general Heihe River. The eastern one is main stream, whose upper streams include an eastern branch named Erbo River originated from Jingyang Range, with a length of over 80 km from east to west, and a western one named Yeniugou taking source from Tieligan Mountains with a length of about 190 km, both joining together into Ganzhou River at Huangzang Temple, then flowing northwards to the Corridor plain, around 90 km away, through Yingluo Gorge. The western branch, the tributary Heihe River as commonly called, takes source from Taole Temple. The tributary upper stream, called Taolai River, consists of two branches, and joining near the Zhulong Temple to Beida River, or Linshui River. Generally, the upstream areas of Heihe River are areas up the Yingluo Gorge, with a river length of 303 km, and a catchment area of 10 000 km^2.

The average annual outflows are 1.58 billion m^3 at the Yingluo Gorge, 0.237 billion m^3 at the Liyuanhe Gorge, and 0.658 billion m^3 along the rest branches (figure 2).

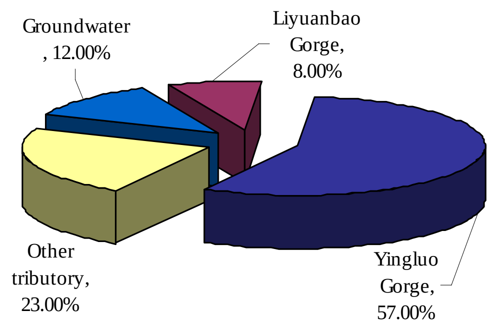

Figure 2, water resources composition in the HRB

Heihe River flows into Hexi Corridor through Yingluo Gorge, turns northwest, 10 km off the Zhangye City where Shandan River and Hongshui River join to the Heihe River, passing through Linzhe County, Gaotai County where Liyuan River and Bailang River join together, and Zhengyi Gorge, and finally enters into the Alxa plain. From Yingluo Gorge to Zhengyi Gorge is the middle reach area of the Heihe River, with a river length of 185 km, a catchment area of 25 600 km^2, and an average riverbed gradient of 2‰. From Zhengyi Gorge downwards is the downstream area, 333 km in river length and 80 400 km^2 in area. Heihe river joins Dingxin River and Beida River in Jinta County of Gansu Province, 150 km away from Langxinshan Mountain in Erjina Banner of Inner Mongolia at north, where the river is separated into Daxiaobao River, the eastern one, which has 8 branches (Nalin River, Baoduge River, and Anci River etc) northwards, entering East Juyanhai Lake at the tail, and Mulin River, the western one, stretching out 5 tributaries (Gongzi River, Kelidu River, and Madigege River, etc), finally entering West Juyanhai Lake.

The minimum runoff is likely to be at January through February, when runoff supply depends on groundwater since rivers are kept frozen this time. The amount of runoff in January to March accounts for only 7.1％ in annual total. From April on, along with the temperature increase, the snow melts away and the river ice gets thawed, both contributing significantly to runoff. April and May account for 11.8% of annual total. Summer and autumn are most rich in precipitation, and rainstorm is easy to happen. June to September will account for 68.5% in entire annual runoff.

Dryness is the main factor to limit the local economic development and worsen the degradation of ecological environment. Hexi Corridor to the north of the Qinghai-Tibet Plateau (QTP) is the driest area in the same latitude throughout the world, under control of downward current formed at the edge of large terrain unit and the north-west East Asia current. The annual precipitation in the midstream area ranges from 200 ~100 mm, and the downstream area less than 60 mm, with the minimum at the terminal of Heihe River less than 40 mm. The meteorological data from 1951 show that the draught often happens in the months of 5, 6, and 7, when water demand happens to be high for Spring wheat growth, accounting for 70% to 80% of total water demand in the whole wheat growth. In this context, the draught would significantly affects plant production in local agricultural areas.

Frost is another factor to injure the growth of crops, forests and grasses. The temperature will fall to -2.0℃~-6.2℃ in the event of frost. This will threaten 80% of maize, wheat and other economic corns, greatly reducing food production. Based on the frequency analysis of frost happening, in the mountainous area frost most possibly occurs in middle and last ten-day of May, up to 29% and 31.9% respectively. The second easy-to-occur time is the early June, accounting for 21.7%. In the plain area, the easiest frost time is late April and early May, 29.1% and 20.8% respectively. Generally there is no frost in June.

As a common natural disaster in arid areas, dry-hot wind is often happened in the HRB, featured with low wind speed, high temperature and extremely low moisture. The dry-hot wind will dry up crops and soils in a very short time. It would decrease the food production, due to large water loss from crops. The extensive plain lower than 1 800 m in elevation is seriously affected, with over annual average 5.5 days. In comparison, areas between 1 800~2 000 m are less dry-hot wind, with annual average days of 3.0.

Gale is referred as the wind faster than 17 m/s, or wind of over the eighth level. Gale is common in arid areas in China due to the impacts of Mongolia-Siberia Plateau anticyclone. Gale is the major force to form sand storms and move sand dunes. In the HRB, gale will more often happen in plain than mountain, with a trend of decrease from northwest to southeast. There are 20 to 30 days with gale in the midstream area, versus 40 to 50 days in the downstream area. Sand storm is the main gale disaster, likely to erode soil surface, bury farmland, and even destroy channels, villages, and railways. Hexi Corridor and Tengger Desert are those frequent and serious areas with sand storm affected. Most parts in the HRB have more than annual 13 days of sand storm, with the maximum of up to 20 days in Jinta County and Erjina Banner.

By statistic of 56-year-long data series in the Yingluo Gorge hydrological station (1945~2000), the Heihe River upper stream starts to freeze in early November, completely frozen in early January to the end of February next year, and thawed away from the middle of March. The maximum thickness of shore ice and river ice will reach 1.14 m and 0.88 m respectively.

(b) Demographic Characteristics:

Total population of the HRB is up to 1 939 thousand people in the year of 2000.

Table 1, population in the principle cities or towns of the HRB

City	People	City	People
Qilian county	43 448	Gaotai county	157 885
Sunan county	35 901	Jiayuguan	159 700
Shandan county	195 330	Suzhou county	332 018
Minle county	235 447	Jinta county	137 644
Ganzhou prefecture	479 307	Erjina Banner	16 156
Linze county	146 137		
Total		1 938 973	

Table 2, average per capita income of major cities in the HRB (*yuan**)

City	Urban residents	Rural residents
Jiayuguan	6 771	4 732
Jiuquan	5 450	3 161
Jinta	4 779	4 833
Zhangye	4 809	2 860

* the currency ratio to US dollar is 7.9956 : 1 on July 2nd, 2006

In 2000, the gross domestic product in the HRB was up to 11 027 million *yuan*, calculated upon the price of that year. Among them, primary industry is 3 905 million *yuan*, the second industry 4

138 million *yuan*, the third industry 3 215 million *yuan*, or 35.41%, 37.53% and 29.16% respectively in proportion. Per capita gross domestic product is 5 687 *yuan*.

The HRB is subject to the extremely strong continental climate. From southwest to northeast of the mid- and down-stream area, the average rainfall declines from 140 mm to 47 mm in long term, while the average annual potential evaporation from 1 410 mm to 2 250 mm, and arid index is up to 82. Even taking 93% of the entire drainage area, there is nearly no surface runoff generation in the midstream and downstream areas. In 1999, water resources amount is 2 100 m^3 per capita, and 680 m^3 per *mu* (1/15 hectare), lower than the average national level.

Recent Regulation and Planning for the Heihe River basin reviewed by the State Council of China, August 2001, stated that we had to recognize the urgency of the long-term ecological construction, and to take comprehensive measures to regulate the water resources utilization by stages. Implementation of the regulation includes two stages.

The first stage from 2001 to 2003 is to reform the water saving facilities in the irrigation farmland of the midstream area. The content includes consolidation and adjustment of canal systems, construction of field water-saving engineering, abolishment of a portion of plain reservoirs, restriction on water storage of plain reservoirs during flood period, exploitation and utilization of groundwater, introducing of high-tech water-saving technologies, and effective measures such as returning farmland to forest or grassland. The main objective is to save water up to 0.255 billion m^3 to the year of 2003. At least 0.95 billion m^3 of water discharge to the downstream area at the Zhengyi Gorge should be guaranteed when the inflow to the Yingluo Gorge is 1.58 billion m^3.

The second stage beginning 2004 to 2010 will continue to carry out water saving reformation on the basis of the first stage, and to build mountain reservoirs to substitute plain reservoirs. The Zhengyi Gorge reservoir and a primary water-transfer canal to Inner Mongolia are in plan. Based on strengthened administration and rationalized allocation of water resources, the discharge at the Zhengyi Gorge will be maintained at the level of 0.95 billion m^3.

Endowment insurance and provident fund system have been completely carried out in most local agencies. Unemployment insurance, medical insurance, and systems of “subsistence allowances for the poor” and “home for the aged” have been extensively applied. Taking the Zhangye prefecture as an example, the service system of health care and medical treatment consisting of more than 300 medical organizations has been primarily formed, covering all counties, towns and villages of this prefecture. There were totally 349 medical organizations to the end of 2001; it means 23.8 beds and 32.4 health personnel, of which 14.4 are doctors, for per ten thousand persons.

(c) Land Forms and Land uses:

Based on LandSat ETM data, areas and percentages of each land type in the HRB are listed as follows.

Table 3, areas and percentages of principle land uses in the HRB

Land use type	Area (m^2)	Percentage (%)
Irrigation land	5 201 890 302	4.08
Dry land	121 195 278	0.09
Forested land	5 021 636 288	3.94
Shrub	228 566 333	0.18
High cover grass land	5 094 722 920	3.99
Low cover grass land	23 387 028 431	18.33
River	691 317 565	0.54
Lake	274 708 765	0.22
Reservoir and pool	92 643 269	0.07
Glaciers and Snow	498 805 438	0.39
Resident	529 785 393	0.42
Sand	12 763 566 784	10.00
Gobi	39 425 016 757	30.90
Saltings	10 877 766 187	8.53
Bare rock, stone, and gravel	21 820 977 543	17.10
Bare land	1 558 842 281	1.22

(d) Water resources and uses in the basin:

The overall amount of surface runoff in the HRB by the first water resources assessment during 1956~1979 was 3.670 billion m^3; 3.680 billion m^3 by the second one during 1956~1990; and 3.632 billion m^3 by the third one, equivalent to 25.87 mm in runoff depth. All the three assessments show that the amount of water resources in the HRB is basically stable in the past 50 years. Table 4 shows the results of the third water resources assessment for the HRB.

Table 4, the total water resources in the HRB

Water system	Catchment area (km^2)	Amount of precipitation (10^8m^3)	Surface water resources (10^8m^3)	Underground water resources (10^8m^3)		Underground water resources (excluding surface water) (10^8m^3)			Total amount of water resources (10^8m^3)		
				Mountains	Plain	Mountains	Plain	Sum	Mountains	Plain	Sum
Eastern	115 990	122.56	24.75	11.10	23.36	1.29	2.04	3.33	26.04	2.04	28.08
Middle	5 793	9.77	2.79	1.49	2.53	0.18	0.00	0.18	2.97	0.00	2.97
Western	21 090	33.54	8.82	5.08	7.34	0.40	0.00	0.40	9.22	0.00	9.22
Sum	142 873	165.87	36.36	17.67	33.23	1.87	2.04	3.91	38.23	2.04	40.27

There are 98 reservoirs of various storage capacity in the HRB, most of which are medium or small sized, i.e., 1 large-sized reservoir, 9 medium-sized, and 88 small-sized. The potential maximum capacity is 456.7 million m^3, and currently water supply capability is 1.0471 billion m^3.

In 1999, supplied water amount of all types of hydraulic facilities in the HRB is 3.146 billion m^3, among which surface water accounts for 2.781 billion m^3. According to types of hydraulic facilities, the water storage facility (for ex. reservoir) supplies water of 0.386 billion m^3, or 12.3% in proportion, water transfer cannel 2.384 billion m^3 or 75.8%, and proposed water facility 0.011 billion m^3 or 0.4%.

The rest 0.365 billion m^3 is supplied by groundwater, including spring spillage, among which wells supplies are 0.302 billion m^3, accounting for 9.6% out of total, and the others, especially springs, 0.063 billion m^3, accounting for 2.0%.

The water resources utilization amounted to 2.1323 billion m^3 in the whole basin of 1990-1995 years, with a utilization ratio of 57.4%. By definition of the United Nations of "areas with water resources utilization ratio over 50% should be defined as highly water-deficit area", the basin had already reached the critical line, especially the Zhangye city and Jiuquan city that were in extremely water deficiency.

Water resources utilization ratios of Jiuquan and Zhangye in 1995 were 77.1% and 79.2% respectively, and water supply was smaller than demand. Recharge and discharge of groundwater resources were almost in balance. Under the current irrigation condition, incrementing the amount of water resources utilization is hard. Moreover, since we are absent of detailed study of ecological environment in the midstream area, the reuse of groundwater evaporation in the midstream area is remained to be studied in more depth.

By looking at the equilibrium analysis outcome of utilization ratio of water resources and groundwater, only the middle river subsystem have the capacity to be further exploited, 0.0252 billion m^3 by estimation. However due to the small runoff amount, short riverway, and geographically dispersed distribution, this unused capacity of middle subsystem is hard to be utilized by irrigation areas.

The total water consumption in the HRB is 3.146 billion m^3 in 1999, among which irrigation consumption is 2.465 billion m^3, ecological consumption 0.521 billion m^3, industrial consumption 0.115 billion m^3, domestic consumption 0.045 billion m^3 (figure 3).

Midstream area of the HRB is the major water consumption area, with a consumption of 2.598 billion m^3, accounting for 82.6% out of total water consumption, among which irrigation use is 2.331 billion m^3, ecological use 0.152 billion m^3, industrial use 0.08 billion m^3, and domestic water 0.035 billion m^3. Downstream area consumes 0.508 billion m^3, accounting for 16.1%, while the upstream area 0.04 billion m^3, accounting for only 1.3% (figure 4).

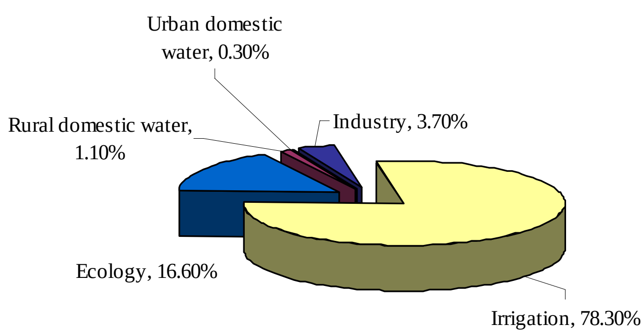

Figure 3, water consumption percentages among different sectors in the HRB

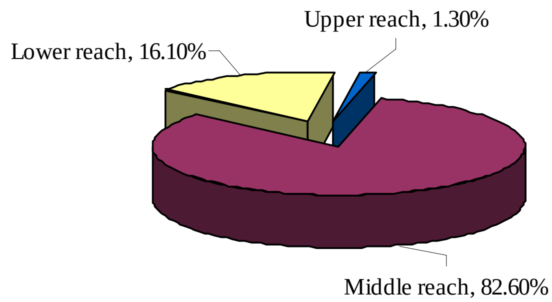

Figure 4, water consumptions in the HRB

The climate of this region belongs to the arid type and the local water resources are deficient. The development of local economy does not consider much about water resources shortage, and places much less concerns on the ecological water use. The existing water conservancy engineering is not rationally deployed, making the situation worse, with a large evaporation and infiltration amount. This can be explained by the followings.

1) Absence of a key coordinating engineering for the main river. Runoff records of the Heihe River show variability within year. Amounts of May and June only take 20.4% of the annual runoff, while in the same period irrigation demand is 35% of annual demand. Due to the absence of a key coordinating project, the water use conflicts are especially intensive.

2) Excessive plain reservoirs, irrational cannel layout, and unqualified engineering equipments, all leading to insufficient groundwater utilization and considerable evaporation loss. There are totally 40 plain reservoirs, with a total reservoir capacity of 79 million m^3 and a small storage depth of around 2 m, likely to result in a 20.0% loss due to the impacts of evaporation and infiltration. Surface water and groundwater transforms to each other frequently in the midstream area; some groundwater tables are close to 2 m. In sum, the utilization degree of groundwater is lower and evaporation loss is greatly high.

There is currently no concentrated management for the water resources in the HRB, along with highly water use insufficiency. Basin management began to work only after 1999. Both the framework and underlying mechanism of the basin management are far from the satisfaction to the current demand.

As a result of the heterogeneity of the water and land resources distribution, the water conflicts have been in existence for a long time. With growing of population, developing of economy and improving of people's living level, conflicts between the midstream and downstream areas are growing intensive. At the same time, ecological problems, such as salinization of farmland, drought up of rivers and lakes, declination of ground water table, reduction of natural forest in area, degradation of pasture and grassland, and land desertification and sandstorm, to name a few, comes to appear.

By using the equilibrium analysis of water resources supply and demand, simulations of the years of 2003 and 2010 have been done (table 5).

1) Equilibrium analysis of the year of 2003

In 2003, water demand for economic and ecologic uses was 2.116 billion m^3 in the HRB, while the actual supplied amount of water resources was only 1.628 billion m^3 based on the long-term statistics. There was a deficit of 0.488 billion m^3 from the demand amount. Provided the water dischage at the Zhengyi Gorge was 0.69 billion m^3, the deficit ratio for the ecological use in the Erjina oasis would be 53%.

In moderate dry years, the water supply for economic and ecologic uses was 1.455 billion m^3, and a deficit of 0.662 billion m^3 from the demand amount. Provided the water discharge at the Zhengyi Gorge was 0.54 billion m^3, the water deficit ratio for the ecological use in the Erjina oasis would be 75%.

In extremely dry years, the actual water supply for economic and ecologic uses was 1.313 billion m^3 and a deficit of 0.803 billion m^3 from the demand amount. Provided the water discharge at the Zhengyi Gorge was 0.42 billion m^3, the water deficit ratio for the ecological use in the Erjina oasis would be up to 91%.

2) Equilibrium analysis of the year of 2010

In the year of 2010, water demand for economic and ecologic uses would be 2.402 billion m^3 in the HRB, while the actual amount of water resources supply would be 1.628 billion m^3, with a deficit of 0.774 billion m^3. Provided the water discharge at the Zhengyi Gorge was 0.61 billion m^3, the water deficit ratio for the ecological use in the Erjina oasis would be 71%.

Table 5, water balance table in the levels of years 2003 and 2010 of the HRB

Unit: billion m^3

Year	Guarantee ratio	Surface water	Ground water	Total amount	demand	supply	loss	deficit amount	Discharge at the Zhengyi Gorge
2003	Mean	2.475	0.333	2.808	2.116	1.628	1.051	0.488	0.690
	75%	2.224	0.333	2.557	2.116	1.455	0.974	0.662	0.540
	90%	2.021	0.333	2.354	2.116	1.313	0.912	0.803	0.420
2010	Mean	2.475	0.333	2.808	2.402	1.628	1.051	0.774	0.610
	75%	2.224	0.333	2.557	2.402	1.455	0.974	0.947	0.460
	90%	2.021	0.333	2.354	2.402	1.313	0.912	1.089	0.340

Conclusion from the above analysis warns of the more intensive conflicts between the demand and supply of water resources there would be, along with growing population and local economy. The ecological issues arisen would be more serious. In this case, it has already been highly urgent to enhance planning and management, optimized allocation, saving, and protection of water resources, as well as to coordinate domestic, industrial, agricultural, and ecological uses, to prevent from further ecological system deterioration.

(e) Environmental Characteristics:

Except examples from the Dingxin town and Huxi New village which are slightly high in hardness, water indicators exampled along the main Heihe River including PH value, mineralized degree, and contents of chloride, sulfation, and major trace elements, conform to the national living water standard. The water quality for the irrigation use is generally better.

Based on the monitoring data of 1996-2000, the main pollutants of the Heihe River are NH3-N, CODcr, BOD5, the volatile phenol, As, colon bacillus, and others. Statistics can be seen in tables 6 and 7. The monitoring results of tables 6 and 7 show that the water quality in the Heihe river has been polluted to a certain degree, primarily by organic pollutants. Every pollutant is relatively higher in low water season, and lower in high and normal water seasons.

Table 6, the monitoring data of main pollutants along the Heihe River in 1996-2000

Unit: mg/L

Items	low water season			high water season			normal water season		
	mean	density range	exceeding multiple**	mean	density range	exceeding multiple**	mean	density range	exceeding multiple**
NH3-N	2.454	0.012-5.870	1.45	0.684	0.045-4.076	0.00	0.778	0.012-3.154	0.00
BOD5	7.240	0.720-15.420	0.81	2.780	0.390-6.810	0.00	6.640	0.530-8.270	0.00
CODcr	22.84	1.250-61.760	0.14	16.600	2.410-47.530	0.00	16.270	1.180-39.350	0.00
volatile phenol	0.003	0.001-0.006	0.00	0.002	0.001-0.061	0.00	0.002	0.001-0.005	0.00
As	0.008	0.004-0.739	0.76	0.012	0.004-0.051	0.00	0.026	0.004-0.185	0.00
Colon bacillus*	18.154	0-96000	0.82	9.721	210-24000	0.00	7.543	40.-24000	0.00

* the unit of colon bacillus is /L.

** value of exceeding multiple is the ratio of mean value of this item to the value in the national living water quality standard.

Table 7, the monitoring main pollutant densities of selected sections

Unit: mg/L

Section	NH3-N	BOD5	CODcr	volatile phenol	As	colon bacillus*	comprehensive pollution index	pollution level
Yingluo Gorge	0.289	2.05	6.93	0.001	0.005	2.278	0.28	clean
hydrographic station	1.214	3.50	16.28	0.002	0.008	24.873	1.06	seriously
Shandan River	1.847	6.14	24.67	0.002	0.077	12.577	1.30	seriously
Liaoquan	0.764	1.95	11.99	0.001	0.006	6.652	0.47	slightly
Liuba	0.664	2.52	18.41	0.004	0.005	6.966	0.63	slightly

* the unit of colon bacillus is /L.

The water quality data of year 2002 was evaluated by the GB 3838-2002 specification “the standard of surface water environment quality”. Evaluated ranges consist of a 364 km riverway from the Zhamashike hydrologic station of the upreach to the Dingxin station of the downreach along the main Heihe river, and 269 km riverways along tributary rivers including 34 km from the Shuangshusi reservoir station of the Hongshuihe tributary, 153 km from the Baiquanmen station of the Liyuan river to the joining point to the main river, 10 km from the Jingan bridge station of the Shandan river to the joining point to the main river, and 72 km from the Binggou station to the Yuanyangchi reservoir station of the Taolai tributary.

Within this 364 km riverway along the main Heihe River, river length with water quality of both class I and II is 169 km, accounting for 46.4% out of entire 364 km length, while river length of class III is 35 km or 9.6%, class IV 105 km or 28.9%, and class V 55 km or 15.1%.

Within the 269 km tributary water quality evaluation, classes I and II take 225 km in length, accounting for 83.6%, class III 16 km or 6.0%, classes V and V+ 28 km or 10.4%. See the table 8 for more details.

Table 8, river lengths under different water quality levels

	evaluated length /km	period	riverway length under different water quality level / km				
			I,II	III	IV	V	V plus
main stream	364	high water season	47.8	16.5	35.7		
		low water season	45.1	2.7	22.2	30.2	
		whole year	46.4	9.6	28.9	15.1	
tributary	269	high water season	94.0	2.2			3.8
		low water season	73.0	9.5			17.5
		whole year	83.6	6.0			10.4

Pollution entering to the Heihe River primarily comes from industrial and household wastewater of cities along this river as well as from farmland fertilizers. In addition, household waste along the Heihe River deteriorates the water quality. In the Zhangye prefecture, there are currently 72 industrial factories that are discharging wastewater into the Heihe River in a direct or indirect way, with an annual amount of 6.68 millions tons.

Several wetland reserves were established in the HRB. The Zhangye wetland reserve, lying in the Gaotai county of the midstream area of the HRB, with an area of wetland up to 229.9 thousands hectares, quite vulnerable in ecological environment, has 105 species of animals and 96 species of plants specific to the desert and wetland condition.

There is a large coverage of lake wetlands and swarm wetlands in the downstream area. As an important ecological defense, wetlands play key roles in climate regulation, wind break and sands fixation. The data of 1950s show the west Juyanhai Lake is around 267 km^2 in area and the east Juyanhai Lake is about 35 km^2. After several decades' development, especially the over-exploitation of water resources by irrigation, the recharge of the downstream has been reduced considerably, for example, inflow amount of the Erjina oasis has decreased from over one billion m^3 in past to present 0.2 billions m^3, making the Erjina river no flow for a long term. In 1970s, the west and east Juyanhai lakes subsequently dried up. The largest Populus Euphratica forest in the west China has been in large scale death, causing the abruptly worsening of ecological environment. This area has been a major source of sand storms.

Water in the upstream area of the HRB is generally fine in quality, agreed with the water quality standard for fishing, except indicators of total phosphorus content and total nitrogen content exceeding the standard slightly. By the investigation in place, there are diverse fish species along the Heihe River, such as Qilian Mountains scale-less carp, and plateau loach, etc. Richness in fish resources is an evidence of the protection of aquatic environment in the HRB.

However, the investigation also discovered that some engineering projects in the upreach area had adversely affecting fishery resources in an extensive degree. For example, without sound consideration during the project planning stage to take care of the aquatic beings, the ladder hydropower stations in the Qilian Mountains worsen the living environment of fish, by separation of surface runoff.

Due to the impacts of climate change and human activities, the environment in the HRB increasingly gets worse. The situation in the downstream area is most serious, evidenced by, for example, decrease in amount of river flow, lengthening of river cut-off days, drying up of terminal lakes in the desert, and the settlement of groundwater table. The cut-off days of the profile at Langxin Mountains, located in the downstream area, become longer, extending to current almost 200 days from 100 days in 1950s. The west and the east Juyanhai lakes were dried up in 1961 and 1962 respectively. Since 1960s, a number of springs and swamps gradually disappeared, groundwater table keeps declining, and water mineralized degree remarkably increases. All evidences suggest that the water environment, forest and grassland ecosystems are under degradation. Reduction in river flow and declination in groundwater table in the downstream area directly result in death or degradation of a large amount of desert vegetation.

Meanwhile, degradation in dry steppe areas and meadow areas is increasingly serious due to water shortage and over-grazing. From 1980s on, the forest-shrub meadow zone with vegetation coverage of over 70% reduces by 78% in area. Low land and swampy meadow with coverage of 30% ~ 70% and meadows of the 4^{th} or 5^{th} level of production reduce by 40% in area. Desert meadow land with coverage less than 30% are facing severe desertification, areas of gobi and deserts rising by 68%. Comparative analysis of aerial photographs of 1960s and TM imagery of 1980s show, that area of gobi and desert in the Erjina banner with a coverage of less than 10% increases by 462 km^2, at a rate of 23.1 km^2 per year. The Alxa prefecture where Erjina Banner is located inside is considered as a major contribution to the sand storm frequently happened in recent years in northwest China. In 1990s, there were more than 200 days without flow on annual average of Heihe River.

From the viewpoint of eco-economy, the water and soil resource sustainable development confront such problems as following: 1) a low carrying ability of water and soil resource; 2) disparity in carrying capability of community, economy and ecosystem; 3) variation in local development between regions.

In order to address the problem of the Heihe River, the State Council authorized the administration bureau of the HRB of the water conservancy committee of the Yellow River to be in charge of water administrative business and implement the water resources allocation scheme starting from 2000.

(f) Baseline information availability:

- observation networks;

There are 22 meteorological stations (including WMO stations and project-level stations) and 34 hydrological stations, 4 automatic weather stations over typical units of the Heihe River basin.

- available data

1) basic data

Table 9, basic data for the HRB

name	scales	format
Topography	1: 100 000	TIFF
DEM	30 m	ArcView Grid
Boundary	1: 100 000	Arcinfo
River	1: 100 000	Arcinfo
Road	1: 100 000	Arcinfo
Residential area	1: 100 000	Arcinfo

2) remote sensing imagery

Table 10, remote sensing imageries available in CAREERI for the HRB research

name	resolution	time
AVHRR	1 km	1986－2004
Spot Vegetation	1 km	1998－2005
Landsat MSS	60 m	1973-1978
Landsat TM	30 m	1990
Landsat ETM+	30 m	2000
ASTER	15 m	2002
Others		

3) thematic data

Table 11, thematic datasets available of the HRB

name	scales	time
Land use/Land cover	1: 100,000	1986/2000
Vegetation map	1: 1,000,000	
Soil map	1: 1,000,000	
Glacier distribution map	1: 100,000	
Landscape	1: 100,000	
Meadow map	1: 100,000	
Hydrogeology map	1: 1,000,000	
Others		

4) observation data

Table 12, observation data available of the HRB

name	data	time
Meteorological observation	temperature, precipitation, evapotranspiration, wind speed, wind direction, humidity, air pressure	station built -2004
Hydrological observation	precipitation, streamflow, evapotranspiration, sand, water level, temperature	1980 - 2000
Groundwater observation	water table	
Automatic weather station	flux, soil moisture and etc.	1998 - now
Field observation	LAI, spectrum and etc.	

5) social economic data

Table 13, social economic data of the HRB

Name	city
Demographic data	Zhangye
Agricultural statistics	Jiuquan

6) data sharing website

The website of "Digital Heihe" is supported by a CAREERI project to share most scientific data in the HRB including remote sensing imageries, observation data, re-analysis data, modeling datasets over Internet. Access the following link to reach this website, http://heihe.westgis.ac.cn

- research centers

1) Cold and Arid Regions Environmental & Engineering Research Institute, Chinese Academy of Science. More information is available at http://www.casnw.net.

2) Institute of Water resources Conservation Forest in Qilian Mountains
Zhangye, Gansu, 73400, P.R.China

3) Gansu Meteorological Administration. More information is available at http://www.gsqx.com.

4) Gansu Bureau of Hydrology and Water resources Survey. More information is at http://www.gsmwr.com.cn.

2.3 Main issues

(a) Hydrological and Water Management issues

Formed in the upstream mountainous area, water resources of the HRB are consumed in the midstream oasis and downstream desert. Because the increases of water demands for the development of local agriculture and industry, and the maintaining of ecosystem in the basin, the amount of water sources is insufficient to the need.

With a vast extent, the HRB crosses three provinces in the northwest of China. From upstream to downstream, the river winds through Qilian County of Qinghai Province, Zhangye Prefecture, Jiuquan Prefecture and Jiayuguan City of Gansu Province and the Ejina Banner of Inner Mongolia Autonomous Region. Due to the geographical priority of the upstream and midstream areas, water resources allocation problems have been existed for a long time. Around several decades before 2001, Zhangye, Jiuquan and Jiayuguan, the three important cities in the midstream area, have taken most water resources in the Heihe River. With more water than natural conditions, the area of midstream oasis has extended significantly; agriculture and industry in the midstream cities have also make quite great progresses than before.

However, excessive utilization of water resources in midstream area has caused significant decrease of water in amount which reaches to the downstream area. As a result of massive construction of plain reservoirs in Jiuquan and Jiayuguan, the west branch of the Heihe River has lost the hydraulic connection with the main stream. Zhengyixia gorge divides the midstream and downstream of the Heihe River basin. Water discharged from Zhengyixia gorge from the east branch, which is also the main stream of the Heihe River, can not satisfy the water demand of maintaining the desert and oasis ecosystems in the downstream area. East and west Juyanhai lakes, which are tow lakes in the tails of the Heihe River, have been dried up successively due to the shortage of recharge. Surface runoff in the riverway has dried up as well in the recent two decades. Without surface water inflow, the oasis and desert ecosystems are maintained by groundwater basically. However, due to the descending of groundwater level, natural vegetations in some areas have withered and then died. The area of downstream oasis shrinks year by year, moving toward the riverway. It is obviously that the decrease of water resources has brought the ecological problems of downstream oasis and the riverine ecosystems.

The conflict of water allocation between regions in the HRB has drawn the attention of the central government of China. In order to solve the problem, Administration Bureau of the Heihe

River Bain (ABHRR), in charge of the water resources management crossing provinces in this basin, has been established under the supervision of Yellow River Conservancy Committee. ABHRR carries out the water allocation scheme made by State Department and makes the cross-region water management possible. With the continuous work of ABHRR, water supply for the recovery of downstream ecosystem has been guaranteed

(b) Environmental issues

The environmental issues in the basin can be distinguished by locations in the basin.

In the upstream area, environmental issues include grassland degradation and glacier retreat. The former one is featured with “black soil type” degradation, noxious grass and weed spread, grassland desertification, and decrease of precious and rare species.

In the midstream area, environmental issues include desertification and salinization of land, and water pollution. Since 1990s, the desertification of land in the Jinta county and Gaotai county, locating in the midstream area, has been extending continuously. Water pollution in this area is serious and shows an increasing worsening trend. In the west branch of the HRB, water pollution is very serious; in the east branch, water pollution reaches grade III. Due to lack of counter-measures and limited environmental capacity of riverway by itself, potential trend of water pollution is not optimistic. In addition, the trend of salinization in shallow groundwater aquifer is clear and the water pollution in urban area is getting more serious. Area of grassland has decreased significantly because the large scale reclamation of wilderness. Existing grassland is suffering serious degradation due to high intensive grazing.

The environmental issues in the downstream area are most serious in the entire basin, characterized by disappearance of terminal lakes, abandonment of riverway, formation of new desert inside the oasis, shrinking of natural oasis, and acceleration of land desertification. Environmental problems in downstream not only decrease local living condition, species diversity, local economical development and the stability of local society, but also threaten the ecological security of the whole basin.

(c) Livelihoods issues

Restricted by natural conditions, there are still some residents facing livelihood difficulty in the river basin. Local governments have been endeavoring to eliminate poverty for a long time. The construction of “water-saving” society in the river basin will help to solve problems associated with shortage of water resources.

(d) Policy and legislation issues

There has been a long history of water resources management by legislation in the HRB. As early as Han dynasty, there were regulations for water allocation by the area of farmland in river basin. In Qing dynasty, Nian Gengyao, the viceroy of Shanxi and Gansu provinces, constituted a local regulation for the water allocation in the Heihe River basin according to the guideline of evenly water allocation. Due to the carrying out of the regulation with the help of military forces, number of conflicts associated with water allocation decreased rapidly. Nian’s regulation had been in use in the HRB until 1949.

After the establishment of People’s Republic of China in 1949, Nian’s regulation has been revised five times, with the last revision in 1960s. The updated Nian’s regulation has more detailed items about the water allocation in the midstream area but show no concern to the ecological water demand in the downstream area.

Recently, as the result of rapid increase of population, development of local economy and deterioration of ecological environment, the water resources in the HRB are considerably insufficient to demand and the conflicts between midstream and downstream areas are more furious than ever. In this background, the State Council set up “provisional regulation for water management of the mainstream of the Heihe River” and “1999-2000 real time regulation plan for the mainstream of the Heihe River” in the spring of 2000 to alleviate potential conflicts. Those two regulations are the first legislations by State Council for water resources management in the HRB.

In the newly established water allocation regulations, a parallel principle, which means the runoff through the Zhengyixia gorge is proportional to the incoming runoff of the Yingluoxia gorge, is applied. The new regulation not only assures the water supply to important regions, but also takes care of the whole basin. It is more reasonable than former regulations. From August, 2000 on, the new regulation have been carrying out and its applicability has been shown.

(e) Institutional change and capacity building issues

The Zhangye city in the midstream area was selected to the experimental city to construct a “water-saving” society in 2001. Starting with clarifying water right, the functional agencies of local government has explored a new approach to save water, which is composed of controlling water consumption in every level, putting water bill regulation in force, establishing farmer water-using association, and inviting farmers to take part in water management. With the water-using certificate, farmers can buy water bill from water management agencies. Farmers can have their irrigation water amount according to their water bills. The excessive water bills can be exchanged in water market. The collective water right of a village is managed and maintained by the village-level water-using association which is elected by local residents.

Apart from construction of “water-saving” society, irrigation channel system has been refined. 523 km main channels and branch channels, and 266 km sublateral channels have been reconstructed. By this means, water supply and utilization ratio of local channel system has been improved significantly.

2.4 Present State-of-art methodology

As the largest national institute having longest history in the research of environmental problems in arid regions, led by professor and academician of CAS Cheng Guo-dong, Cold and Arid Regions Environmental and Engineering Research Institute (CAREERI), CAS has been focusing on the study of hydrology and water resources in the HRB for over 20 years. A large amount of national funded projects have been conducted in the HRB by scientists in CAREERI. A digital basin, named “Digital Heihe”, has been established primarily based on existing research works and field observations. Digital Heihe has been the pioneer work of watershed study in China.

Nowadays, studies on model integration in river basin, catchment scale hydrological data assimilation and comprehensive basin management are undertaking in CAREERI, with collaboration with other research institutes. With advances in the research of hydrology and water resources management, and more involvement of local residents in the policy making in the HRB, we believe that the management of the HRB will be more scientific, scientific and democratic.

2.5 Schedule of proposed activities:

As part of G-WADI pilot basin research, the following activities are set up.

- July 2006-December 2008, included in the model integration study
  - To develop an integrated hydrology-ecology-economy-management model for the whole Heihe River basin.
  - To independently establish a distributed hydrological model for general purpose.
  - To develop a decision support system (DSS) based on GIS and hydrological models, making the DSS to be used in local water management agencies.
  - To develop a watershed ecological modeling environment based on Spatial Modeling Environment (SME).
  - To develop a groundwater model in the midstream area of the Heihe River basin, with cooperation with China University of Geosciences.
- Proposed activities for training in construction and application of DSS
  - August, 2007 G-WADI training program and the workshop in the area of DSS application for water resources management and groundwater; this proposal has been submitted to the G-WADI steering group.

2.6 Monitoring and evaluation:

Our objectives in the study of G-WADI pilot basin can be monitoring and evaluated through following aspects:

- Update and maintenance of "Digital Heihe" website by enriching with more data, documents. It will be also the important discussion and communication platform for scientists of common interests.
- A release version of GIS based DSS software which is scheduled to be free available by scientists, stakeholders, and decision makers of interest.
- Training and technical support to the application of the DSS in water management agencies and groups.
- A global workshop upon development and application of decision support system and/or groundwater if proven by the G-WADI steering group. And
- Publications on hydrology and water resources management in international journals.

PART-3

3.1 Principle Purposes:

Starting from 1970s, the hydrological studies for the HRB have been getting into increasing depth. Objectives of those studies have been in consistence with those proposed by G-WADI program.

First, as a typical inland basin in arid area, the HRB has common characteristics as any other basin in arid area, while it possesses specific geophysical conditions and unique characteristics of water resources utilization. The existing studies integrated ecology, economics, and water resources management with hydrology aimed to understand the characteristics of hydrological system of the HRB, consequently deepening the understanding of common hydrological characteristics of basins in arid regions and the needs of the basin management, through available techniques and models. A pilot city has been selected in the framework of building a "water-saving society", where water right exchange and water price management system have been set up. The implementation of "water-saving society" in the HRB will provide instructive experience to other basins with similar water problems. During the past research activities, the state-of-the-art geographic information system techniques are applied to construct a spatially-explicit decision support system for the HRB, targeting at users of water managers and corresponding authorities. Those attempts explored the possibility of applying latest technology to the basin research study.

Second, there are already a number of meteorological and hydrological observing stations over different typical units of the HRB, as well as an integrated state-level observation station, the Linze station. There is also a state-level institute, CAREERI/CAS, contributing to the hydrological and water resources research in arid regions. CAREERI has tight relationship to domestic and international institutes, and has rich experiences obtained through undertaking of existing projects. Those experiences, regardless of success or failure, can be referred by other G-WADI pilot basin. Numerous scientific data have been accumulated during those research activities, including not only the observation data, laboratory testing parameters, but reanalysis data derived by data assimilation and parameter estimation techniques, and datasets prepared for evaluation of hydrological and ecologic models in the HRB. Currently most of those data have been shared via Internet with scientists of common interest, and continue to be enriched and updated.

Third, professionals and scientists with deep understanding about the water issues in arid regions have been trained through the research practices. To date, there are over 50 doctoral and master theses taking this pilot basin as the case study graduated from CAREERI/CAS. Those young scientists have grown up to be the backbone of the research force in those fields. Apart from the normal projects, CAS has launched several programs specifically addressing the capability building, such as the "innovation group" and "hundred talents program". CAREERI has also established long-term cooperation with institutes and universities over the world. For example, an agreement has been reached with USGS, to apply and evaluate the PRMS model to the HRB, as well as to train CAREERI staffs by USGS PRMS group experts. In addition, CAREERI has also initiated institution-level capability building programs. Through those programs a competitive team comes to form, with members from varying age stages.

Last, CAREERI has tight collaboration with local water authorities, providing training to their technical staffs, and instructions to rational basin management. CAREERI is active to attend the public activities to spread water knowledge as well.

The primary intention of including the HRB to the G-WADI framework is to improve the understanding of water in the HRB, better to answer concerned questions common to basins in arid region, thereby enhancing the capability of integrated basin management. Meanwhile, the inclusion will enhance the cooperation with international colleagues, especially G-WADI pilot basins members, by exchanging experiences and lessons from each other. Data, experience, and technology in the HRB are ready to share with international colleagues.

3.2 Outputs/Deliverables:

Principle outputs include but not limit to:

1) Development of hydrological models applicable for the HRB, which will improve the simulation ability in the HRB, and consequently will further the understanding of hydrology for the HRB as well as for the inland river basin in arid regions. This is the common target the whole hydrologist community over the world pursued.

2) A more in-depth integrated watershed research, developing an effective methodology to address multi-disciplinary involvement, e.g., water, ecology, economy, etc.

3) Development of scientific management methods (for ex. the “water-saving society” policy in progress) for water use and water allocation for the local society to address the current situation of water shortage and insufficiency. Those measures will be tested in the typical inland basin of arid region, and will be moved to other basin if proven successful.

4) Developing a practical spatial-explicit decision support system (DSS), based on geographic information system (GIS), to help the corresponding authorities and governmental agencies make the scientific decision on water plan, by integrating important models in research field but not adequately used in management field into such a DSS. By providing a wizard-driven graphic user interface, water managers can use those complicated models in a rather easy way.

5) Scientific datasets from all related research field. Those datasets will be archived and shared via Internet with scientists all over the world who have the common interests.

6) Capability building for scientists and local water managers. Through the cooperation with other G-WADI pilot basins, local scientists and water managers will get rapid grown by means of such as exchange visit and sharing experiences and lessons.

7) Sharing of the experiences and lessons learning from all undertaken projects and practices with other basins with similar characteristics and conditions.

3.3 Contributions to promote G-WADI Objectives:

- Local and national awareness of issues in the G-WADI pilot basin

The HRB crosses Gansu Province and Inner Mongolia Autonomous Region. The limited water resources brought numerous problems, even fighting between different areas or different departments. The exhaustive water use within the middle reach area of this basin directly worsened the environment of the lower reach area. Those problems have always been the concern of both local and national government. Major authorities, including the State Council, National People’s Council, National Committee of the Chinese People's Political Consultative Conference, the state Department of Water Resource, and provincial functional authorities. Without the effort of government, the water diversion work associated with direct interest re-allocation between different areas/departments cannot be successful. The local people’s awareness and support is another important decisive factor.

1) After the former Premier Zhu Rongji learned the severe problems in the lower reach area of the HRB, he said we should not let the Juyanhai Lake be the second Luobupo, the ancient city located inside Xinjian Autonomous Region buried under the sands due to desertification.

2) By considering the complexity of administration in the HRB in terms of natural condition and interest conflicts, a special management committee has been established to coordinate the administrative affairs. The Zhangye City is one of first batch of the pilot cities to be the "water-saving society". This city has made some instructive attempts upon the practical water management.

3) Positive support from local stakeholders led to the final success. The farmers changed their planting structure, adopting new irrigation method. Water use associations have been organized to involve water administration together with government. Industries are demanded to control their pollution. A forest protection project has been initiated to sustain the water quality and environment in the upper area of this basin.

4) Funding agencies have started a number of programs to support the hydrological research in the HRB. During the national Ninth Five-years plan, Tenth Five-years plan, and Eleventh Five-years plan, some national key programs have launched or planned on the water-related field of this pilot basin. The National Natural Science Foundation of China (NSFC) supported and will continue to support studies focusing on hydrology in arid regions. Recently, NSFC invited hydrologists to discuss the possibility to initiate a large basin science project.

5) 109,000 items found by Google due Jun 20, 2006 with the keywords "Heihe River Basin" (with Chinese characters), indicating the concern of the HRB to certain extent.

- Research activities

A large number of studies have been carried out by CAREERI/CAS in terms of hydrology/water resource, physical geography, ecological environment, land surface process, economic geography and remote sensing and geographic information systems, through which, a rich set of data, relevant information, and achievements are achieved. The period can be divided into 3 stages.

The first stage deals with data accumulation, featured with fundamental investigations and monitoring. *Water and Soil Resource Exploitation and Ecological Environment Investigation in Heixi Corrdior*, a project organized by CAS in 1984, found out the general situation of soil and water resources and ecological environment in HRB, and suggested a concept of exploitation potential capability of water and soil resource. During 1985 to 1986, a project, initiated by the planning department of former Hydraulic Power Bureau and executed by former Lanzhou Desert Research Institute of CAS, was to study on water and soil resource exploitation and ecological environment protection. On the basis of those projects, a series of thematic maps were compiled and several specialized monographs, such as *Rational Development and Exploitation of Water and Soil Resource in Hexi Corridor*, and *Rational Exploitation of Water and Soil Resource in Heihe River Basin*, were published. Afterward, a five-year long experiment project dedicating to land and atmosphere interaction in the HRB was conducted by former Plateau Atmospheric Physics Research Institute. Though this project, a systematic observation was carried out to monitor the exchange of energy and vapor in the HRB land surface, especially at the transition zone between oasis and desert, collecting a large amount of meteorological and hydrological data, which provided a basis for water balance research at watershed scale.

The second stage is the one of systematic research, where all sorts of works incorporated together. With the help of the two national "Nine fives" key project, *Rational Exploitation of Water and Soil Resource and Coordinated Growth of Community, Economy and Eco-environment in Heihe River Basin*, and *Study on Ice and Snow Water resources and Variation and Tendency of Mountain Runoff*, and one Natural Scientific Foundation supported project, *Preliminary Research on the Formation and Variation of Water resources in Inland Watershed in*

Arid Areas of Northwest China, former Lanzhou Institute of Glaciology and Geocryology deepened the water resources research in arid and semi-arid areas, taking the HRB as the research base. Scientific problems in this stage focused on carrying capability and eco-environment investigation at a macro level, and establishing a number of models with respect to sustainable development and planning. Most of these models included complete economic subsystems and a basic coupled system between economy and ecology. However, the integration of ecologic and economic problems becomes difficult due to the shortage of a suitable model simulating the process of ecosystem. On the other hand, a relatively complete water resources information system as well as a prototype of water resources carrying capability decision support system was set up. In addition, a progress was made in ecological water consumption in a watershed level.

The third stage is an integration stage, to put economy, water, and ecology together to study. Under the support of knowledge innovation project of CAS, CAREERI/CAS has initiated such projects as *Water-Ecology-Economy Systematic Synthetic Management Experiment Demonstration in Heihe River Basin*, *Research on Water Circulation and Water resources Carrying Capability in the Northwest Arid Region*, *Inland Virtual Digital Basin and Dynamic Management System*, and *Development of Integrated Models and Modeling Environment for Inland River Basins, with a Case Study in the Heihe River Basin, Northwest China*.

- Stakeholder participation

March, 2001, Zhangye City, located in the middle area of the HRB, was specified as the pilot city to carry out the water-saving society policy. This policy got supports from all major functional agencies of Zhangye city. The water resources bureau, agricultural bureau and forestry bureau coordinated the detailed water use/allocation among all departments.

On agriculture part, the government is in charge of adjusting, allocating, managing, and supervising of water use and water exchange. The users can hold the water use rights only they get the permission from the government. The saved water can be exchanged and transferred to other organizations or individuals to some degrees. Farmer water use committees are widely established in rural areas of the HRB to defense their rights, as well as to communicate to the government. Those committees have a limited of rights to manage the water resources within village-level small canals, and are responsible for the charging of the cost of water use. By this way, the farmers realize their self-administration.

On industry part, most of factories have passed the certificate of water discharge standard to prevent from the water body pollution. The similar water price has been established to control the water use. The biggest industry in this basin, the Qiuquan steel company has adjusted the original water use pattern, currently holding an advanced waste water processing and cycling system.

The water-related policy obtained wide support from communities of various levels. Women participation is assured by the raw. Women representatives should take certain seats in every water use committee.

- Organization of training program, workshop etc.

Over ten large projects have been carried out in the HRB financially supported by diverse funding agencies. Each project had held a number of workshops with difference scales. For example, the 4-year project "*Development of Integrated Models and Modeling Environment for Inland River Basins, with a Case Study in the Heihe River Basin, Northwest China*", started from 2003, had a yearly 2-day workshop normally at the end of each year or early next year during the program period. This program will invite experts from both within and outside the project to participate. Usually tens of reports from different fields will be presented to summarize the recent progress.

Large international symposiums in the last two years include:

"International Symposium on Sustainable Water Resources Management and Oasis-hydrosphere-desert Interaction in Arid Regions" (October 27-29, 2005，Beijing, China) co-hosted by Tshinghua University and CAREERI, CAS, with a post-conference field trip to the HRB.

"Eighth International Conference on Dry Lands Development" (February 25-28, 2006, Beijing, China) cosponsored by CAREERI, CAS includes topics related to the development of the HRB, especially the control of the desertification in the lower stream area of the HRB.

- Good publicity material

During the more than 20 years of comprehensive studies upon the HRB, numerous papers and monographs have been published to report or summary the research progress covering broad areas, from hydrology, water resource, ecology, soil, to multi-disciplinary field. Additionally, many doctoral dissertations and master theses are available for the HRB research.

Partial monographs list as below (in Chinese):

Chen L.-H., Qu Y.-G. 1992. Water and Land Resources and Their Rational Development and Utilization in the Hexi Region. Beijing: Science Press. pp168.
Li S.-M., Lu G.-Q., Li Y.-H., et al. 2000. Sustainable Development and Rational Utilization of Water Resources in the Hexi Corridor Area. Beijing: Environmental Science Press. pp252.
Chen X.-J. 2000. The Oasis Agriculture of Hexi Corridor. Beijing: The Agriculture Press of China. pp250.
Pan Q.-M., Tian S.-L. 2001. Water resources in the Heihe River Basin. Zhengzhou: Water Conservancy Press of Yellow River. pp398.
Li S.-M., Cheng G.-D., Li Y.-H., et al. 2002. Rational Utilization of Water Resources and Echo-Environmental Protection in the Hexi Corridor Area. Zhengzhou: Water Conservancy Press of Yellow River, 2002. pp250.
Ministry of Water Resources P.R.China. 2002. The Management Plan for the Heihe River Basin. Beijing: China Water resources and Hydropower Research Press. pp85.
Wang H., Chen M.-J., Qing D.-Y., et al. 2003. Rational Allocation and Bearing Capacity of Water Resources in Northwest China. Zhengzhou: Water Conservancy Press of Yellow River. pp242.
Seyin. 2003. The Anthropoecology of Heihe River. Chengdu: Sichuan People's Publishing House. pp156.
Li X., Tian B.-Z. 2003. Construction of Water-Saving Society. Beijing: Water resources and Electric Power Publishing House. pp236.
Chen L.-H., Xiao H.-L., 2003. Mountainous Soils and Their Utilization in Hexi Region. Beijing: Ocean Press. pp132.
Kang E.-S., Cheng G.-D., Dong Z.-C., 2002. Gacier-Snow Water Resources and Mountain Runoff in the Arid Area of Northwest China. Beijing: Science Press. pp304.
Xu Z.-M., Zhang Z.-Q., Chen G.-D. 2003. Theories and practices of ecological economics[M]. Zhenzhou: Yellow River Water Conservancy Press. pp306.
Zhang G.-H., Liu S.-Y., Xie Y.-B., et al. 2005. Studies on Water Cycling and Ground-water Formation and Evolution Pattern in the inland Heihe River Basin, West China. Beijing: Geology Press. pp398.
Yang G.-X., Hou C.-H., Han X.-H. 2006. Erginar Oasis of Heihe River Basin Eco and Water Resource. Zhengzhou：Water Conservancy Press of Yellow River. pp136.

- Important websites

Digital Heihe (http://heihe.westgis.ac.cn) provides numerous data including hydrological field data, meteorological observations, satellite images, social statistical data of the HRB, as well as model dataset (for ex. SWAT datasets) for this basin plus re-analysis data derived by data assimilation techniques. This website is funded by CAREERI/CAS, and continues to be updated.

The Heihe River Network (http://www.yrcc.gov.cn/vh/heihe/index.php), the official page of the administrative bureau of the HRB, presents the latest news, administrative regulations and policies, as well as some descriptive documents about the HRB.

Data Center for Environment and Ecology Research in Western China (http://westdc.westgis.ac.cn), funded by National Natural Science Foundation Committee of China (NSFC), collects the data and documents yielded from projects of "West Plan" supported by NSFC, sharing with scientists who are interested in the research of Western China. This website provides a number of materials and scientific data of HRB as well.

Integrated Modeling Research in Heihe River Basin (http://hhmodeling.westgis.ac.cn) is the official page of the project "*Development of Integrated Models and Modeling Environment for Inland River Basins, with a Case Study in the Heihe River Basin, Northwest China*" financed by Chinese Academy of Sciences, reporting the latest dynamics of this project. Information about the research activities and progress in the Heihe region will be found through this website as well.

Heihe forum (http://forum.westgis.ac.cn), the largest hydrology research-oriented forum in West China, hosted by Lab of Remote Sensing and Geospatial Science, CAREERI, has more than 3000 registered members. Currently only Chinese language is supported.

- High profile personality support from government, industry or media.

Located in the west part of China, with a slower economy development than the eastern area in China, the HRB has attracted many attentions from government, industry and media. Many "hope schools" has been set up under the sponsorship of enterprises and governmental agencies to provide more opportunities to women and children in West China. In the year of 2005, Mr. Ka-shing Li from Hong Kong established the "Li Ka Shing Education Foundation for West China" to support the education in the western China including Gansu Province, and Inner Mongolia Autonomous Region.

1992, Jia Zheming, the president of China, during the visit to the Hexi Corridor, the most developed area in the middle reach area of the HRB, inscribed "Golden Zhangye" for the Zhangye city, a major city of the basin, showing his appraisement for the economic development of this city as well as his encouragement. In order to speed up the development of the west China, in the year of 1999, President Jiang proposed the plan of "Development of West China" which aims to balance the economic level between the western and eastern areas of China by means of institutional and financial support.

In addition to the economy concerns, the water issues and ecological degradation, especially in the lower part of this basin, has got high priority from the leaders of China, due to its special location covering Gansu Province and Inner Mongolia. Zhu Rongji, the formal premier of China, has instructed the work of water diversion from the upper area to the lower area to satisfy the ecological water use for over 3 times on his person in the year of 2002. The comment of Premier Zhu in December 15, 2000 praised the significance of the diversion work as "a green song". Then in 2001, his instruction required the east Juyanhai Lake, the trail lake of the Heihe River, be full of water in three years. More than 10 times of water diversion without conflicts between different areas of the basin witnessed the work of both national and local governments. The east Juyanhai Lake finally sees water throughout a whole year since 2005.

Premier Wen Jiabao, the successor of Premier Zhu, continues to take care about, especially the water diversion and environment protection, in the HRB. He demanded the protection of ecological system along the water diverting canal should be carefully carried out during the diversion.

The academician Qiang Zhengying, the vice president of the National Committee of the Chinese People's Political Consultative Conference, together with 39 academicians and professors, inspected the HRB and the nearby Shiyang river basin in 2001. She said although ecological environment of some areas has been considerably improved, the overall situation kept worsening, suggested we should rationally allocate the use of limited water resource, and protect the ecological environment, making sure the sustainable development of the lower stream reach area of the HRB.

- Academic or civic awards for water-related work in the basin

Many awards of various levels have been received for the research work in the HRB, among which some awards follows:

First prize of Science and Technology Awards of Gansu Province of year 2003 for the project "*Fundamental theory research of ecological economics and ecological hydrology in inland river basins*" led by Professors Cheng Guo-dong, and Xu Zhong-min, etc., of CAREERI/CAS;
Second prize of Science and Technology Awards of Gansu Province of year 2000 "Ecological environment evolution and sustainable development in the Heihe River basin" conducted by Professors Wang Genxu and Cheng Guo-dong, etc., of CAREERI/CAS;
Science and Technology Progress Award of the Yellow River Committee, the Ministry of Water Resources of the PRC for the project "*Sustainable development and water resources comprehensive utilization in the Heihe Corridor*" in 1999;
And first prize of Science and Technology Progress Awards of Chinese Academy of Sciences for the international collaborative project "*Heihe river basin Field Experiment*" (HEIFE) in 1995, etc.

- Management responses.

The major residence areas in the HRB are short of water, facing severe water-related problems common in arid regions of China. The China government assigned Zhangye City of the HRB as the pilot area to build a "water-saving society". The government of Gansu province therefore compiled a complementation schema for all the five major cities in the Hexi Corridor of the HRB. The "water-saving society" policy has produced preliminary effects to address the water problem. Some responses are following:

1) A special committee established to administrate water of the HRB. This committee is the only department to make the local regulations/specifications associated with water resources in HRB. Making the details of the water diversion from the upper and middle reach area to the lower reach to satisfy the ecological needs is a primary work of this committee.

2) A serial of measures to establish a water-right exchange system. This system clarifies the water rights in the HRB, and rules the water right exchange. Water bill is designed to exchange the water. Planned water consumption needs a basic water price, while the excessive part will be subject to a higher price. The water-right exchange should be in accordance with the water laws and regulations/specifications. Special attentions should be placed to protect the ecological

system and water quality in the lower reach areas. A dynamic water price system is carried out, the actual price depending on the relationship of demand and requirement.

3) Several reservoirs deployed along the Heihe artery, intending to improve the ability of water diverting, to replace the existing plain reservoirs which generally have known problems, e.g., exhaustive evapotranspiration, as well as to make good use of the hydro-power resource.

4) Local plant pattern and irrigation methods have been changed to be more effective. Currently the ratio of agricultural utilization is rather higher, while the area of the plant with high water consumption is fairly large. By recognizing this situation, the government starts to popularize water-saving agriculture, water-saving irrigation methods, and use of water-saving instruments. Industries with severe water waste or pollution have been either cancelled or demanded to reform the water-processing system.

5) Various means to advertise the concept of "water saving society" as well as to improve the awareness of water saving and the recognition of rule by law, for example, by television, telecast, newspaper, Internet websites, and community activities, etc.

However, the activity of "water-saving society" is still far from the satisfactory, requiring numerous efforts. More ideas and contents need to be input to the framework of the "water-saving society" to improve it.

3.4 Support to other G-WADI pilot basin program

There are common challenges in water research and watershed management in any arid and semi-arid regions; the experiences and lessons could be learned by each other. The HRB is a typical inland basin in arid region of West China, with common characteristics of arid basin. Water the restricting factor of the development of local economy. Supported by various levels of funding agencies, a large amount of studies have been carried out in the HRB, deepening the understanding from all perspective, including water, ecology, and social-economy, etc. In recent years, Chinese scientists, by recognizing the research in a watershed scale should be an integrated approach, started the interdisciplinary integrated research. Water focusing integration is the key research of international hydrological circle as well, evidenced by reports published in international journals. Researchers of the HRB are willing to communicate with international colleagues concerning all fields including experiences, technologies and data, improving the hydrological research and water management capability together.

At the same time, due to the unique physical conditions and variation in economic development, this pilot basin is facing special water problems as well. It requires the studies for this basin follow the characteristics of basin, and water management be made in accordance with special issues existing within this basin. In general, we wish we could collaborate with other G-WADI pilot basins in following aspects.

1) Hydrological modeling. Based on review of existing work in other pilot basins, the modeling activity in the HRB is expected to be boosted, including migrating and improving appropriate models for other basins, and developing specific hydrological models suitable for the HRB. Our obtained experiences are ready to share with other scientists.

2) Integrated watershed research. Integrated hydrological research is a trend for basin research. This work in the HRB has obtained preliminary results; much work is required to be undertaken further. More cooperation is expected to be taken with international colleagues.

3) Methodology of data acquirement and data sharing. Diverse approaches of data acquiring and data analyzing will be adopted, including normal field observation, remote sensing, radar,

data assimilation, and parameters estimation, etc. We have shared a large part of the datasets, except those subject to the security provisions of China, in the HRB through the website “Digital Heihe River”. Datasets from other basins are also expected to improve the applicability of models currently only used in HRB.

4) Basin management. Applicable management methods can be moved to other pilot basins. The HRB hopes to learn the advanced basin management method from peers, such as the approach of water allocation optimization, and share its successful experiences. Additionally, the collaboration will accelerate the development and adoption of advance decision support system, which is considered as an affective tool to support the basin management.

5) Capability building. Through frequent exchanges, capability building of not only individuals but institutions can be considerably speed up. CAREERI will financially support the training programs and water-related workshops for the basins in arid regions.

(Signature and Seal of the responsible person from the proposing organization)

(Signature and seal of the nodal agency)

Appendix. Xin Li: Curriculum Vitae

Personal Information	Name: Xin Li	Gender: male
	Date of Birth: Oct. 22, 1969	Nationality: Chinese
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Research Interests	Land data assimilation, hydrology, application of remote sensing and GIS in cryospheric research, application of remote sensing and GIS in hydrological research	
Education	1988-1992, B. S. in GIS and Cartography, Department of Geo and Ocean Sciences, Nanjing University 1992-1998, Ph. D. in GIS and Remote Sensing, Chinese Academy of Sciences	
Work Experience	1995, 09-1997, 12, Research Assistant, Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences 1997,12-1998, 12, Research Associate, Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences 1999, 01-1999,12, Research Associate Professor, Lanzhou Institute of Glaciology and Geocryology, Chinese Academy of Sciences 2000, 01-Present, Professor, Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences 2000, 01-12, Research Scientist, Department of Civil Engineering, the University of Tokyo 2002, Director of the Remote Sensing and GIS Laboratory, Cold and Arid Regions Environmental and Engineering Research Institute, CAS 2005, Director of the WDC for Glaciology and Geocryology at Lanzhou 2005, 01-12, Research Scientist, Department of Civil Engineering, the University of Tokyo	
Membership	Fellow, Working group for Environmental Remote Sensing, Chinese Society of Geography Fellow, Working group for theory and method, China Association for Geographic Information System Member, American Geophysical Union Member, International Association of Hydrological Sciences Member, Chinese Society of Geography	

Selective Publications

1. **Li, X.**, Cheng, G-D., and Lu, L., 2005. Spatial analysis of air temperature in the Qinghai-Tibet Plateau. *Arctic, Antarctic, and Alpine Research*, 37 (2): 246-252.
2. Che, T., Jin, R., **Li, X.**, and Wu, L.-Z., 2006. Glacial lake change and the detection of potentially dangerous glacial lakes during the recent three decades in the Pumqu River Basin, Tibetan Plateau. *Arctic, Antarctic, and Alpine Research*, in press.
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13. Lu, L., **Li, X.**, and Cheng, G-D., 2003. Landscape evolution in the middle Heihe River Basin of northwest China during the last decade. *Journal of Arid Environments*, 53 (3): 395-408.
14. **Li, X.**, Koike, T., and Cheng, G-D., 2002. Retrieval of snow reflectance from Landsat data in rugged terrain. *Annals of Glaciology*, 34: 31-37.
15. **Li, X.**, and Cheng, G-D., 2002. Review on the interaction models between climatic system and frozen soil. *Journal of Glaciology and Geocryology*, 24 (3): 315-321. (in Chinese)
16. Huang, C-L., and **Li, X.**, 2002. Comparison of three different methods to distribute spatial data on the Internet. *ACTA Geographica Sinica*, 57 (supplement): 44-51. (in Chinese)
17. Nan, Z-T., **Li, X.**, and Li S-X., 2002. Architecture design of the digital embankment and numeric simulation platform of the Qinghai-Tibetan Railway. *Journal of Glaciology and Geocryology*, 24 (5): 646-651. (in Chinese)
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Information System. *Journal of Glaciology and Geocryology*, 24 (5): 652-658. (in Chinese)

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