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ERSEC
Water Workshop Proceeding

Ecological
Research for
Sustaining the
Environment in
China

Sustainable Water Management: Problems and Solutions under Water Scarcity

International Conference

Beijing, P.R. China
November 6-8, 2006

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A Study of Rain Fall Effects On Meadow Irrigation
降雨对绿地灌溉用水量影响研究

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Abstract

By analyzing the contradiction between water resource shortages and the demands for green land irrigation, this paper presents an optimization measure of irrigation scheduling, under various rainfall conditions, to improve irrigation efficiency of green land. 9 kinds of meadow treatment plots were used to study the effects of different sunken depths as well as the optimal proportion between rain harvesting surfaces and meadow plots. Based on the research, an optimization measure was calculated using the Crop Water Indictor and this was put forward as a useful reference for urban water saving.

摘要

本文通过对北京地区日益增长的绿化灌溉用水和水资源短缺矛盾和现状灌溉制度的分析，提出了城市草坪绿地在充分利用降雨条件下的灌溉制度优化方法。在小区绿地试验中设置不同集雨面比例和下凹深度，共形成9种处理，通过对比不同处理绿地灌溉水量和灌溉制度，提出了利于雨水利用的绿地构建模式。并在试验的基础上，提出了利用作物水分指标优化灌溉制度的方法，为实现城市绿地节水提出了有益参考。

1 Introduction

Beijing is a city with a serious water shortage, with its water resources, per capita, representing only 1/6 of the national average and 1/25 of the world average. In order to improve the quality of life for the people, realize the "Green Olympics" and achieve the ideal of a "green hugging Beijing", the ratio of urban green coverage in Beijing will reach 40% by 2010 despite the water shortage. According to the current irrigation level per square meter, green land will use 1m^3 of water, and the contradiction between a serious water shortage and the development of a greenbelt will become more conspicuous.. The contradiction between water resources and increased green space is an urgent technical problem. Beijing is located in semi-arid zones, and precipitation is unevenly distributed. Spring and autumn are seasons of drought while the total rainfall during flood season (July—September) accounts for more than 80% of annual rainfall. Every year, about 100 million m^3 of rain water directly flows out of Beijing without being used. Particularly, a lot of clean runoff from roads and surfaces flows into waste pipe network and creates drainage pressure. How to make full use of rainwater to alleviate the water shortage is an important aspect of water resources management and utilization.

Rainwater infiltration and rainwater storage by green spaces can be used as a simple and easy-to-popularize way to supply the irrigation water for green spaces. By approaching and adopting certain measures to increase rainfall accumulation, and reduce irrigation, it will ease the contradiction between the shortage of water resources and the large-scale development of green land.

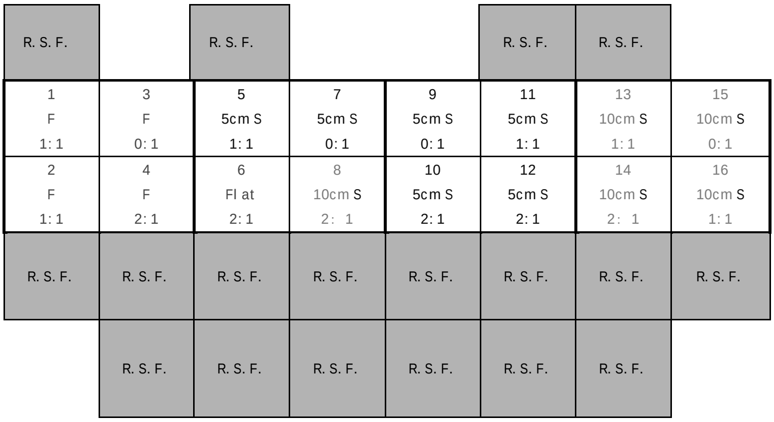
2 Objectives

To research different experimental patches, analyze the different impacts of irrigation with rainfall, create an indicator of irrigation with rainfall, and then summarize conclusions on how irrigation is affected by rainfall. Finally, analyze the irrigation impacted by rainfall in an average year in order to guide an optimization of irrigation scheduling.

3 Materials, Measures and Processes

Given the uneven distribution of rainfall during the year, the use of rainwater can reduce irrigation to a certain extent, nevertheless, recycled water and winter water for irrigation must be sufficiently supplied. In the experimental design process, in order to fully consider the effects of rainfall, we used a soil moisture sensor (CNC100 type) to measure soil moisture, and determined irrigation by 72-hour weather forecast. Both measures can optimize the irrigation scheduling.

The experiment area was in the scientific experiment and demonstration base of Beijing Hydraulic Research Institution. The groundwater table is 20m so the respect of underground water recharge can be neglected. The experimental area was divided into sixteen plots; eight flat meadows, four 5cm sunken meadows, and four 10cm sunken meadows. Different sunken meadow plots were aligned with different rainwater harvesting surfaces with proportions of 1: 0, 1:1 and 1:2. There were 9 experimental patches, among which, 7 patches included two duplicate groups. Where rainwater was collected; the duplication was added outside of the other two experimental patches where rainwater was not collected. There were 9 treatments of the experiments and 7 treatments had two plots (the other two plots out of the experiment area). The type of grass used in the experiment is annual bluegrass. The arrangement of the experimental plots is depicted in figure.1.



R. S. F.		R. S. F.			R. S. F.	R. S. F.	
1 F 1: 1	3 F 0: 1	5 5cm S 1: 1	7 5cm S 0: 1	9 5cm S 0: 1	11 5cm S 1: 1	13 10cm S 1: 1	15 10cm S 0: 1
2 F 1: 1	4 F 2: 1	6 Flat 2: 1	8 10cm S 2: 1	10 5cm S 2: 1	12 5cm S 2: 1	14 10cm S 2: 1	16 10cm S 1: 1
R. S. F.	R. S. F.	R. S. F.	R. S. F.	R. S. F.	R. S. F.	R. S. F.	R. S. F.
	R. S. F.	R. S. F.	R. S. F.	R. S. F.	R. S. F.	R. S. F.	

R.H.F——Rain Harvest Surface; F——Flat; S——Sunken

Figure 1: Experiment Layout Plan

The water consumption of a meadow consists of two parts: leaf transpiration and evaporation. Generally, the soil's water is supplied by: rainfall, irrigation and groundwater. If the groundwater depth is more than 4m, there is no groundwater supply. The water balance formula of meadows is as follows:

$$(1)\quad W_t - W_0 = W_T + P_0 + K + M - E$$

W_t , W_0——water of plan moist layer in time T and initial, mm;
W_T——added water because of plan moist layer adding, mm;
P_0——effective rainfall, mm;
K——groundwater supply in time T, mm;
M——irrigation in time T, mm;
E——ET value in time T, mm.

The key measure of rain utilization is achieved by increasing rainfall infiltration into green land. These measurements can be attained by building sunken meadows to reduce runoff as well as delivering more runoff from surfaces and roads into green land.

The precipitation, evaporation and irrigation of the experiment area are in Figure 2 and Table 1.

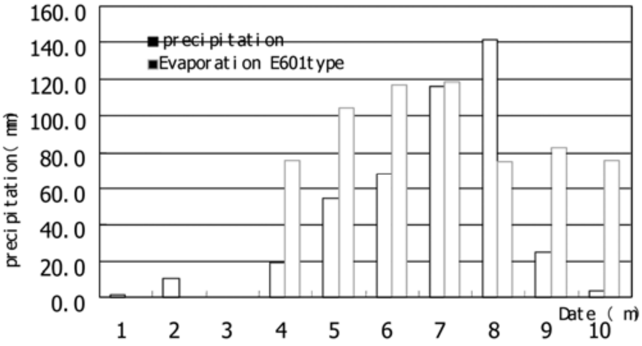


Figure 2: Precipitation and Evaporation in 2005

Table 1: Record of irrigation of experiments area in 2005 unit: mm

	F 0：1	5cmS 0：1	10cmS 0：1	F 1：1	5cmS 1：1	10cmS 1：1	F 2：1	5cmS 2：1	10cmS 2：1
2005-3-28	60	60	60	60	60	60	60	60	60
2005-4-9	15	15	15	15	15	15	15	15	15
2005-4-20	15	15	15						
2005-4-26	15	15	15						
2005-5-13	15	15	15						
2005-5-22	15	15	15						
2005-6-20	15	15	15						
2005-6-27	15	15	15						
2005-7-5	15	15	15						
2005-7-18	15	15	15						
2005-8-22	15	15	15	15	15	15			
2005-8-30	15	15	15	15	15	15			
2005-9-7	15	15	15						
2005-9-13	15	15	15						
2005-10-16	15	15	15						
Total Irrigation	270	270	270	105	105	105	75	75	75

4 Results and Discussion

The drought of green land is not only a result of complicated natural factors such as rainfall, temperature, soil, terrain and so on, but is also influenced by human and plant factors. In the experiment, only the natural factors were considered and measured using a Crops Water Indicator, used since the 1960s in China. The Crop Water Indicator is expressed as follows:

$$(2) \quad D = \frac{P - R_e + \rho_0 / \rho_g + R_g}{E_0 + \rho_m / \rho_g}$$

P —— precipitation in plants growing period, mm;

R_e—— runoff out of land and leakage, mm;

ρ_0—— soil water in root system layer in initial stage, mm;

ρ_g —— water by 1 mm rainfall infiltrating into soil, mm;

R_g—— groundwater supply, mm;

E_0—— potential evapotranspiration, mm;

ρ_m ——soil moisture suit to plant growth, %

If Crops Water Indicator is D>1.3, the soil has excessive moisture. If the Crops Water Indicator is 0.8<D<1.3, the soil moisture is normal. If the Crops Water Indicator is 0.5<D<0.8, the soil moisture is semi-arid. If the Crops Water Indicator is D<0.5, the soil moisture is arid.

Generally, the Crops Water Indicator was used to judge the extent of crop drought. We added rain harvest and irrigation factors into the formula and used the new formula (formula 3) to judge the extent of green land drought under conditions of rain and irrigation.

$$(3) \quad \mathrm{D} = \frac{\alpha \bullet P - R_e + \rho_0 / \rho_g + R_g + I}{E_0 + \rho_m / \rho_g}$$

α —— rain harvest surface area/corresponding green land area;

I—— irrigation，mm。

A typical, a crop can maintain a normal moisture condition by modifying the proportion of rain harvesting surface area and irrigation if the Crops Water Indicator is between 0.8 and

1.3 to. In accordance with these findings, the experimental irrigation of each meadow plot is calculated and the results are shown in table 2.

Table 2: Irrigation of different treatment meadows

Proportion of RHF/GL	Sunken depth	D	P (mm)	R_e (mm)	ρ_0 (%)	ρ_g (mm)	R_g (mm)	E_0 (mm)	ρ_m (%)	I
0:1	F	1.00	426.7	18	22	0.9	0	648	20	240
	5cmS	1.00	426.7	0	22	0.9	0	648	20	220
	10cmS	1.00	426.7	0	22	0.9	0	648	20	220
1:1	F	1.40	853.4	42	22	0.9	0	648	20	100
	5cmS	1.46	853.4	0	22	0.9	0	648	20	100
	10cmS	1.46	853.4	0	22	0.9	0	648	20	100
2:1	F	1.95	1280.1	73	22	0.9	0	648	20	75
	5cmS	2.05	1280.1	8	22	0.9	0	648	20	75
	10cmS	2.06	1280.1	0	22	0.9	0	648	20	75

From the calculation of the Crop Water Indicator we could determine that the grass which receives no rainwater needs to be irrigated with 220-240mm of water in each plot (from March to November). Treatment plots with a ratio of 1:1 needed to be irrigated several times with 100mm of water, using recycled water, overwintering water and only 1 or 2 irrigations during the dry season to supplement the use of recycled water. Since the plots received 2 times the amount of rainfall the moisture ratio that resulted of 2:1 in the treatment plots was excessive. Due to the uneven distribution of rainfall, a total of 75mm of recycled water and irrigation during crucial times was needed. The irrigation recorded of water volume for real irrigation was 270，270，270，105，105，105，95，95，95mm. There was little difference between the calculated value and real value, when the two values were compared. These findings also proved that the Crop Water Index is acceptable for measuring experimental meadow plots.

The Crop Water Indictor calculation showed that the extra rain water harvesting surfaces had a great significance for reducing irrigation. In the experimental observation, treatment meadows with a ratio of 2:1 reduced irrigation by nearly 200mm and treatment meadows with a ratio of 1:1 reduced nearly irrigation levels by 100mm. From 2004 to 2006, relevant experimental results showed that the optimization irrigation scheduling was consistent with the real plants water consumption.

We made the Beijing Municipal Statistical Analysis of average precipitation and evaporation (Table 3). Then we calculated the Crop Water Indictor and irrigation every month (Table 4) as samples.

Table 3: Average precipitation and evaporation in Beijing

	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.
Precipitation（mm）	196.5	162.2	51.3	21.2	6.4	2.0	2.2	4.9	8.7	20.0	32.5	76.8
Evaporation（mm）	117.3	121.9	117.9	84.6	50.5	32.8	35.3	47.4	82.5	128.0	153.0	149.2

Table 4: Crop water indictor and irrigation calculation

Month	**Item**	**0:1**			**1:1**			**2:1**			**explain**
		F	**5cm S**	**10cm S**	**F**	**5cm S**	**10cm S**	**F**	**5cm S**	**10cm S**	
Jul.	Crop Water Indictor	1.3723	1.5132	1.555	1.443	1.724	1.809	1.513	1.936	2.0624	
	Groundwater supply	0	0	0	0	0	0	0	0	0	Rain water recharge
	Irrigation	0	0	0	0	0	0	0	0	0	Soil water
	Redundant Water	0	0	0	157.2	157.2	157.2	314.4	314.4	314.4	
Aug.	Crop Water Indictor	1.1262	1.2388	1.273	1.182	1.408	1.475	1.239	1.576	1.6777	
	Groundwater supply	0	0	0	0	0	0	0	0	0	Rain water recharge

Month	Item	0:1			1:1			2:1			explain
		F	5cm S	10cm S	F	5cm S	10cm S	F	5cm S	10cm S	
	Irrigation	0	0	0	0	0	0	0	0	0	Soil water
	Redundant Water	0	0	0	129.8	129.8	129.8	259.5	259.5	259.52	
Sept.	Crop Water Indictor	0.4856	0.5223	0.533	0.797	0.87	0.892	1.108	1.218	1.2508	
	Groundwater supply	20	20	20	25	25	25	30	30	30	Soil water supply
	Irrigation	50	50	50	0	0	0	0	0	0	plants
	Redundant Water	0	0	0	0	0	0	0	0	0	
Oct.	Crop Water Indictor	0.3975	0.4174	0.423	0.566	0.606	0.618	0.735	0.794	0.8123	
	Groundwater supply	15	15	15	20	20	20	40	40	40	
	Irrigation	40	40	40	15	15	15	0	0	0	
	Redundant Water	0	0	0	0	0	0	0	0	0	
Nov.	Crop Water Indictor	0.4109	0.4197	0.422	0.486	0.503	0.509	0.561	0.587	0.5949	
	Groundwater supply	10	10	10	10	10	10	10	10	10	Overwintering

Month	Item	0:1			1:1			2:1			explain
		F	5cm S	10cm S	F	5cm S	10cm S	F	5cm S	10cm S	
	Irrigation	40	40	40	25	25	25	15	15	15	irrigation
	Redundant Water	0	0	0	0	0	0	0	0	0	
Dec.	Crop Water Indictor	0.4752	0.4788	0.48	0.506	0.513	0.516	0.537	0.548	0.5511	
	Groundwater supply	0	0	0	0	0	0	0	0	0	
	Irrigation	0	0	0	0	0	0	0	0	0	
	Redundant Water	0	0	0	0	0	0	0	0	0	
Jan.	Crop Water Indictor	0.4575	0.4613	0.462	0.49	0.498	0.5	0.522	0.534	0.5374	
	Groundwater supply	0	0	0	0	0	0	0	0	0	
	Irrigation	0	0	0	0	0	0	0	0	0	
	Redundant Water	0	0	0	0	0	0	0	0	0	
Feb.	Crop Water Indictor	0.4109	0.418	0.42	0.471	0.485	0.489	0.531	0.552	0.558	
	Groundwater supply	0	0	0	0	0	0	0	0	0	
	Irrigation	0	0	0	0	0	0	0	0	0	

Month	Item	0:1			1:1			2:1			explain
		F	5cm S	10cm S	F	5cm S	10cm S	F	5cm S	10cm S	
	Redundant Water	0	0	0	0	0	0	0	0	0	
Mar.	Crop Water Indictor	0.304	0.3123	0.315	0.375	0.391	0.396	0.445	0.47	0.4777	Regreening irrigation
	Groundwater supply	10	10	10	10	10	10	10	10	10	
	Irrigation	30	30	30	30	30	30	30	30	30	
	Redundant Water	0	0	0	0	0	0	0	0	0	
Apr.	Crop Water Indictor	0.2759	0.2892	0.293	0.389	0.416	0.424	0.502	0.542	0.5541	
	Groundwater supply	10	10	10	10	10	10	20	20	20	
	Irrigation	80	80	80	60	60	60	30	30	30	
	Redundant Water	0	0	0	0	0	0	0	0	0	
May	Crop Water Indictor	0.2972	0.3157	0.321	0.455	0.492	0.503	0.612	0.668	0.6848	
	Groundwater supply	10	10	10	10	10	10	20	20	20	
	Irrigation	90	90	90	60	60	60	20	20	20	
	Redundant Water	0	0	0	0	0	0	0	0	0	

Month	**Item**	**0:1**			**1:1**			**2:1**			**explain**
		F	**5cm S**	**10cm S**	**F**	**5cm S**	**10cm S**	**F**	**5cm S**	**10cm S**	
Jun.	Crop Water Indictor	0.5234	0.5682	0.582	0.904	0.994	1.021	1.285	1.419	1.4598	
	Groundwater supply	10	10	10	0	0	0	0	0	0	
	Irrigation	90	80	70	0	0	0	0	0	0	
	Redundant Water	0	0	0	0	0	0	50	60	70	
Total	Crop Water Indictor	0.5447	0.5796	0.59	0.672	0.742	0.763	0.799	0.904	0.9351	
	Groundwater supply	85	85	85	85	85	85	130	130	130	
	Irrigation	420	410	400	190	190	190	95	95	95	
	Redundant Water	0	0	0	287	287	287	623.9	633.9	643.92	

5 Conclusion

Rain harvesting surfaces and sunken meadows can reduce the need for irrigation. The rain harvesting surfaces deliver runoff onto green land to contribute to the moisture provided by rainfall in green land and sunken meadows. The irrigation of a plot with no rain harvesting surface requires 270mm. A treatment plot with a ratio of 1:1 requires 100mm, and a treatment plot with a ratio of 2:1 requires 95mm of water. According to the experiments, the recommended proportion of rain harvesting surface and meadow is 2:1 and the recommended depth of a sunken meadow is 5 to 10 cm.

The Crop Water Indictor can be used to optimize irrigation scheduling of annual bluegrass meadows under the consideration of rainfall, soil moisture, evaporation and irrigation factors. The Crop Water Indicator has the potential to make a positive contribution to scientific and rational irrigation scheduling of green land in Beijing. It has positive significance to make scientific and rational irrigation scheduling of green land in Beijing.

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Study on the Effect of Sewage Water Treatment in Rivers with Aerated Biological Fluid Tank (ABFT)

ABFT 技术处理河道污水的效果研究

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Abstract

ABFT, namely Aerated Biological Fluid Tank, is an advanced technique of wastewater treatment for use both inside and outside of the home. It is an aerobic biological reactor with the immobile technology that combines microorganisms and enzymes and the carrier self-immobilization technology. The monitoring result of the first pilot project of sewage water treatment in China showed that ABFT could treat a large deal of sewage water with good outcomes. The elimination rate of organic pollutants was 85%. A high ratio of nitrogen and phosphors pollutants also could be removed by the ABFT system. In low temperature, the water quality of the treated water could reach the second grade of “Discharge Standard of pollutants for municipal wastewater treatment plant (GB18918-2002)”.

摘要

ABFT 即曝气生物流化池是一项国际上比较先进的水处理工艺，是一种结合微生物、酶与载体自固化技术的好氧生物反应器。通过对 ABFT 工艺在国内应用于生活污水处理的第一个示范性工程的监测研究表明：该工艺能够处理大量的污水，曝气效果好，对有机污染物的处理率可达 85％以上，对含氮、含磷污染物也有较高的去除率。在低温条件下也能够将高浓度污水处理至“城市污水处理厂污染物质排放标准（GB18918-2002）”的二级标准。

1 Introduction

The technology of the Aerated Biological Fluid Tank uses advanced techniques of wastewater treatment for home and non-home use. It is an aerobic biological reactor with the immobile technique that combines microorganism and enzyme with the carrier self-immobilization technology. The average density of the carrier self-immobilization technology which were combined with microorganisms is equal to the density of water. So, they are being suspended in water. A kind of synthesized, macromolecule and reticulated carriers, which have some advantages of large specific surface area, even interface, high speed of mass transfer and low loss of pressure, were introduced in the Aerated Biological Fluid Tank system during the course of the study. There are amidogen, carboxyl and epoxy groups in the carriers. The diversity of microorganisms was maintained in the ABFT system, where aerobic, anoxic and anaerobic microorganisms were all found. Due to the diversity of organisms, the ABFT system can eliminate far-ranging kinds of pollutants in water.

Er Daohe sewage water treatment project, located in the North canal in Beijing, was the first pilot project of ABFT in China. Er Daohe River, whose inflows included the sewage water from residential areas such as Lisi Garden and Tianzu Townhouse, flows across the district of the Capital International Airport. The River is an important branch of the North Canal, however, the raw water of Er Daohe River was very polluted and, was also a main source of pollution for the North Canal.

The influents flowed along the left side of the river through the ABFT pilot project that in turn consisted of a screen, deposition and regulation pond and finally the ABFT component. The effluents that have been treated by the ABFT were discharged into the river directly. There were two shutter dams on the right side of the river, which could store enough raw water for the ABFT system to be treated in normal situations or turn over for flood discharge during flood season. The hydraulic retention time of the whole treatment courses was about 4 hours.

In order to study the treatment effects of the pilot project, water quality and water quantity were monitored continually on the spot for a day and night from December 1st to 2nd in 2005.

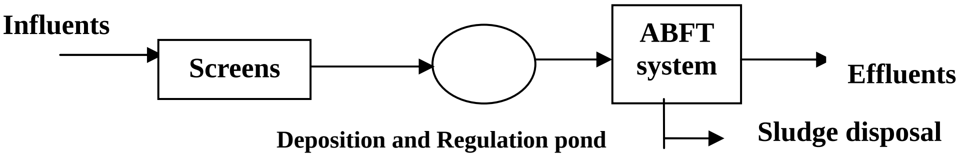

Figure 1: Flow Sheets of Er Daohe Project

2 Instruments and Water Quality Parameters

The instruments for measurement：

pH197i portable pH meter	Oxi197i portable DO meter
Photolab Spektral Analyzer	OxiTop BOD Analyzer
DPJ-Ⅱ velocity of flow meter	

According to the characters of the raw sewage water, some parameters of water quality were determined, including water temperature, value of pH, DO, NH_4, NO_2, NO_3, TN, O-P, TP, COD and BOD_5.

3 Monitoring and Analysis of Water Quantity

The effluents discharged from the ABFT system flowed through two semicircle channels that were distributed on both left and right sides at the end of the system into the river. In order to get the accurate data, the instantaneous velocities of the two channels were measured every 4 hours from 12:10 Dec.1st to 8:10 2nd on account of the water quantity was varied with the sewage water discharging. There were six groups of data in total. It was calculated that the average quantity of effluents was 7835.21m^3/d. The maximum value of the instantaneous velocity of flow was 0.84m/s. The determined data was shown in Table 1.

Table 1: The determined data of water quantity

Time of monitoring (Dec.1st～2nd)	**The instantaneous velocity of flow on the left side（m/s）**	**The instantaneous velocity of flow on the right side（m/s）**	**Quantities of water（m^3/d）**
12:10	0.42	0.37	4935.56
16:10	0.59	0.47	6965.85
20:10	0.65	0.54	7819.35
0:10	0.68	0.59	8331.45
4:10	0.66	0.56	7990.05
8:10	0.84	0.83	10951.03
The value of average	0.64	0.56	7835.21
remarks	The semi diameters of the channels were varied from 215mm to 220mm with the water level.		

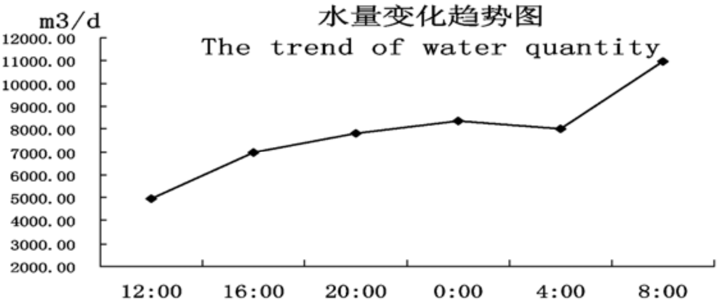

Figure 2: The Trend of Water Quantity

4 Monitoring of Water Quality

In order to get the typical water samples, the water samples were collected every 2 hours continually, for a whole day and night, from 12:10am on Dec.1st to 8:10am. On December 2nd, in order to account for variation of the sewage water quality in time and space, the raw water samples were collected at 16:00, 20:00 on Dec.1st and 8:00 on December 2nd respectively. Taking into consideration that the water leaked from the shutter dam would influence the water quality downstream, the mixed sample was collected at 8:00 on Dec.2nd to stand for the actual water quality downstream from the project. At the same time as sampling, the values of water temperature and dissolved oxygen were also measured. All the water samples were taken to the monitoring laboratory for analysis at 9:00 on Dec. 2nd. The determined data was shown in table 2.

Table 2: The determined data of water quality

Parameters	Tem.	PH	DO	NH_4-N	NO_3-N	TN	TP	O-P	NO_2-N	CODcr	BOD_5
Mixed samples of the downstream	8.0	7.8	6.02	7.65	3.30	15.0	2.7	2.07	0.26	40	14.2
The average values of raw water	8.30	7.68	0.34	15.13	1.00	29.33	7.83	2.79	0.15	241.33	94.07
The average values of effluents	9.13	7.72	7.56	4.52	4.65	16.16	4.15	2.55	0.38	30.58	6.78
The minimum of effluents	10.2	7.66	6.34	0.72	2.50	14.3	2.6	1.80	0.26	18	3.6
The maximum of effluents	8.3	7.76	8.27	8.80	6.80	18.0	10.7	5.09	0.58	42	10.8
The average ratio of elimination			-2123%	70%	-365%	45%	47%	9.0%	-147%	87%	93%
The maximum ratio of elimination			-2332%	95%	-150%	51%	67%	35%	-70%	93%	96%
The minimum ratio of elimination			-1765%	42%	-580%	39%	-37%	-83%	-278%	83%	89%

5 Analysis and Evaluation of the Data

All the determined data of water quality parameters was analyzed and the ratios of elimination were calculated by the following formula.

$$\text{The ratio of elimination} = \frac{(Cin - Cout)}{Cin} \times 100\%$$

Comments： C_{in}——the average concentration of a pollutant in influents

C_{out}——the average/maximum/minimum concentration of a pollutant in effluents

The conclusions were as follows：

Table 3: The elimination ratio of the pollutants

parameters	DO	NH_4-N	NO_3-N	TN	TP	O-P	NO_2-N	CODcr	BOD_5
The average ratio of elimination	-2123%	70%	-365%	45%	47%	9.0%	-147%	87%	93%
The maximum ratio of elimination	-2332%	95%	-150%	51%	67%	35%	-70%	93%	96%
The minimum ratio of elimination	-1765%	42%	-580%	39%	-37%	-83%	-278%	83%	89%

5.1 The effect of aeration

The effect of aeration had positive results during this project. The concentration of dissolved oxygen increased on average more than 20 times. The nitrification became more effective in the water, where the concentrations of NO3-N and NO2-N increased 2.65 times and 0.47 times respectively.

The trends of DO and NO_3-N

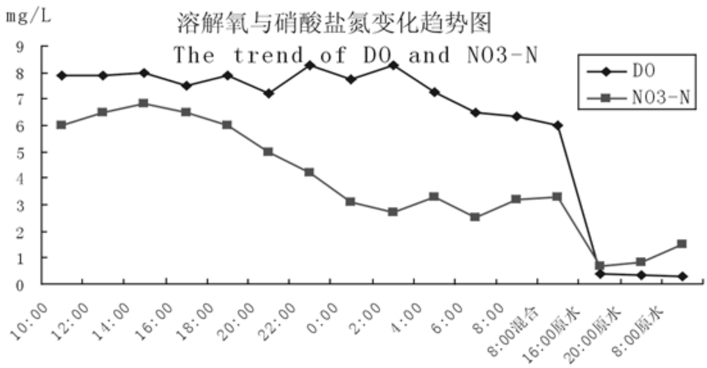

Figure 3: The Trends of DO and NO_3-N

5.2 The elimination effect of organic pollutants

There was a remarkable effect on the elimination of organic pollutants in water sampled during the pilot project. The elimination ratios of COD and BOD_5 were more than 85% on average. The elimination ratio of BOD_5 was higher than that of COD, which indicated that there was a better biochemical reaction in the project. The two parameters were evaluated by using the "Environmental quality standard for surface water (GB3838-2002)". The effluent results showed the average concentrations were better than Class V while the best was Class III.

The trends of organic pollutants

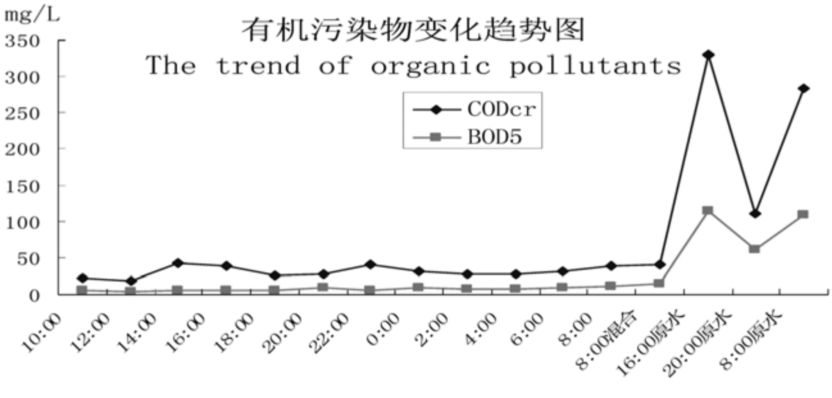

Figure 4: Trends of Organic Pollutants

5.3 The elimination effect of nitrogen pollutants

The elimination effect on nitrogen pollutants was not evident in the pilot project because of the low water temperature in winter. The elimination ratio of NH_4-N was 70％ on average, which became lower and lower as the temperature decreased. However, the elimination ratio of total nitrogen was fairly stable, 45% on average. The data was evaluated according to the “Environmental quality standard for surface water (GB3838-2002)”. The results showed that the concentration of NH_4-N was Class III during the period of high temperature, which was worse than Class V in other period and the concentration of total nitrogen was worse than Class V all the time.[1]

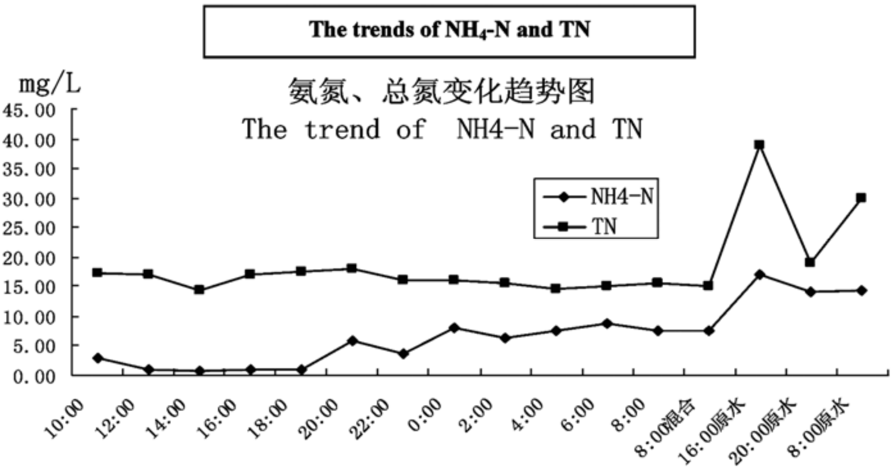

Figure 5: The Trends of NH_4-N and TN

5.4 The elimination effect of phosphors pollutants

The elimination ratio of phosphors pollutants was less than 50% in the project, especially that of the dissolved phosphors which was only 9.0％. It was concluded that most phosphors pollutants were treated by mechanical filtration and natural deposition in the project. On the other hand, the monitoring data showed that the elimination effect on phosphors was likely affected by the influents and the anti-impact properties were weak. According to the “Environmental quality standard for surface water (GB3838-2002)”, the concentration of phosphors pollutants was worse than Class V.

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[1] Editor’s Note: In China, water bodies are divided into five classes according to their utilization purposes and protection objectives: Class I is mainly applicable to water from natural sources and national nature reserves. Class II is mainly applicable to high quality protected areas used for centralized sources of drinking water, protected areas for rare fishes, and the spawning fields for fishes and shrimps. Class III is mainly applicable to second class protected areas used as centralized sources of drinking water and as protected areas for common fishes and swimming areas. Class IV is mainly applicable to the water for industrial uses and entertainment and water which is not directly touched by human bodies. Class Ⅴ is mainly applicable to the water bodies for agricultural uses and landscape requirements.

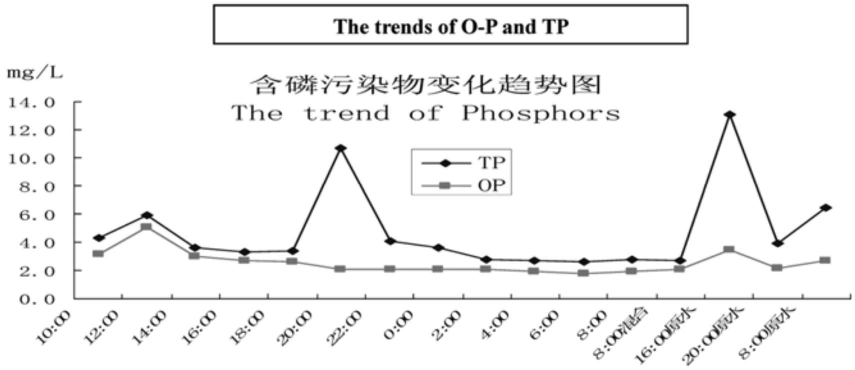

Figure 6: The Trends of O-P and TP

6 Conclusions

The monitoring data showed that ABFT system was suitable for treating large volumes of sewage water, and the average amount the system was able to process was determined to be 8000m^3/d.

The main pollutants, organic pollutants and ammonia, in raw water were eliminated to acceptable levels after treatment by the ABFT system. However, because the initial water quality of the raw water was extremely polluted, when the monitoring data was evaluated according to the “Environmental quality standard for surface water (GB3838-2002)”, all the values of the parameters were excessive, except for those of pH and DO. According to the “Discharge standard of pollutants for municipal wastewater treatment plant (GB18918-2002)”, the effluents from the pilot project to the river could reach Class II.

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A Hierarchical Control Approach to Integrated Water Resources Management
水资源综合管理的分级控制方法

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Abstract[1]

Modern Integrated Water Resources Management is seen as a cooperative effort of a number of fields. It combines the disciplines of hydrology, hydrogeology, soil physics, hydromechanics, and ecology on one hand with disciplines from the humanities namely law, economics, and decision analysis. A general approach for Integrated Water Management barely exists as it is only vaguely defined. It therefore has to be filled with concrete meaning in every practical application. In some countries stake holders participate in the decision making regarding the exploitation and allocation of water resources, in other countries decision makers decide in a strictly hierarchical way of top-down control organizations.

Scarcity and pollution of water resources necessitate a tight management in order to satisfy demand in many densely populated areas of the world. This results in challenging control and optimization problems, which have a long tradition. For an overview see [LB-06]. In the thesis a novel hierarchical control and optimization approach is developed, which is applied to two case studies. In the first case a well field of a municipal water utility is controlled in real time to avoid undesirable degradation of pumped water quality. In the second case a long term control strategy is designed for the water supply of Beijing.

摘要

现代水资源综合管理被视为一项需要多方共同合作努力的工作。它综合了水文学，水文地质学，土壤物理学，流体力学，生态学原理和人文学科，也就是法律，经济学和决策分析的原理。水资源综合管理的一般方法仅仅以一种定义含糊不清的形式存在。因此它必须在每一次实际应用中被赋予具体的含意。在一些国家，利益相关者参与有关水资源开发和配置的决策过程，而在另一些国家是由决策者按照自上而下的管理机构进行严格的分级决策。

水资源的短缺和水污染要求严格的管理来满足全世界人口稠密地区的供水需求。这导致长期存在的管理困难和优化配置的问题。本文通过两个案例研究提出了一种独特的分级管理和优化配置的方法。在第一个例子中，采取对市政用水的实时监控来避免水泵供水水质的不必要下降。在第二个例子中，则为北京的供水系统设计了长期的管理策略。

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[1] Editor’s note: In this paper, the author didn’t provide reference.

1 Objectives of Case-studies

The first case study deals with the implementation of a model predictive control for the feedback- control and optimization of pumping and infiltration rates at the ground water works of the Hardhof area in Zurich [WVZ-06]. The well field in the Limmat valley is situated near an old industrial zone of the city, which affects the pumping wells with contaminated ground water. The exploitation of the uncontaminated part of the groundwater body depends on the flexible control of the fragile equilibrium of piezometric heads in the protection zone between the city area and the well field. Figure 1 shows the well field of the Hardhof area.

Figure 1: Well Field of Zurich Hardhof [WVZ-06]

In the second case-study a new approach to the hierarchical control concept will be implemented for the decision analysis and calculation of Pareto optimal solutions of the Beijing water supply system. The supply depends on four water resources: a shrinking ground water body, local rivers dammed in reservoirs, treated waste water, and surface water that comes from the Yangzi-river (South-North water transfer scheme) and is transported through a channel and stored in several groundwater and surface water reservoirs. Figure 2 shows the scheme of the system:

Figure 2: Beijing Water Supply System [Rau-03]

Note:

Reservoirs		Rivers and Channels		Pumping Stations	
[1]	Baihebao	A	Miyun-Jingmi-Channel	a	Yongding-River
[2]	Miyun	B	Miyun-Channel to Waterworks No. 9	b	Nanshuibeidiao
[3]	Guanting	C	Miyun-Channel to Waterworks No. 8	c	Tonghui-River
[4]	Huairou	D	City-Channel	d	Tonghui-River
[5]	Shisanling	E	Yongding-Tonghui-Channel	i	Kunming-Lake
(2)	South-North Water Transfer Scheme (Nanshuibeidiao)	F	South-North Water Transfer Scheme (Nanshuibeidiao)		

2 State of the Art Analysis

2.1 The multilevel and the multilayer concepts

Figure 3 shows the multilevel concept of a hierarchical control system for a water supply system. Optimal real time controllers operate on a local level of the process, which itself is a model of the natural process. All of the three controllers in the schematic drawing are supposed to be supervised by a global coordinator who varies or optimizes the parameters of the local controllers. Different methods for the long term calibration or tuning could be used, such as Model Predictive Control theory, Discrete Dynamic Programming, or linguistic concepts e.g. Fuzzy Control in order to steer the large scale system into an optimal behavior over a short time horizon.

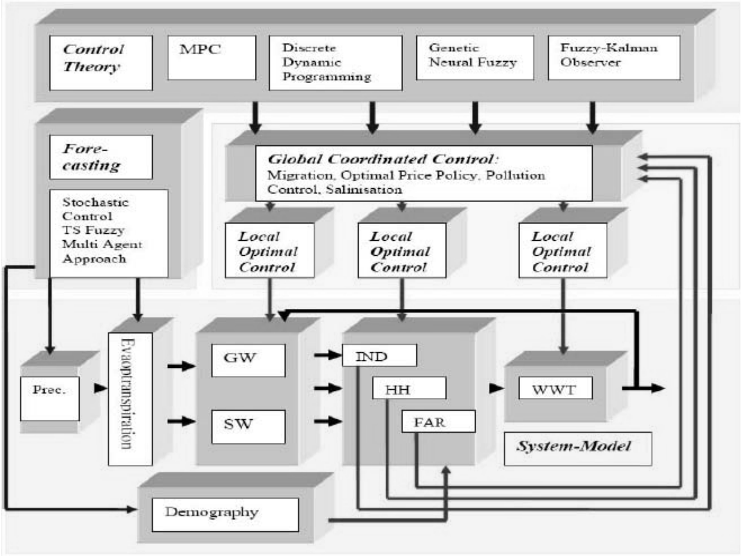

Figure 3: Multilevel Concept of Hierarchical Control

The Multilevel-Concept has the disadvantage that changing environments or changing boundary conditions often cannot be treated in an easy way. Necessary enhancements of the system model or the control system often need a re-designing of the general hierarchical control concept. The hierarchical (multilevel) control concept shows a good performance in the field of real-time process control, whereas it has the above mentioned problems regarding long term control scenarios. [Lob-05], [Nic00], [Sep-00], [Sin-77], [Sin-78]. Multilevel approaches can incorporate data and parameter uncertainty in an attempt to obtain a robust control, if the algorithms are using derivatives [BM-05] or derivative free approaches [Bra-01]. Control problems can also involve optimization of parameters of the local controllers [Byr-03].

The most common form the process design of Integrated Water Resources Management could take is the Multilayer concept consisting of several spheres or layers that use different kind of information, such as crisp information i.e. discrete data sets of the physical process, or fuzzy information i.e. risk proneness or risk aversion of strategic long term decision makers, (See Fig.4) Management decisions require a decision support system (DSS) as an interface between the physical process and the sphere of decision making.

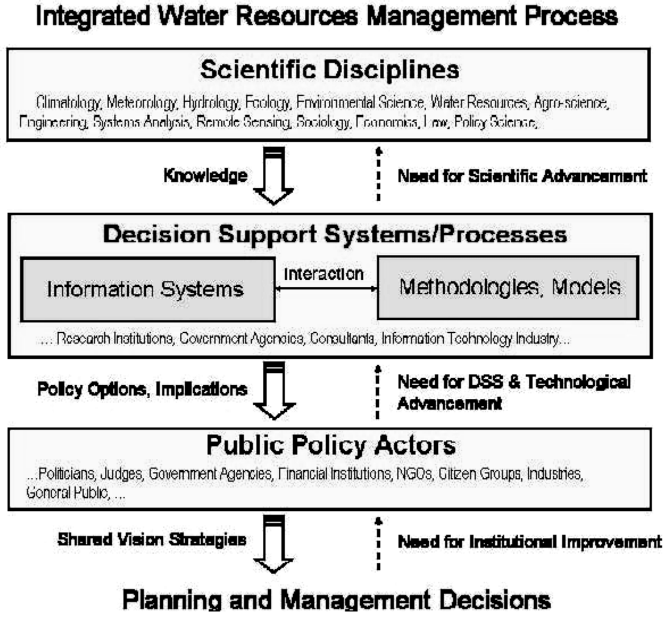

Figure 4: Multilayer Concept of Water Resources Management [Geo-04]

Decision support systems have the disadvantage of growing complexity and a lack of a general taxonomy. However, there exists a classification, according to [Wik-06] whether a DSS is data-driven, knowledge-driven, or model-driven. A Multilayer concept is more appropriate for the simulation of long term scenarios of a large scale supply system but needs multi-disciplinary design and management teams which provide the expert knowledge. The constant improvement of the different layers requires an extensive documentation in order to provide future experts and decision makers with training information. An additional Achilles` heel lies in the gap of information loss between the layers. [Bos-04a], [Bos-04b], [Bos-89], [Bos-94], [Geo-04], [Rau-03], [SSH-88].

2.2 Current state of research

In order to avoid the disadvantages of both concepts, a modified and also new combination of a multilayer-multilevel concept is the core of the doctoral thesis. In order to guarantee a constant information flow in a long term simulation under changing conditions, the typical layer structure is dissolved. Fig.5 shows a rough scheme of the new approach. The objectives of the strategic (long term) decision making, such as water stress, pollution or increasing engineering costs are functionally connected to the resources that have to be managed. These include ground water, surface water, treated waste water, energy supply and monetary budgets and their respective constraints. The resources are also connected to the sphere of technologies that are supposed to exploit, store and transport the common good water in order to satisfy the demand of industrial, domestic, agricultural or ecological stake holders.

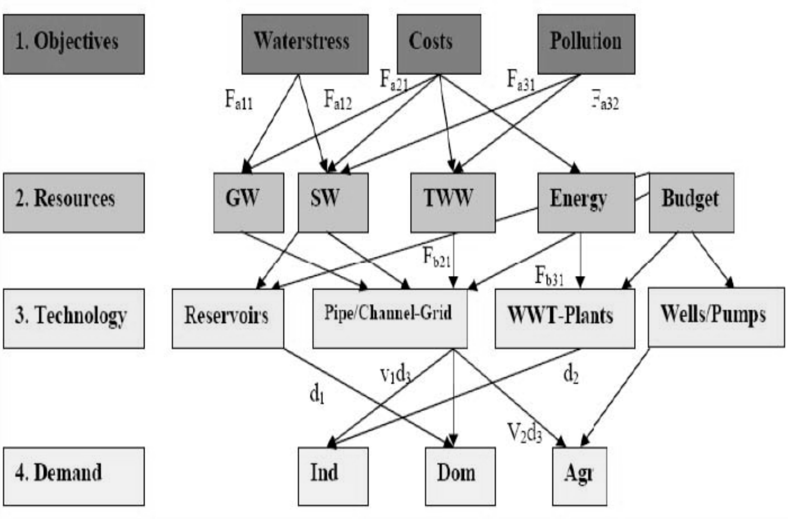

Figure 5: Multilayer-Multilevel Concept

First attempts of such a combination exist in the literature. [Gol-93], [Lux-90] and [Nga-00]

3 Detailed Research Plan

The thesis starts out with the conceptualization of the Hardhof real-time control problem. The software for this problem will consist of a steering unit in MATLAB/SIMULINK and simulation programs for the physical system in C++. MATLAB/SIMULINK provides many necessary toolboxes for the design and simulation of control systems that are supposed to manage even large scale systems such as water supply and treatment systems. Figure 6 shows a screen shot of a SIMULINK control model of the Hardhof well field. Several Control concepts, e.g. Fuzzy Control, PID Control or State Control have been tested and first results have been discussed with the project partners of Wasserversorgung Zürich (WVZ). The controller calibration depends on a SPRING groundwater model of the Limmat valley aquifer. So far, a typical multilevel control approach has been implemented and tested. A first design of a Multilayer-Multilevel concept will be completed by the end of this year and first long term scenarios of the Hardhof well field will be simulated thereafter.

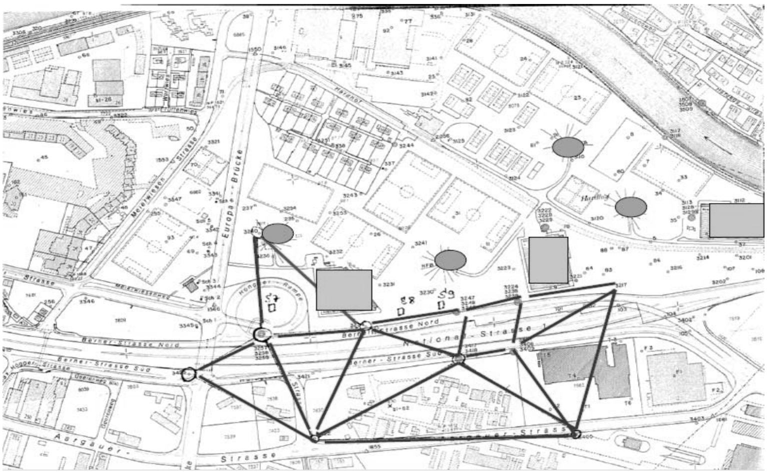

Figure 6: Piezometric Heads in the Hardhof Well Field

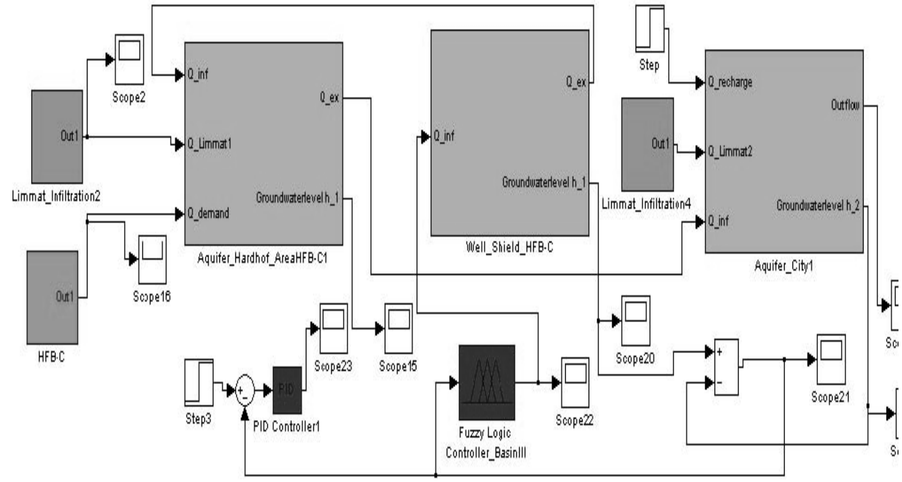

Figure 7: SIMULINK Control Model of the Hardhof Well Field

All programmed MATLAB/SIMULINK modules will be formulated in such a general fashion that they can also be used in the second case study. A first version of a MATLAB/SIMULINK model of the Beijing water supply system exists. It has been developed by a team at the Fraunhofer Center of Applied Systems' Technology Ilmenau, Germany, of which the doctoral student has been a member. It consists of discrete transfer functions for input and output data. The model simulates the water process cycle from precipitation to evapotranspiration, as well as the exploitation and allocation of freshwater to different urban and rural stake holders.

A Multilayer-Multilevel concept that has to be designed within the next year will provide the basis for the simulative calculation of long term control and management scenarios. The Objectives of the decision makers is the optimal allocation of the different water resources to the user sectors with respect to multiple criteria such as:

- *minimum groundwater levels*
- *minimum overall cost*
- *safety of compliance with demand (e.g. for rare and extreme events or climate change scenarios)*

The handling of multiple criteria will be based on Pareto optimal sets of solutions. These allow the natural incorporation of uncertainty in parameters.
The general task would be the implementation of a Multilayer-Multilevel approach that provides a hierarchical and flexible control and management method that can be handled and also enhanced or changed by one person without any loss of information or knowledge. The simulation run time within a time horizon of 50 years should be no more than two or three days.

The main target of the doctoral thesis is to create a multilayer-multilevel concept that will be tested in the two case studies introduced above. Long term control methods for the water resources management system will be simulated. Therefore the impact of possible extreme and rare events, as well as ordinary day-to-day decision making and re-organization or renewal of the infrastructure will be calculated with the help of MATLAB/Simulink models and MODFLOW/SPRING models.

An additional achievement would be the "organic" development of water resources management due to the fusion of crisp (short term) information and fuzzy (long term) information of different decision layer or control layer types. The presented multilayer-multilevel concept has the advantage of easy handling.

4 Significance for Science and Economy

In many countries water is the strategic corner stone of a balanced and sustainable path of economic growth [Ita-05], [Fic-01], [Hou-01].Struggling with growing populations, limited budgets as well as limited energy supplies, and possibly climatic change, decision makers in these countries have an increasing demand for methods of rational water allocation. The planning of economic sectors attached to the exploitation and allocation of water has to take into account single or rare events to reduce societal risk. In this situation hierarchical management concepts that calculate optimal solutions for long time horizons are of considerable interest. This thesis is a contribution to this sector, a sector which is growing in importance.

Demonstration Engineering and Benefit Analysis of Rainwater Harvesting for Utilization in Urban Areas of Beijing
北京城区雨洪利用示范工程与效益分析

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Abstract

As part of a Chinese-German demonstration project, five different approaches to harvesting rainwater were installed in six urban developments in Beijing, totalling an area of 60 ha. The techniques applied included storm runoff storage and treatment, discharge control, infiltration, water saving and recycling facilities. In some facilities, processes and effects were monitored under real conditions. Economic, environmental and social benefits were analyzed. The social benefits were found to be much higher than the short term economic benefits to investors or owners. To further promote such sustainable techniques, government should regulate and stimulate investors and owners to install rainwater harvesting and utilization techniques.

摘要

作为中德示范项目的一部分，在北京的 6 个城市开发区安装了 5 种不同类型，总面积 60 公顷的雨水收集设备。应用的技术包括雨水径流储存和处理，排水控制，渗透，节水和循环利用设备。对一些设备的运行和效果进行了实际监控。分析了实施雨洪利用的经济效益、环境效益和社会效益。结果表明，雨洪利用的社会效益远大于小区建设者或业主的直接经济效益。为了进一步推广这种可持续的技术，政府应该制定政策并刺激和鼓励小区建设者或业主投资建设雨洪利用工程。

1 Introduction

With the rapid increase of urbanization, impervious surfaces increase quickly. As a consequence, runoff coefficients and peak flows increase as well as the flood risk within urban areas and for rivers downstream. In order to solve these problems a 4-year project, “Sustainable water management in urban areas – flood control and groundwater recharge” was launched in 2000. This project included research on quantity and quality processes of rainfall and runoff, techniques of rainwater collection, detention, transport, treatment and infiltration for groundwater recharge were investigated systematically. New types of pervious bricks and pervious types of pavements were tested and rainwater harvesting options suitable for semi-arid climates as well as new policy standards were developed. To demonstrate these techniques, a 60ha demonstration area was built up to demonstrate the economic and social effect of rainwater harvesting. Five years of monitoring and an analysis of the benefits are presented. Of course, in order to decrease runoff rates and to reduce flooding, rainwater harvesting techniques must be applied widely, at least in all newly developed, rebuilt and expanded areas. The same applies for recharging ground water resource projects.

2 Demonstration Engineering

Six demonstration sites, with a total area of 60 hm^2, were constructed between 2000 and 2004. These represented five different types of urban development, namely old existing areas, new developments, densification of old existing areas, commercial areas, schools and parks.

2.1 Beijing Geology Institute Rainwater harvesting demonstration site

One of the demonstration sites was located in a residential area of the Beijing Geology Institute (BGI), and it aimed to demonstrate that a five year rainfall runoff to surrounding streets, which frequently occurred in the past, could be avoided in Beijing's old downtown.[1] This demonstration site covers 3 hm^2， including 1 $hm^2$of roof, 1.8 $hm^2$of yard, and 0.2 $hm^2$of roof. It represents the typical old downtown that was built in the 1980s. The process was basically the detention of surface runoff, followed by thorough treatment and then infiltration underground through recharge wells. The drainage area was then subdivided into two independent sub areas, which were reconnected after pre-treatment to include 3 recharge wells altogether. Each of the wells has a capacity of 4 l/s. Special attention was paid to the treatment of yard runoff. Storm water from small open spaces was infiltrated through low-lying grass plots underground.

The first system collects runoff from roof, roads, yards and sidewalks in the northern part of the demonstration site. Furthermore, runoff from the roofs of auxiliary buildings, which have no gutters and down pipes, will enter the system through the connected surfaces. The contributing catchments amount to 0.65 hm^2. The runoff enters a trunk sewer with a diameter of 1 m with a downstream control well prior to entering the two recharge wells. This chamber also serves as a sediment trap and oil separator. The total storage of this system is about 250 m3. The emptying time for a 5-year event is about 13 hours. figure 1 shows this process.

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[1] Editor's Note: Beijing's old downtown area is generally the area within the second Ring Road, compared with the 'new' town which refers to the area outside of the second Ring Road.

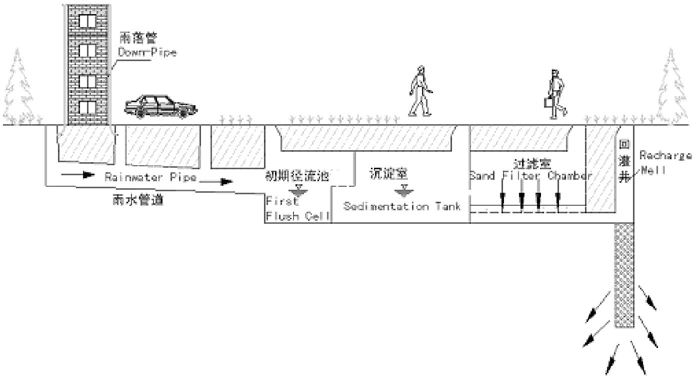

Figure 1: Process Chart of Rainwater Harvesting in BGI

The second system collects roof runoff from the southern part of the demonstration area. The total roof area is 0, 27 hm^2. The roof runoff is collected and transferred into the first flush tank and then to the sediment tank. Finally it flows to the recharge-well.

2.2 Demonstration site in the Shuangziyuan residential area

Shuangziyuan, a new residential development with an area of 2 ha, represents modes of rainwater harvesting used at the end of the last century. After treatment and storage, the rainwater is used to irrigate the vegetation. The system is designed to cope with 5 years of storm event. It includes a 850 m^3 cistern, a 1350 m roof with roadway rainwater collection pipes and side channels, a 4028 m^2 greenbelt irrigation system and a water volume inspection system, as well as a permeable road of 820 m^2。The system was completed in June 2001. During the flood season of 2001, the total precipitation was 195.6 mm, the maximum daily precipitation was 39.1 mm, and the maximum precipitation over two days was 71.0mm. During the entire season, no runoff from outside the testing area was observed. Over the entire period, the total volume of collected rainwater was 434 m^3; 166 m^3 from the roofs and 268 m^3 from the roadways. During the 2002 flood season, the total precipitation in the area was 280.4 mm, and 625 m^3 of rainwater was collected.

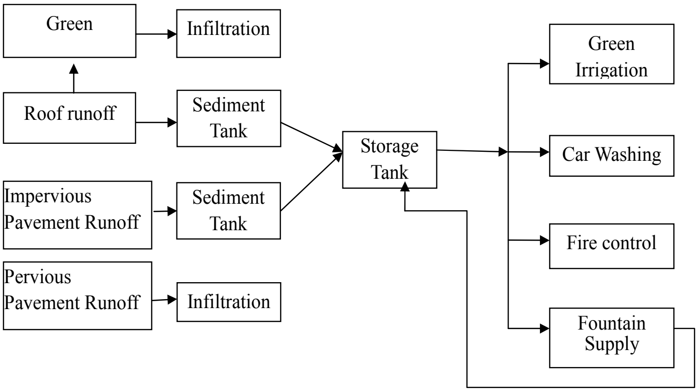

Figure 2: Process chart of rainwater harvesting in Shuangziyuan residential-areas

Figure 2 shows the total storm water harvesting process on the demonstration site. Some of the roof runoff was collected and treated for green irrigation and car washing or put directly onto green spaces around the buildings for infiltration. Some roads were paved with pervious bricks to increase infiltration, and other roads were paved with impervious pavement. Runoff from the impervious roads was collected and treated for other uses.

2.3 The storm water utilization demonstration site in the Tianxiu residential area

The Tianxiu residential area represents the scenario of a completely new development. Early in the designing states, an 11 ha area was designated for testing the concept of storm water utilization. The storm water utilization system and the housing developments were built at the same time. The principle of storm water utilization is: after treatment, runoff from roofs and some of pathways is used to supplement the irrigation of green spaces with surplus water being infiltrated into the ground (Fig. 3). Some of the roadways and pathways were covered with permeable pavement. Also, green spaces were leveled beneath roadways in order to catch storm water for direct infiltration.

The roof and road drainage systems are located north and east of the man-made lake. The runoff from 14 roofs is harvested by the roof drainage system, and the road drainage system collects the rainwater from roads. The storm water is piped to a pre-treatment system in order to remove the first flush and to filter the remaining water. Then the clean water is directed to the recharge wells. In the treatment structure, a water pump was installed so that the treated water also can be used for the man-made lake. The area, from which storm water is harvested amounts to 15959 m^2, including 10297 m^2 of roofs, 2811 m^2 of permeable roads and 2851 m^2 of normal roads. In order to prevent miscellaneous objects from entering the system, a type of gully was designed and built at the side of the road. The whole system was designed to prevent flooding for up 5-years. However, if the return period of the storm is greater than one year, the system will overflow into the city's storm sewer through two weirs located at the middle and at the lower end of the system.

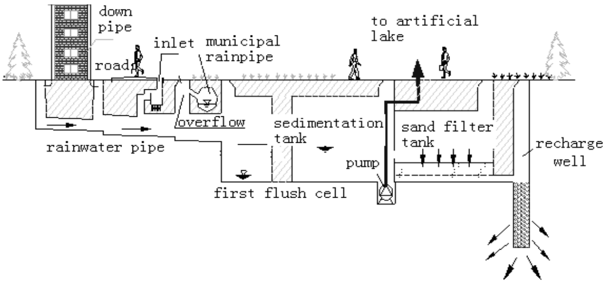

Figure 3: Storm water utilization flow chart in Tianxiu Residential Area

2.4 The storm water utilization demonstration site in EFW

The Beijing Hydraulic Engineering Foundation Work (EFW) site, covers an area of 1 hm^2. This demonstration site focuses on the utilization of both rain and recycled water. The project mainly harvests storm water from the roofs of buildings No.6 and No.7. After filtration through the IRM® High-Flow-Inline filter, the rain water was stored in underground storage tanks. If needed, the water could be used for flushing toilets in building No.7. Water for showers and washing from building No.6 building was collected through an independent system and pipelined into the GRAYWATER treatment system, then stored in clean water storage cells to be used for toilet flushing. The GRAYWATER treatment system adopts biological treatment technology. The whole system, including inflow, outflow and deposit discarding, is under automatic control. The units of the system consist of: the pool for waste water harvest, the water tank for storage, the inclined pool for deposition, a four-level turntable for biology treatment, a pot for filtration by sand, and a UV device for disinfection.

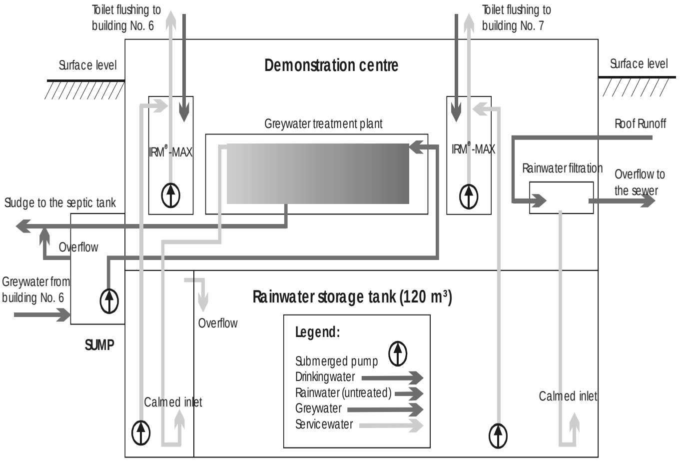

Figure 4: Scheme of Installations in of the "Demonstration Centre Rainwater Harvesting and Greywater-Recycling" at Demonstration Site II EFW

2.5 The storm water utilization demonstration site in Haidian Park

The Haidian Park demonstration covers an area of 38 ha, with 2.18 ha of impermeable surfaces, including built-up spaces and roadways, and 2.32 ha of water surfaces. . The rest of the area is composed of green spaces. The Storm Water Utilization Demonstration Site in Haidian Park represents the scenario of a Beijing park that has significant green coverage. The rainwater from impervious surfaces is collected, removing the initial runoff and recharging groundwater directly. The rainwater from the green areas is collected by an infiltration trench and infiltration channels due to the low permeability of surface soil.

The runoff from a square and other built-up areas is piped into a storm water utilization system through gullies, where it is stored and treated by the principle outlined in Figure 1. The system was designed to cope with 5-years of storm events. If the storm cycle is longer than five years, the system will overflow into the city's storm sewer.

In the green areas of the park, some undulate terrains are formed. Along the pathways, infiltration channels are built to increase the permeability of surface soil. The system is designed so that flooding and fouling of the grass is prevented for up to 5-years of storms.

2.6 The storm water utilization demonstration site at the Beijing Technical School of Water Conservancy and Hydro-power

The storm water utilization site at the Beijing Technical School of Water Conservancy and Hydropower is 4 ha and which aims to represent a typical schoolyard. This system has the multiple functions of demonstration, education and promotion of water use. The principle of the system is as follows: the storm water from roof is harvested and after treatment, the clean water is used to supplement irrigation and water for flushing toilets. The runoff from the playground is collected by infiltration channels and from ring ditches built around the playground. After the removal of the first flush and the cleaning of the remaining water by sedimentation, the surplus water is stored for meadow and playground watering. Some of playground has permeable pavement. The principles of the system are characterized in Figure 5.

The roof drainage system serves an area of 5494 m^2, and it collects the rainwater from the school building and a new dormitory. The runoff from these buildings is believed to be less polluted and therefore directly stored in a 500 m^3 storage tank after first flush removal. The dirtier runoff from the runway, whose area is 2360 m^2 flows into ring ditches and then directed towards a filter tank in order to remove particles prior to storage. The artificial grass in the playground, whose area is 6116 m^2, is laid onto a permeable layer so that the water can effectively infiltrate into the soil. Surplus water can overflow along the infiltration channels towards a storage tank.

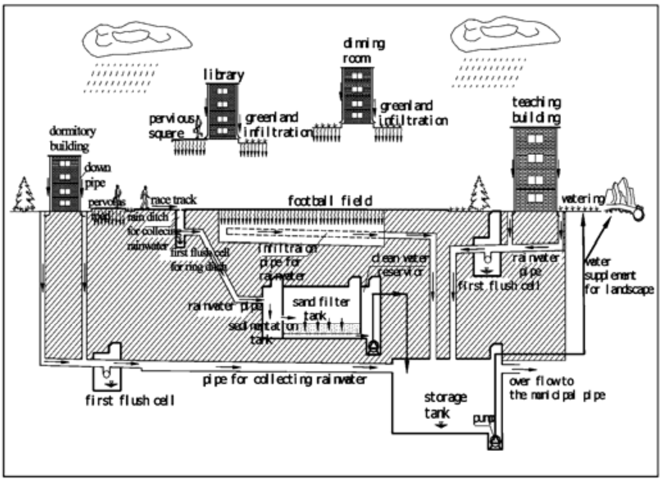

Figure 5: Techniques flow chart about infiltration channels and ring ditches around racetrack in Beijing Technique School of Water Conservancy and Hydropower

3 The Benefits of Storm Water Utilization

Rainwater harvesting is believed to produce great economic, social and environmental benefits.

3.1 Economic benefits

The economic benefits of storm water utilization mainly include:

(1) Saving tap water and replacing some of it with storm water thus reducing fresh water consumption. The economic gain can be calculated by looking at the volume of harvested rainwater and using the the price of tap water to calculate how much is saved.

(2) Rainwater infiltration recharges groundwater. The economic gain can be calculated by looking at the volume of the rainwater that infiltrates underground and comparing the price of underground water extraction.

(3) Saving water leads to increased national income The economic benefit can be calculated by the income losses that would have occurred due to a lack of water. According to official reports, more than 600 cities in China are short of 10 million m^3 water per day, which leads to a loss of 20 billion Yuan for the country annually. The lack of $1m^3$ water corresponds to a loss of 5.48 Yuan. One can say if we save 1 m^3 water, 5.48 Yuan would be gained.

(4) Reduction of social losses caused by pollution. 1 Yuan put towards reducing pollution means 3 Yuan can be saved that would have gone towards cleaning up pollution. The rate of input to output is 1:3. It was observed at the demonstration sites, that the quantity of runoff was significantly reduced as river pollution decreased. The money saved corresponds to a reduced need for water and the many other ecological benefits.

(5) Costs of operating the city’s drainage system are reduced as storm water harvesting and utilization reduces the quantity of the rainwater that flows into the city’s drainage system. Therefore, the pressure to enlarge the city’s drainage system will be reduced as well as its operational costs.

(6) Less pressure to enlarge river and lake capacities for flood control. If storm water is retained and runoff from old and new urban areas is reduced, the pressure on the city’s rivers is relieved. As a result, the runoff will not increase in proportion to the growth of the city. The reduced cost corresponds to the avoided cost of repairing and enlarging river beds.

(7) Reducing the need for irrigation of green spaces. By locating green spaces below adjacent impervious surfaces increases the natural runoff of water and will increase infiltration and the soil’s moisture. Thus reducing the need for irrigation.

(8) Reduce the need for larger storm sewers. Because storm water utilization reduces the runoff that flows into the city’s drainage system, the diameter of drainage pipe can be decreased. Consequently, the cost of more piping can be partially avoided.

(9) Reducing the cost of backfill for greenbelts. When lower green spaces are adopted, the quantity of soil that usually has to be backfilled is reduced.

According to observations at the testing sites, around 100 thousand m^3 was harvest over a one year period, with a total economic benefit of 10 million Yuan (RMB). Therefore, $1m^3$ storm water can result in an 11.53 Yuan profit the necessary investment to collect $1m^3$ is only 1.89 Yuan. The ratio of output to input is 6: 1. The economic benefits of storm water utilization are therefore very significant.

3.2 The benefits for society and the environment

The benefit for society and the environment include:

(1) Reduced runoff and reduced flood peaks. The flood peak is also delayed thus increasing the capability to take countermeasures.

(2) Increase in groundwater recharge and reductions in the downtrend of Beijing's groundwater levels. Besides, utilization of rainwater reduces the demand for tap water, relieving the pressure on water supply and water resources.

(3) Reduced water log on the ground and improved waterscapes further reduces the risk of traffic jams, accidents and, would suggest more generally, a safer urban environment.

(4) Help raise consciousness on the need to save water.. This supports China's sustainable development strategy. Storm water utilization projects can help counteract the effects of local thermal islands and regulating the microclimate. For example, the temperature near the permeable road surface is about 0.3degrees lower than at the normal road, and the relative humidity is 1.12% higher than usual.

(5) Raise property values. with the current emphasis on greener living spaces and general well-being, storm water utilization project attracts people's attention. Greener residential areas are increasingly favorable places to live.

(6) Stimulate new industries which bring along economic prosperity and new jobs. Storm water utilization systems are comprised of different units which require diverse equipment thus increasing the need for industries to support these projects.

4 Conclusion

According to the above analysis, the social benefits are seen to be greater than the direct economic benefit to residents. Government support is still needed to encourage developers or owners to built storm water utilization systems.

The direct economic benefit to residents and owners is not great and for investors the benefit is less than if the discharged storm water went directly into public sewers. This highlights that the economic benefits result primarily in public savings rather than in the personal gain of private investors or owners, at least in the present economic system. Relevant policies should be implemented as soon as possible to motivate investors. However, it may be difficult to generalize from the few demonstration sites.

The benefit to society of storm water utilization is clear. However these benefits can only be maximized if the technology is used over a larger area. This will also require further policy stimulation.

Storm water utilization is a new technology that incorporates many subjects, such as water resources, water saving, drainage, city planning, garden planning and site planning. The research on this topic and its application is only just beginning. This topics needs to continue to be highlighted in the future, along with the necessary supporting regulations and standards.

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Demonstration Study on Water Quality Improvement by Constructed Wetlands in Low Temperature Areas of Northern China
中国北方低温地区人工湿地
水质净化示范研究

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Abstract

The Guanting Reservoir, a large reservoir in the Yongding River, is one of the most important water sources for the municipality of Beijing. When pollutants entered upstream, Guanting reservoir lost its function as a source of drinking water in 1997. In order to restore the ecological environment of the Yongding river watershed and guarantee the safety of the water supply, Beijing's municipal government, together with Brandenburg state government organized the following project: Technical Solutions for the Sustainable Water Supply of Beijing from Yongding River Basin. This paper examines the Heituwa constructed wetland system, one of the key sections of the project which aimed at exploring the technical solutions for the utilization of wetlands in order to treat polluted river water in low temperature areas of northern China. The study provided the integrated ecological technical schemes, which could be used as an important support in the implementation of ecological restoration projects in the Yongding river basin.

摘要

官厅水库为永定河上的一座大型水库，是北京市的重要水源地之一。由于上游污染日益严重，1997 年底官厅水库被迫退出首都饮用水供应系统。为了修复官厅水库流域水生态环境，确保首都供水安全，北京市政府与德国勃兰登堡州合作开展了“官厅水库流域水生态环境综合治理示范工程”项目，本文所述黑土洼湿地系统示范工程既为该合作项目的重要组成部分，其目的是通过示范研究，探索在北方低温地区利用生态湿地系统处理河道受污染水体的关键技术，提出一套适应于官厅水库流域经济适宜的生态工程技术方案，为全面实施官厅水库流域水生态环境综合治理工程提供重要技术支撑。

1 General Layout of the Heituwa Wetland System

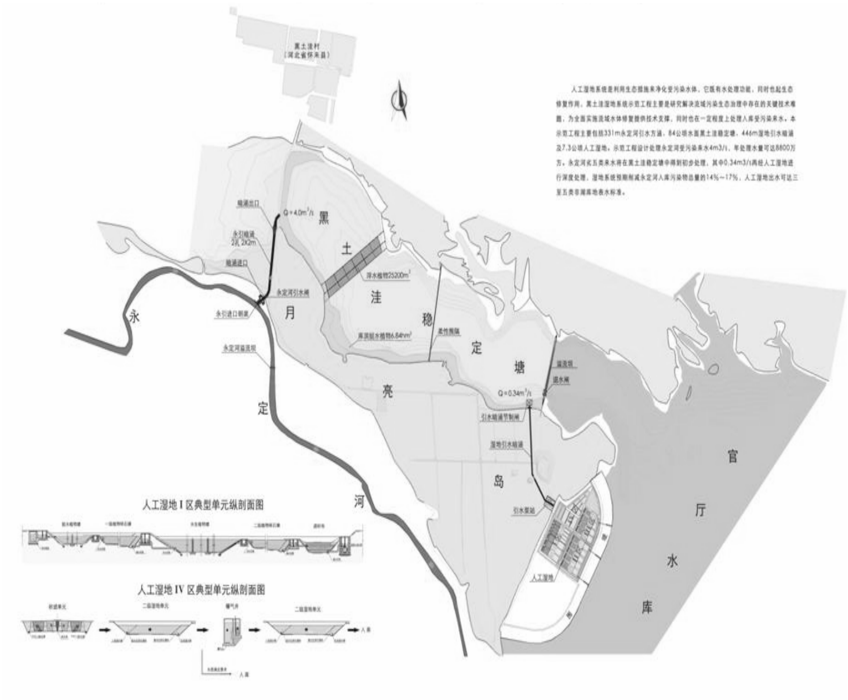
The Heituwa wetland system lies at the mouth of the Yongding river and it directs the flow of water into the Guanting reservoir. The system is composed of a stabilization pond and a constructed wetland. The upstream water with a quality worse than class V on the National

Surface Water Standard is diverted to a stabilization pond, which is regarded as a pre-treatment area. Then, some of the water directly enters the Guanting reservoir and some water is directed towards the constructed wetland for further treatment.

The Heituwa wetland pilot project includes the Yongding river diversion, a stabilization pond, a pumping station and a constructed wetland. The Yongding river diversion is composed of an overflow dam and a water diversion culvert with a designed discharge of 4m^3/s. The stabilization pond includes an overflow dam, a riparian plants area and a foil wall. The pond covers an area of 84 ha, with a storage capacity of 2.64 million m^3. The pumping station project includes a water diversion culvert and a pump station. It has a designed discharge of 1.0m^3/s. The constructed wetland occupies 7.3ha of land area and treats 17.5 million m^3 of water per year. It consists of 4 sections and 2 structure models. The general layout of the Heituwa wetland system is shown in fig.1. The two models are described below:

- Model 1:
  main distribution well → emersed macrophyte pond → 1st stage of plants and gravel bed → aquatic plants pond → 2nd stage of plants and gravel bed → sand filtration pond → outflow pond
- Model 2:
  main distribution well→sand filtration pond→delivery pipe→distribution well for the wetland units→aeration well →plants and gravel bed→drainage pipe

  └→ aeration well→ plants and gravel bed



人工湿地系统是利用生态措施来净化受污染水体，它既有水处理功能，同时也起生态修复作用。黑土洼湿地系统示范工程主要是研究解决流域污染生态治理中存在的关键技术难题，为全面实施流域水体修复提供技术支撑，同时也在一定程度上处理入库受污染来水。本示范工程主要包括331m永定河引水方涵、84公顷水面黑土洼稳定塘、446m湿地引水暗涵及7.3公顷人工湿地。示范工程设计处理永定河受污染来水4m3/s，年处理水量可达8800万方。永定河劣五类来水将在黑土洼稳定塘中得到初步处理，其中0.34m3/s再经人工湿地进行深度处理，湿地系统预期削减永定河入库污染物总量的14%~17%，人工湿地出水可达三至五类非湖库地表水标准。

Figure 1: The general layout of the Heituwa wetland system

2 The Effects of the Heituwa Wetland System on Water Quality

2.1 Conditions of the surrounding wetland systems

- Quality of the inflow from the Yongding River

  Based on continuous monitoring results of the inflow into the Yongding River, most of indicators of water quality indexes were higher than the standard levels. NH_3 and TN were two indexes that revealed the worst results. The average concentration of NH_3 and TN were 9.5 mg/l and 15.9 mg/l, 5~12 times the class V ranking of the national standard. The average concentrations of TP and DP were 0.9mg/l and 0.5mg/l respectively, which also exceeded class V. Concentration of BOD_5 and COD_{Mn} were 17.5 mg/l and 95.5 mg/l, and SS commonly varied from 20 mg/l to 250 mg/l.

  During the winter freezing period, the water quality of the Yongding River usually worsens. Among the water quality indexes, the concentrations of NH_3 and TN increased most significantly. However, as the waste water is often discharged in a concentrated manner during this period, pollutants in the river's water fluctuated.

  The statistical results on the pollutant load in Guanting reservoir from April 2005 to March 2006 shows that although inflow into reservoir is only 0.13 billion m^3 per year, the pollutant loads of TN, TP and SS reached 1533 t/a, 89 t/a and 60000 t/a respectively.

- Weather conditions

  The Guanting reservoir watershed lies in a semi-arid continental climate region, where winter is long, dry and cold, summer is short, and in spring and autumn large and frequent wind events. Average annual air temperature is 9.4 °C, and the average monthly temperature is between –7.7 to 4.4 °C. Average annual wind speed is 3.0 m/s with a maximum of 13.6 m/s.

  The Guanting reservoir commonly freezes at the end of November or in early December, and thaws in March. During the duration of the operating period of the wetland system, the lowest air temperature is -18.9 °C and the ice depth reaches about 48cm.

- Hydraulic loading of the Heituwa wetland system

  From May 2004 to March 2005, the inflow to the wetland system was intermittent due to the construction of the overflow dam on the Yongding river. But since April 2005, the inflow and flows to the wetlands was normal. During this time, the average flow rate of inflow was about 1.5 m^3/s, and for sections 1 and 4 of constructed wetland, the flow rate was 600 m^3/h. The hydraulic loading of the stabilization pond was about 0.1~0.4 $m^3/m^2/d$, and that of the constructed wetland was about 0.4~0.8 $m^3/m^2/d$.

2.2 The wetland system’s treatment effect on organic pollutants

The treatment effect on organic pollutants is shown in figures 2 and 3 and the effects were significant. The removal rate of BOD_5 reached 58%~77%, and the removal rate of COD_{Mn} was higher than 40％. Most of the time, indexes on the outflow from wetland system reached class III of the national standard classification. During the freezing period from December to the following March, and the ecosystem’s rehabilitation period from April to May, the wetland system had a good treatment effect. The two years of data indicates that temperature and DO did not have a significant effect on the degradation of organic materials. The wetland system could be seen as supplied with a good degree of self-adaptive ability.

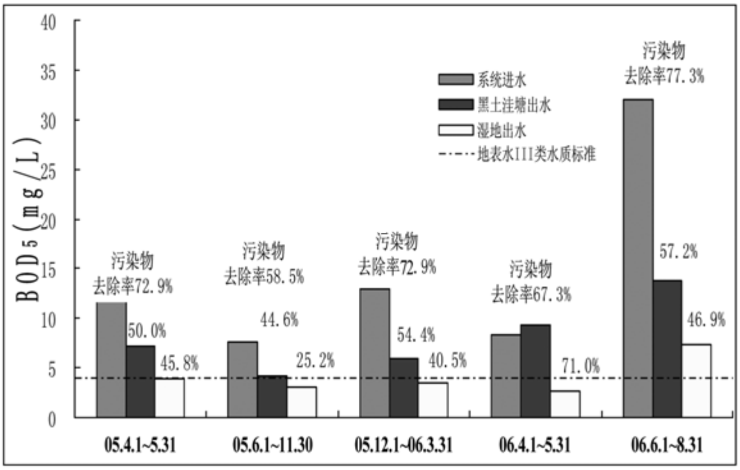


Figure 2: Treatment effect on BOD_5

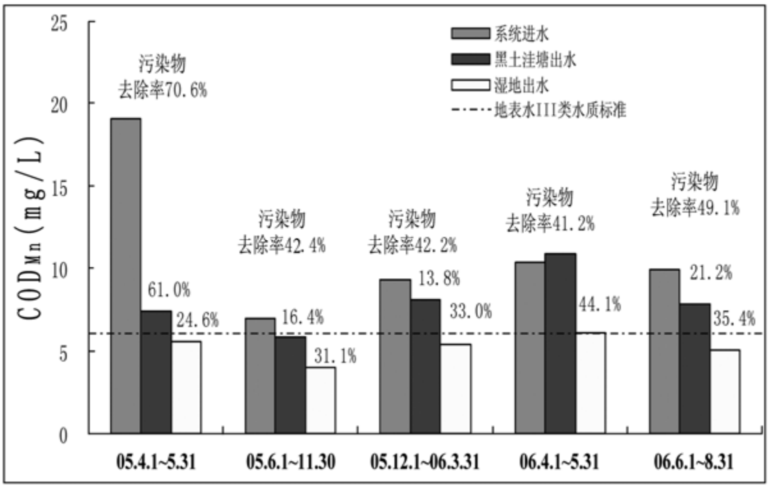


Figure 3: Treatment effect on COD_{Mn}

The evolution of COD $_{Mn}$ concentrations in the subsurface flow constructed wetland unit models is shown in fig.4. Among all units, the gravel bed with a subsurface flow was the most effective at removing organic material. For some bodies of water with low concentrations of organic material, acquatic ponds provide a carbon source which helps to remove TN. We also can see that when COD_{Mn} reached the level of Class III, further removal became difficult. As the 2nd stage of plants and gravel bed and the sand filtration pond had not demonstrated their full capability, the wetland system showed significant potential to remove organic pollution.

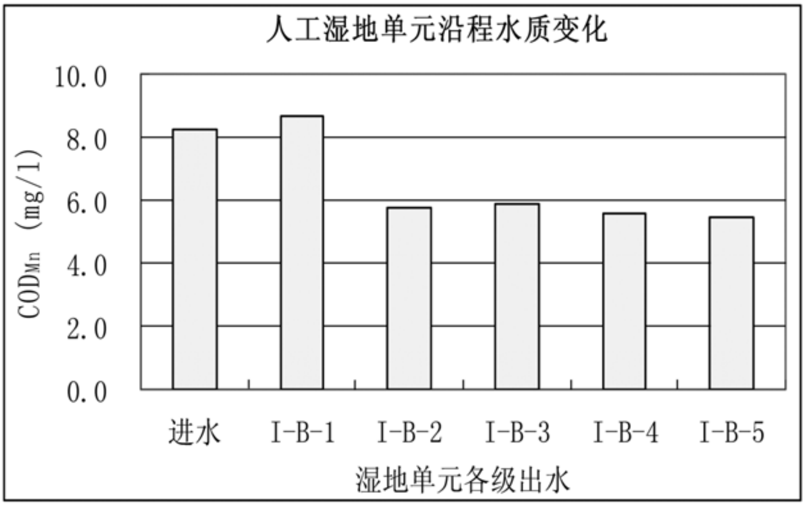


Figure 4: Variety of COD_{Mn} concentration along wetland unit models

2.3 Wetland system's treatment effects on nitrogen

Figures5 and 6 show the variety of nitrogen concentrations. Figure5 shows that the wetland had a good treatment effect on ammonia from June to November. During this period, the removal rate of ammonia was more than 90% and outflow from the wetland system was better than Class III. Such effects become weaker during the freezing period, December to following March, and the ecosystem rehabilitation period from April to May.

Figure 6 indicates that the wetland system had a good effect on TN removal from June to November. The removal rate reached 64.2% the first year, and 80.5% the next year. On the whole, TN removal rates by subsurface flow in the wetland reached 47% the first year and 70.5% the next year. This revealed a TN removal capability that gradually increased as the wetland system developed. Figure 6 also showed that the air temperature and the oxygen deficit during the freezing period affected TN removal, so the treatment effect became weaker during the wetland system's freezing periods and rehabilitation periods.

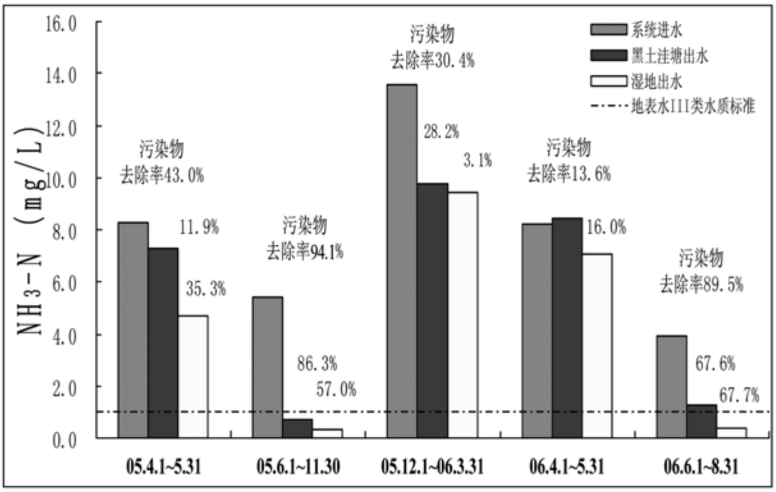


Figure 5: Treatment effect on NH_3-N

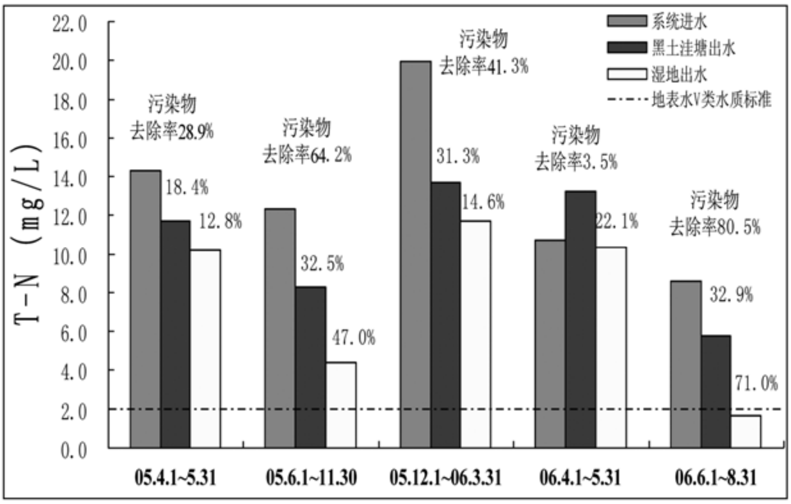


Figure 6: Treatment effect on TN

Figure 7 shows the TN reduction trends among the constructed wetland system. The removal rate by the 1st plant and gravel bed was the highest. Compared to the removal rate of the 1st bed, the rate of 2nd bed was low, which also indicates that there is still a large potential for nitrogen removal within the wetland system.

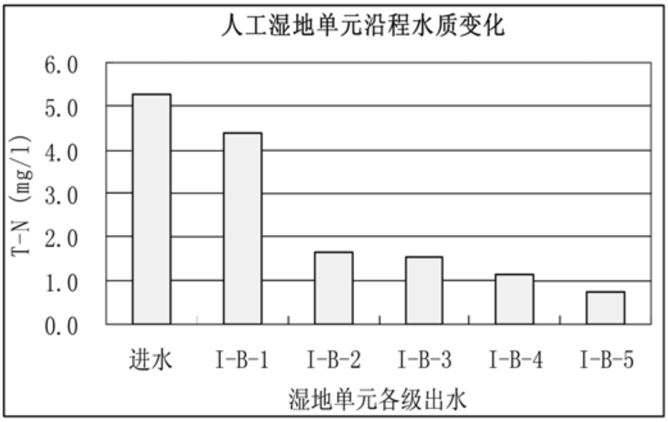


Figure 7: Variety of TN concentration along constructed wetland unit models

2.4 Wetland system's treatment effect on phosphorus

The treatment effect on TP during different periods is shown in fig.8. The TP removal rate reached 35%~75%, mostly due to the effects of the Heituwa stabilization pond which used precipitation and bio-purification. However, the process gradually weakened over time, which reveals that a wetland based on only gravel structures has limited treatment capabilities.

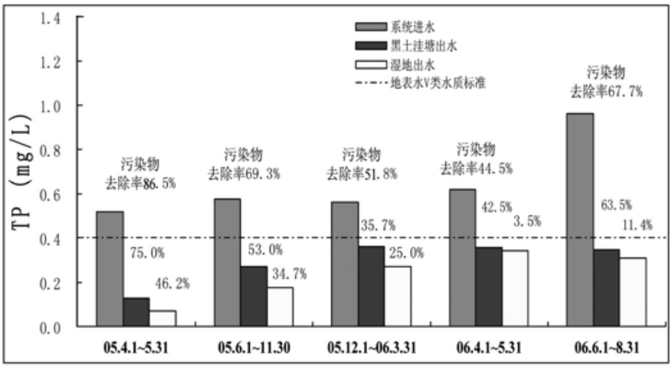


Figure 8: Treatment effect on TP

2.5 Wetland system's treatment effect on aquatic life

Phytoplankton: There are 8 phyla of phytoplankton in the Heituwa wetland system, mainly chlorophyta, diatom and cyanophyta. From the stabilization pond to the outflow pond, the density of pelagic algae was reduced by 75%, and the transparency and sensory attributes of the body of water body improved significantly. The indicator species changed from eutrophic to mesotrophic.

Zooplankton: There are 4 genus and 70 species of zooplankton in the wetland system, mainly protozoan and rotifer. The density reduction reached 82% between the stabilization and the outflow pond. An evaluation of the density of zooplankton indicated that the wetland system changed from eutrophication to mesotrophication.

Zoobenthos: The monitoring indicates that the benthic animal community in the front part of the wetland system was mainly resistant to pollution, while those in the outflow pond were resistant to medium pollution scenarios, and even some species that only live in clean water.

3 Conclusion

A compound wetland system was constructed, composed of a stabilization pond, a wetland with a constructed subsurface flow and an outflow pond. Long-term continuous monitoring data indicated that the wetland system could adapt well to the complex water conditions of high sediment concentrations and fluctuating quality. Most of the pollutants in the water could be reduced by passing through the wetland system.

The pilot project showed that it is technically feasible, low cost, and easy to implement the use of constructed wetlands to treat polluted bodies of water in low temperature areas of northern China. Investment requirements are low and the operation and the management of the wetland system is simple, pointing to the feasibility of this system being applied to other areas with similar conditions as the pilot project.

However, more monitoring and study are needed, mainly on the purification principals and technologies and long term operation effects on the wetland system.

Decision Support Systems for Sustainable Water Management Using Cybernetic Aspects 用控制论的观点 建立可持续水资源管理的决策支持系统

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Abstract

Sustainable utilization of water resources through modern technologies has become an important research subject. Decision Support Systems (DSS) are an effective measure to realize such a sustainable water management plan. Therefore, it is necessary to model and simulate the surface water and groundwater resources of cities and regions. Water systems are characterized by complex, highly nonlinear dynamic, uncertain and locally distributed hydraulic behavior, which is mainly determined by meteorological, hydro-geological conditions as well as the decisions made by a high order controller or an expert. A widely accepted approach in computer aided design and realization of decision systems is to initially develop suitable models to describe the nonlinear process dynamics. The structure and the parameters of the models are chosen or estimated depending on the component of the water system to be modeled. Modeling concepts for monitoring, control and prediction are based on theoretical laws and their parameters are estimated from the measured data of the inputs and outputs of the process. In general, the so-called “hydrodynamic control models” are based on Saint-Venant-Equations. A model aided computer simulation realizes the optimal design of the decision systems. Sufficient quantity and quality of water resources are preconditions for the development of big cities. Water scarcity is especially a main restricting factor for cities in semi-arid or arid climate zones. An example of a city facing this restricting factor is Beijing. The capital of the P.R. China is facing the challenge of a water shortage, the conflict between water supply and demand. Sustainable utilization of water resources through modern technologies has become an important research subject. As an example of the approach of using a decision support system for the joint optimal operation of different water sources such as surface water, ground water, recycled water and transferred water is presented. It will be developed within the framework of the Chinese - German joint project "Towards Water-Scarcity Megalopolis's Sustainable Water Management System". The project is of significance for the sustainable development of economics and community in Beijing and the success of the Olympic Games in 2008. An indispensable requirement for such a DSS is a simulation model of the water resources and the water supply system.

摘要

通过现代化的技术可持续的利用水资源已经成为一项重要的研究课题。决策支持系统（DSS）是实

现这种可持续水资源管理的有效手段。因此，对城市和区域的地表水和地下水资源建模和模拟是十分必要的。水系统的特点在于复杂、高度非线性的动态、水压的不确定性和区域分布性，它们主要取决于气象、水文地质条件和高层管理者及专家的决定。在电脑辅助设计和决策系统运行中被普遍认可的方法是开发合适的模型来模拟非线性的工艺动态。模型的结构和参数依照建模的水系统的构成来选择和评估。监测、控制和预报的建模概念以理论方法为基础，它们的参数以此过程中输入和输出的测量数据来评估。通常，所谓的“水力控制模型”依据圣维南方程组。电脑辅助模拟模型实行决策系统的最佳方案。充足的水量和水资源的质量是大城市发展的前提条件。缺水尤其是处于干旱，半干旱气候带的城市的一个主要制约因素。北京就是这样的城市之一。中国的首都正面临着缺水和水资源供求矛盾突出的挑战。通过现代化的技术可持续的利用水资源已经成为一项重要的研究课题。作为应用的实例，本文介绍了地表水，地下水，再生水和调配水等不同水资源联合优化实施的决策支持系统的方法。这个系统将会在中德合作项目“应对水荒——大城市的可持续水资源管理系统”中开发。这个项目对于北京经济社会的可持续发展以及 2008 年奥运会的成功举办具有重要意义。DSS 的一个必要条件是水资源和供水系统的模拟模型。

1 Cybernetic Aspects

With the book on “Cybernetics, or control and communication in the animal and the machine” written by N. Wiener in 1948, the field of goal-oriented influence of technical as well as non-technical systems and processes – cybernetic or control theory - has evolved enormously. Cybernetic theories are realized, especially by automation techniques and decision making systems.

Important conditions for the application of cybernetic methods include the knowledge of:

- the control goals and their evaluation – cost functions
- the static and dynamic behavior of signals, states and systems – models
- design methods for feasible/optimal control – optimal control / decision making systems
- methods and technical systems for the realization of the control systems – automation

2 Cybernetic Models

2.1 Catchment area models

The catchment area models describe the behavior of hydrological processes such as snow melting process and/or rainfall – runoff process.

2.1.1 Snow melting process models (snow-melt-models)

The basic structure of the model of the snow melting process is shown in Figure 1.

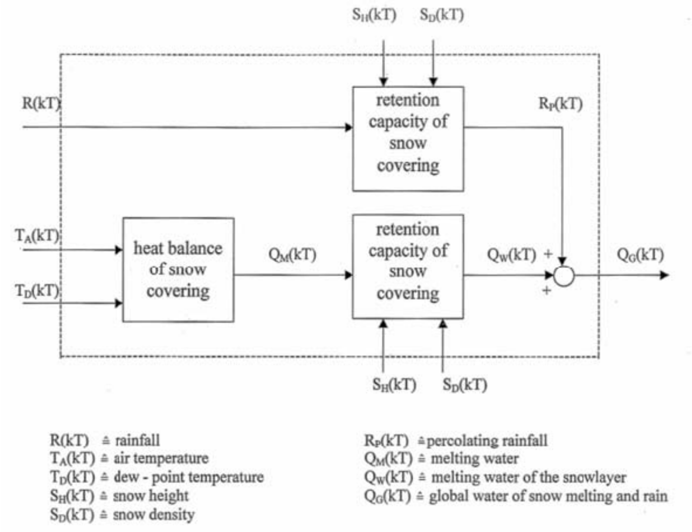

Figure 1: Structure of the Snow Melting Model

The sum of the percolating precipitation and the effective amount of water from the molten snow is the input variable. All the models presented in this paper are a discrete time representation of the process in consideration (Neis/ Hoffmeyer-Zlotnik/ Wernstedt (1981)).

2.1.2 Rainfall – runoff process models (Rainfall-runoff-models)

There are many models that can be used to describe the rainfall-runoff process, but for the purposes of control and prediction the model structure (see Figure 2) developed by Lorent and Gevers (1976) has proven to be very effective.

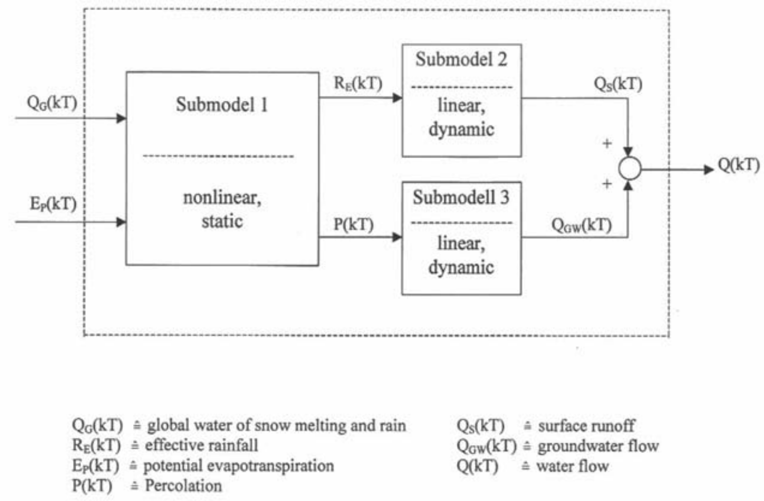

Figure 2: Structure of the Rainfall-runoff Model

Lorent and Gevers' approach describes a simplified model of the catchment area. It comprises a nonlinear static sub-model of the soil moisture and two linear dynamic sub-models to convert the effective rainfall into surface discharge as well as the seepage into base discharges.

2.2 River models

The behavior of a river between a given input and output location can be easily represented by sub-models describing typical hydraulic characteristics of the river.

2.2.1 Water flow – models

A widely accepted approach in the description of the behavior of the water flow rate of a river between a given input and output location is to apply non-linear difference equations with time delay. These models can be expressed as

$$(1)\quad Q_0[(k)T] = -\sum_{i=1}^{n} a_i\, Q_0[(k-i)T] + \sum_{j=0}^{m} b_j\, Q_I^{*}[(k-j-d)T]$$

where Q_I is the input flow in m^3/s; $Q_I^{*} = c_0 Q_I + c_1 Q_I^2 + \ldots$ is the non-linear input flow in m^3/s; Q_0 is the output flow in m^3/s and $d = \frac{T_t}{T}$ (T_t – dead time, T – sample time) (Hoffmeyer-Zlotnik/ Seifert/ Wernstedt (1979, 1981); Wernstedt (1989)). A second model structure was developed based on the classical Saint-Venant-Equations for one-dimensional channel flow (Dyck (1978); Dyck/Peschke (1983); Vischer/ Hager (1998)). The continuity equation can be expressed as

$$(2)\quad \frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0$$

where Q is the flow; x is the distance; A is the cross-sectional area; t is the time.
The equation of momentum is given by:

$$(3)\quad \frac{\partial H}{\partial x} + \frac{1}{g}\left(\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial x}\right) + I_R - I_S = 0$$

Where H is the depth of water: v is the flow speed; I_R is the coefficient of friction; I_S is the gradient of the riverbed. Although most real-life processes are inherently continuous-time processes, for ease of computation in modeling or other applications, a discrete time representation of the process is considered. The numerical solutions of the above equations are preferred for hydro-geological aspects (Nestman (1997)), whereas on the other hand to solve control problems, a division in small river sections will result in excessive estimation and tuning effort of the parameters. Hence, the computational effort for online purposes will be unrealistically high. To solve control problems, it is sufficient to approximate some parts of the equation of momentum (eq. (3)) with the Strickler-Equation and the Taylor series expansion, leading to

$$(4)\quad Q = Q_{stationary} + Q_{non\text{-}stationary}$$

where $Q_{stationary} = k_1H$ and $Q_{non\text{-}stationary} = -k_2B\frac{\partial H}{\partial x}$.

In discrete time form (i.e. $H(x, t) \Rightarrow H[m\Delta l, kT]$ and $Q(x, t) \Rightarrow Q[m\Delta l, kT]$ where Δl is the length of the river section; T is the sampling period, eq. (2) can be expressed as follows:

$$\begin{aligned}(5)\quad Q_0[m_0, k] = {} & a_1Q_0[m_0, (k-1)] + a_2Q_0[m_0, (k-2)] + \\ & b_1Q_I[m_I, (k-k_1)] + b_2Q_I[m_I, (k-1)] + \\ & c\,[H_0(m_0, (k-1))] - H_I(m_I, (k-k_1)) - \\ & H_0(m_0, (k-2)) + H_I(m_I, (k-2))\end{aligned}$$

where $m_0\Delta l$ is the end location of the river section; $m_I\Delta l$ is the start location of the river section (Rauschenbach (1999/1)).

The structure of the model is illustrated in Figure 3.

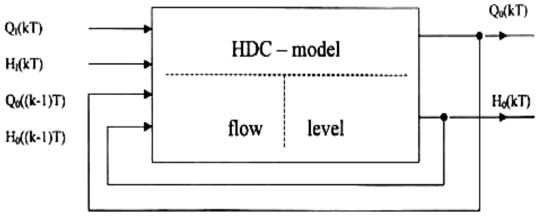

Figure 3: Structure of hydrodynamic control model (HDC-model)

2.2.2 River water level models

The water level of a given location on the river course is estimated from the linear/non-linear characteristic curves of the river flow and level. The main problem hereby is the estimation of the characteristic curves.

The Saint-Venant-Equation is used to determine the water level at any location of the river. Hence, the change in the water level can be expressed as

$$(6)\quad \partial H = I_R\partial L - \frac{v}{g}\partial v - \frac{1}{g}\frac{\partial v}{\partial t}\partial L$$

where $v = \frac{Q}{A}$ is the flow velocity; Q is the water flow. A is the cross-sectional area of the river.

Therefore, the water level at any location of a river or dam can be computed using the so-called “Bresse differential-equation”. It is assumed that a priori knowledge of the cross-sectional area of the river or dam at that definite location is available.

2.2.3 River overflow models

These models represent the relationship between the flows in the river and the flows in the overflow regions. The flow into the overflow regions is a function of the water level of the river.

2.2.4 Models of retention rooms (controlled)

Most rivers have natural overflow regions. These regions help to decrease the flow peak and improve control. The model describes the flow behavior in the overflow regions and calculates the water level in these regions. Incoming flow, from the surroundings (i.e. creeks) is also considered in the model (see Figure 4). Furthermore, the pumping stations in the overflow regions are simulated.

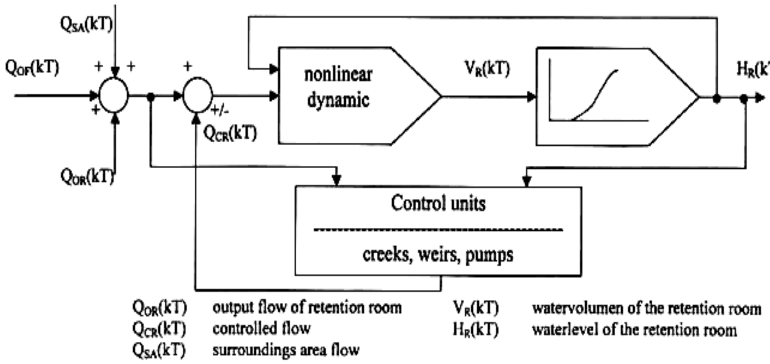

Figure 4: Structure of Retention Rooms

The set of inputs to the model of the retention room (i.e. the retention room comprises a non-linear dynamic and a non-linear static sub-model) include the sum of the flows from the surrounding areas, the overflow, the outflow of the retention room, the controlled inflow/outflow and the water level of the retention room.

2.2.5 Models of backflow effects (uncontrolled retention rooms)

Backflows (i.e. the afflux upstream from a given location on an open channel resulting from impedances offered to flow) appear at narrow places in the river course. The discharge and the incoming backflow can be determined by the model structure in Figure 5.

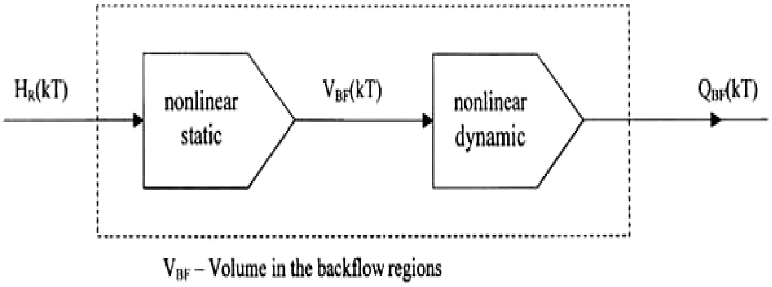

Figure 5: Model Structures of Backflow Effects

The inflow or outflow of the boarding fields can be calculated in relation to the river water level. Hence, the equation for a given location of the river can be expressed as

$$(7)\quad Q_{O,R}(kT) = Q_{I,R}(kT) \pm Q_{BF}(kT)$$

where Q_{BF} (k T) is the backflow. Estimating the characteristic behavior of the backflow is very difficult.

2.2.6 Models of flow and level at back water of dam

This model is used to compute the water level H_D of backwater of the dam as a function of the controlled barrier's discharge (i.e. turbine flow, weir flow and lock flow). The level and the volume of the stored water are essential state variables. The water level varies with the volume of the stored water as follows:

$$(8)\quad \begin{aligned} V_D(kT) &= f\,[H_D(kT), Q_D(kT)] \\ Q_D(kT) &= f\,[Q_T(kT), Q_W(kT), Q_L(kT)] \end{aligned}$$

where Q_T is the turbine flow; Q_w is the weir flow; Q_L is the lock flow; V_D is the volume stored in the reservoir; Q_D is the total water flow out of the reservoir (Figure 6).

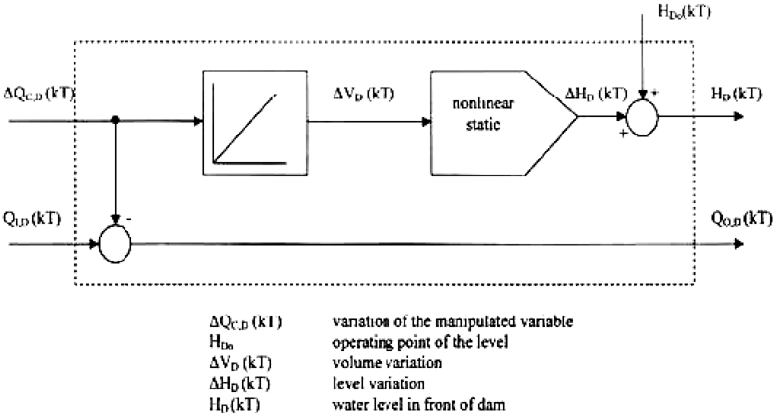

Figure 6: Model Structure of Backwater of Dam

The change in volume ΔV_D (kT) can be expressed as follows:

$$(9)\quad \Delta V_D (kT) = \sum_{i=0}^{k} [Q_{I,D} ((k-i) T) - Q_{O,D} ((k-i) T)]$$

where $Q_{I,D}$ is the water flow into the reservoir. Applying Taylor series expansion to describe the relation between the changes in volume ΔV_D and water level ΔH_D lead to a non-linear static equation expressed as

$$(10)\quad \Delta H_D (kT) = \frac{1}{A(H_D, Q_{O,D})} \Delta V_D (kT)$$

The level of the backwater of dam is the sum of the change in water level and the water level at that given location.

3 Decision Strategies

3.1 Forecast strategies

The forecast methods for the water level and/or flow in river basins are based on the structure in Figure 7 and 8 and the models introduced in section 3.

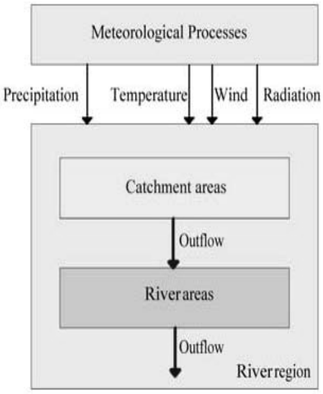

Figure 7: Structure of Forecast System

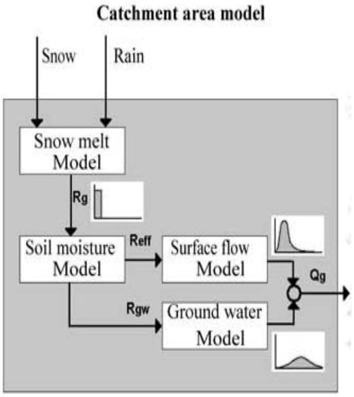

Figure 8: Catchment Area Model

Determination of scenarios for the alternatives (See Figure 9):

- optimistic
- favorable
- probable and
- pessimistic

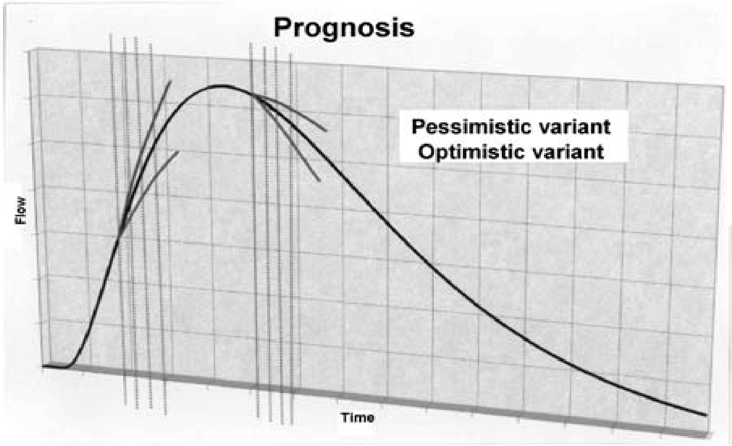

Figure 9: Flood Prediction Using Scenarios

The forecast strategies are all adaptive and are repeated every sampling time for n sample times (Hoffmeyer-Zlotnik/ Wernstedt, (1985)). Other strategies for flood forecasting are introduced in Gutknecht/ Kugi/ Nobilis, 1997.

3.2 Control strategies

3.2.1 Cost criteria

3.2.1.1 Integral criterion

The following cost criteria are defined to determine the quality of control of the flow $Q(\tau)$ or/and the level $H(\tau)$ respectively:

$$(11)\quad I_1(t) = \int_0^t [Q(\tau) - Q_S(\tau)]^2 \partial\tau$$

$$I_2(t) = \int_0^t [H(\tau) - H_S(\tau)]^2 \partial\tau$$

where $Q_S(\tau)$ is the desired water flow; $H_S(\tau)$ is the desired water level.

3.2.1.2 Constraints criterion

The controlled variables Q(t) and H(t) are constrained by $c_1(t)$ and $c_u(t)$. Hence, the integral criterion consisting of two penalty terms for punishing the limits violations

$$(12)\quad I(t) = \int_0^t \eta\,[c_u(\tau) - y(\tau)] + \eta\,[y(\tau) - c_1(\tau)]\,\partial\tau$$

where $c_u(t)$ is the upper constraint; $c_l(t)$ is the lower constraint; $\eta(x) = \begin{cases} 0 & x \geq 0 \\ -x & x < 1 \end{cases}$

3.2.1.3 Multiple criteria

It has been proven to be an advantage to use a multiple-criteria as a cost function for complex systems. The cost function is a weighted sum of partial criteria. Hence,

$$(13) \quad I(t) = \sum_{i=1}^{m} \alpha_i I_i(t)$$

where α_i is a weighting factor for the partial criterion I(t); $0 \leq \alpha_i \leq 1; \sum_{i=1}^{m} \alpha_i = 1$; $I_i(t)$ is a partial criterion.

3.2.2 Automation system structures

There are two approaches to describe the structure of automation systems; level-concept control of a multivariable system is performed in subsystems and layer-concept (i.e. the control task is divided into its functional basis). The next sections discuss the distributed control strategies (i.e. decentralized and hierarchical control).

3.2.2.1 Decentralized control structure

Decentralized control is performed in subsystems where each of which the local control is based on measurement and feedback of local state and output variables (Figure 10). In this control structure, there is no central computer (controller) to evaluate the cost criteria of the global process.

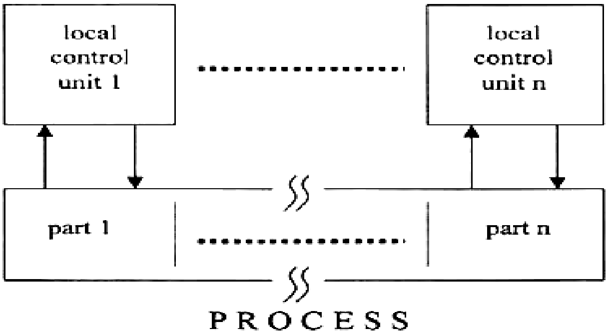

Figure 10: Decentralized Control Structure

The prime objective of the decentralized control unit is to regulate the water levels of reservoirs while minimizing the control effort. The following structures are applied to control the behavior of the water plant:

a) Closed loop control
b) Closed loop with disturbance variable feed forward.

It is possible to apply the following controllers in the above-mentioned structures (Koch/ Kuhn/ Wernstedt, 1996):

a) PID-controller
b) Fuzzy-controller/Neuro Controller
c) Hybrid-controller.

3.2.2.2 Hierarchical control structure

The hierarchical control is performed in subsystems, which generally are assigned to different control levels in which higher level controllers acting as supervisors control several lower level controllers (Figure 11 / Reinisch (1974)).

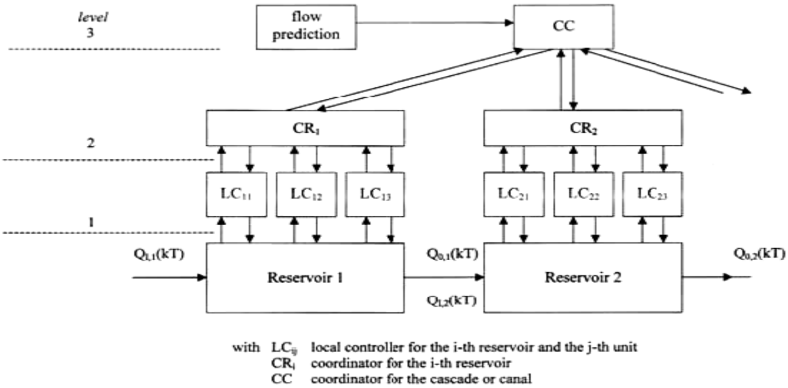

Figure 11: Hierarchical Control Structure

Depending on the complexity of the process, automation systems used for control have in most cases a hierarchical decentralized structure, whereby the controllers of the lower level have to react fast and act locally. The higher-level controllers are used for optimization, coordination, and danger management etc, tasks that do not necessarily require fast responses (Rauschenbach, 1999/2).

An example is the control of hydro power plants. The supervisors (second level controllers) determine the optimal set points for the lower level controllers, which perform the local control (control of turbines, weirs, pumps etc.) based on measurement and feedback of local state and output variables. Each supervisor (coordinator) in the second level represents one hydropower plant or dam. The prime objectives of each second level controller are to:

- Perform the best possible flood control of the dam,
- Regulate water levels,
- Produce maximum energy,
- Make best conditions for navigation and
- Consider ecological aspects.

The inputs to the supervisor controller in the second level are the desired water flow for the hydropower plant, the state variables of the turbines, weirs and pumps and the outputs are the desired set points for the turbines, weirs and pumps.

The prime objective of the third level controller is to coordinate the cascade of hydropower plants or sections of channels in order to:

- Obtain the best possible flood control of each reservoir in the cascade,
- Regulate the water levels in all reservoirs,
- Transfer the system from normal operation to flood control while maintaining maximum energy production
- Protect navigation in the cascade /channel.

The inputs of the third level controller comprise the incoming flows of the cascade and the current states of each reservoir. The control objectives are to compute the control sequence for the hydropower plants so as to minimize a given cost criterion. The cost criterion to be applied is chosen according the control situation (e.g., flood, low water control). The coefficients α i in the cost criterion equation are determined by a fuzzy system depending on the control situation (flood, low water, etc.). The optimization procedure is carried out every time a prediction is updated or when the state variables of the reservoir change. This can be broadly considered as a combination of an on-line estimation method for the process parameters, and a controller design procedure. The objective is to obtain an adapted control trajectory. Iterative non-linear optimization techniques (e.g., simplex method and evolutionary algorithms) are used to optimize the cost functions. The supervisor controllers in the third and second level of the hierarchical control system are only activated in special situations (e.g., flood, low water, and break down).

4 Application

4.1 Development of a water allocation decision support system for Beijing

Beijing is a fast growing city. For several years the total population has increased steadily and the economy has grown rapidly. An increasing demand of several resources, especially water, follows from this development. These factors, in addition to the semi-arid climate, are the causes of the scarcity of water in Beijing. Without consideration of sustainable resource use, the very positive development of the region is endangered.

Central management of all usable water resources for the city is urgently needed. That is why the Beijing Water Authority (BWA) is developing a "Capital Water Resources Allocation Decision Supporting System" to assist in the management of all the water resources of the capital of the People's Republic of China.

The general objectives of the joint Chinese - German project "Towards Water-Scarcity Megalopolis's Sustainable Water Management System" are as follows:

- To build rainfall -runoff models for the catchment areas of the most important reservoirs in the Beijing region with the aim to improve precision of runoff forecast
- To establish water demand prediction models for a large city to solve the problem of water demand prediction under different circumstances
- To build the joint operation model of multi water resources including surface

water, groundwater, recycled water and water diversion as well as to primarily solve the allocation problem of Beijing water resources

- To primarily establish operation-orientated Beijing water resources integrated allocation decision supporting system (DSS) and provide techniques for water resources management and decision-making

The project is under the charge of BWA, German Fraunhofer Institute for Information and Data Processing and Fraunhofer Center for Applied Systems Technology. The project will be completed by 2008.

The DSS will realize an optimal allocation of existing water resources such as surface water, ground water, recycled water and transferred water. That means a multiple optimization problem has to be solved (Rauschenbach (2001)). Therefore, a goal function and a simulation model of the water resources as well as of the water supply system are necessary. In the first phase of the project the simulation model of the Beijing water supply system will be developed. The starting point for this development is a rough model of the simulation of the surface and groundwater resources. This model meets the demands for a decision support system with respect to accuracy and simulation speed. The model takes account of:

- Miyun, Guanting, Huairou and Baihebao reservoirs and their catchment areas
- Groundwater storage
- Rivers and channels linking the reservoirs to the city and
- Pattern of consumption in households, industry and agriculture

4.2 Structure of the decision support system

The objective of the project is to establish an integrated intelligent water resources allocation decision support system based on GIS. It uses advanced computer and network technology and it implements a man-machine interface between decision makers and the system. Figure 12 shows the logical structure of the DSS which will be developed.

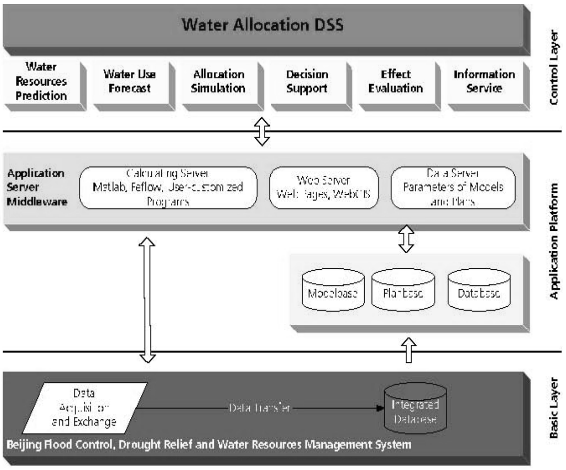

Figure 12: The Logical Structure of the 'Capital Water Resources Allocation Decision Supporting System'

The DSS is designed as a distribute system cation layer (application platform) and the control layer. In the basic layer, the functions for data management and data storage are concentrated. The simulation models and the optimization strategies for decision-making are located in the application layer. Man-machine-interface is provided by the control layer. From here, the locally distributed users can access data and simulation results as well as optimization results. Therefore, different rights of access can be assigned to the users.

4.3 Structure of the water supply system

The structure of the system is shown in Figure 13. All essential parts of the Beijing water supply system will be considered in the model (BWA (2003)). First, there are the four reservoirs Miyun, Huairou, Baihebao and Guanting. The catchments area models are integrated in this system in order to take into account the precipitation and the evapo-transpiration. Further sources are groundwater storages. Secondly, there are the water transportation systems such as channels and rivers. Miyun reservoir and Huairou reservoir are connected with the Beijing-Miyun water diversion. After that, the water flows in this channel towards Beijing. The arrows show the directions of water flows. In the simulation model, these arrows describe hydraulic behavior of water flow. Baihebao and Guanting reservoir are connected with tunnel and river Guishui. From Guanting, water runs inside the Yongding river water diversion system to Beijing. Existing retention areas for flood control will be considered later in the simulation model.

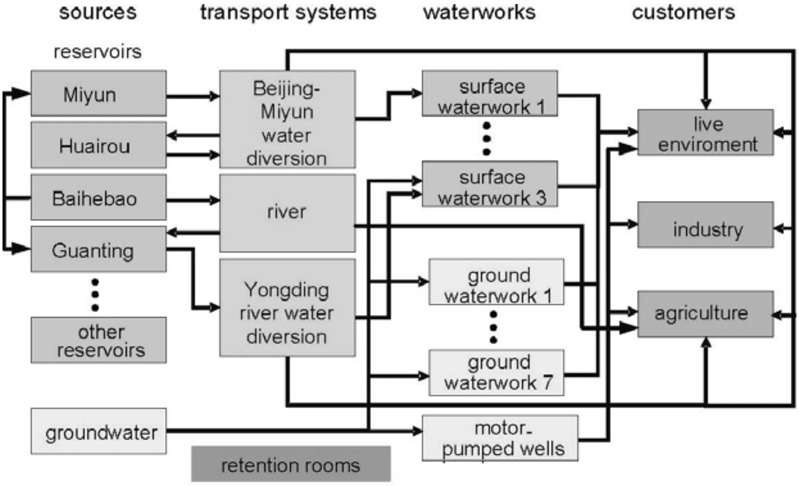

Figure 13: The Structure of Water Supply System in Beijing

The surface water from channels and rivers is delivered to the customers in two ways. Either water is delivered directly from the channels to the customers or the surface waterworks distributing the water. Ground waterworks as well as motor-pumped wells distribute groundwater to the customers. These waterworks are the third part of the Beijing water supply system. The several customers are the fourth part of this system.

4.4 Goal function for optimization

One can take the simulation results up to this point as a basis for characterizing the water supply situation in Beijing as follows (Rauschenbach & Gao. (2005)):

- The surface water and groundwater resources are decreasing
- Main part of precipitation is concentrated in the months July and August
- The demand for drinking-water and industrial water will increase in the next few years

Therefore, the essential aims of the project are to prevent the water resources (especially groundwater) from decreasing and to guarantee the water supply of households, industry and agriculture. In order to achieve these goals a multiple criteria optimization problem has to be solved (Ehrgott (2005), Soncini-Sessa, R.. & others (2000)). A first approach for a goal function *I(t)* to be minimized is defined as follows:

$$(14)\quad \mathrm{I}(t) = \alpha_1 \bullet I_1(t) + \alpha_2 \bullet I_2(t) + \alpha_3 \bullet I_3(t) + \alpha_4 \bullet I_4(t) \quad \text{with} \sum_{i=1}^{4} \alpha_i = 1$$

In eq. (14) the sub criteria *Ii(t)* have the following meaning:

- The groundwater level change $\Delta H_G(t)$:

$$(15)\quad I_1(t) = \begin{cases} \min(-\Delta H_G(t))\, for 5 to 9 years (\Delta H_G(t) \le 0) \\ \Delta H_G(t)\, for 10 to 14 years (\Delta H_G(t) \approx 0) \\ \max(\Delta H_G(t))\, for \ge 15 years (\Delta H_G(t) = 0) \end{cases}$$

- The supply deficits of households $D_H(t)$, industry $D_I(t)$ and agriculture $D_A(t)$ in the following two possible forms:
  - Mean deficit:

$$(16)\quad I_{2,3,4}(t) = D_{H,I,A}(t) = \frac{1}{n}\sum_{i=1}^{n}(d_i - s_i)^+$$

$$\text{with } (X)^+ = \begin{cases} X & for \quad X > 0 \\ 0 & for \quad X \le 0 \end{cases}$$

with d_i demand per time unit and s_i supply per time unit.

- Days or months with deficit:

$$(17)\quad I_{2,3,4}(t) = D_{H,I,A}(t) = \sum_{j=1}^{n} g^j$$

$$\text{with } g^j = \begin{cases} 1 & for \quad s_i < d_i \\ 0 & otherwise \end{cases}$$

In the next phase of the project, this goal function will be used for the optimization of water resources allocation in Beijing. That means the DSS delivers optimal trajectories (in the sense of the goal function) for the control of reservoirs, sluices, pumping stations etc. An essential precondition for this way of proceeding is the simulation model described above.

5 Conclusions

Cybernetic methods are very well suited for the development of sustainable water management systems. Simulation models which are adapted to the decision making process are necessary, on the basis of the subject of the cybernetics - the goal-oriented influence of systems on the basis of information. The control models for the sub-processes of movement of water and / or level in catchment areas, rivers and reservoirs are introduced. Based on the models, the decision-making strategies using repetitive forecast and decentralized decision-making, as well as hierarchical control strategies for hydrological processes are designed.

For the planned "Capital Water Resources Allocation Decision Supporting System" a simulation model of the water resources and the water supply system is indispensable. That is why in the first step of the joint Chinese-German project "Towards WaterScarcity: Megalopolis's Sustainable Water Management System" a rough simulation model was developed.

Now, the project partners are working on an enhancement of the presented rough simulation model. A more detailed simulation model is in the process of development. The basis for this model is detailed information about the structure of the elements of the Beijing water supply system as well as extensive data sets of measured historical data.

In that process, the simulation tool will have to be adapted to fit the tasks required for the decision support system. Both are necessary: sufficient accuracy to meet the needs of the intended application, and sufficient simulation speed to enable swift and reliable weighing of alternative decisions (Rauschenbach,1999/2).
Optimization methods are used for the decision making process. Thus, it is necessary to define a goal function for use in the optimization algorithm. A first possible goal function in the form of a sum criterion was presented in this paper. This will be the starting point for the next phase of the project. The planned decision support system will be developed, tested and put to use until 2008.

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Recommendations for Sustainable Groundwater Management in Tianjin Municipality,People's Republic of China
天津可持续地下水管理的建议

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Abstract

Groundwater is a precious resource which is at risk in the municipality of Tianjin as a result of excessive abstraction. Sound management is urgently required to cope with emerging problems, such as water table drawdown, land subsidence, groundwater pollution, and the management groundwater in a sustainable manner. In fact, most water-related conflicts in Tianjin result from the 'scientific water management shortage' rather than a 'resource shortage'. Scientific groundwater management should be implemented in accordance with the local hydro-geological, social, economic and cultural conditions. This paper presents the general information on these factors and proposes recommendations which target various stakeholders, such as policymakers, involved in groundwater management.

摘要

地下水是一种宝贵的资源，但在天津却由于过度开采而处于危险之中，急需有效的管理来解决水位下降，地面沉降，地下水污染等问题和用可持续的方法来管理地下水。事实上，在天津，由“缺乏科学的水资源管理”引起的水问题要远多于“水资源短缺”的问题。实施科学的地下水管理应该符合当地的水文地质、社会、经济、文化条件。本文介绍了这些方面的总体情况，针对不同的利益相关方，诸如地下水管理的政策制定者，提出了合理的建议。

1 Introduction

Approximately 95% of the total available freshwater worldwide is in the form of groundwater (Morris et al. 2003). Groundwater is a fundamental resource which provides reliable, good quality water. Tianjin is experiencing a shortage of water resources and cannot meet the demands of its socioeconomic development. These demands have lead to an overexploitation of groundwater, leading to such problems as water table drawdown, land subsidence, groundwater pollution and decreasing well yields. We need to consider how we can conserve this precious resource while taking full advantage of it for the city's development needs.

2 Background Information

2.1 Geographical location

Tianjin is situated in the Northeast part of the North China Plain. It is geographically located between 38°33′57″~40°14′57″ north latitude and 116°42′05″~118°03′31″ east longitude with its boundary bordering on Hebei Province and the capital, Beijing. Measured from the centre of the Tianjin, the city is 137km from Beijing and Tianjin plays an important role as the capital's portal as it is located to the east of Beijing *(see figure. 1below)*.

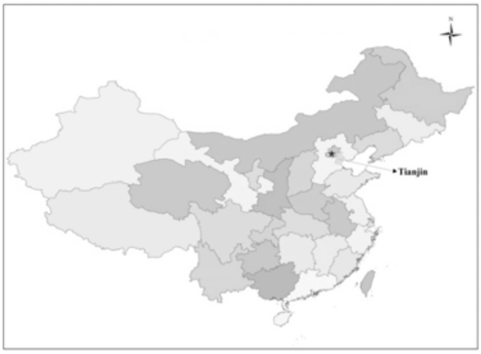

Figure 1: Geographical Location of Tianjin in China

Tianjin covers a total area of 11,919.7km^2, of which 94% are plains. Its length from north to south is about 186km and about 101.3km from east to west. It includes 15 districts and 3 counties *(see Fig. 2 below)*. Tianjin lies in a temperate zone with a semi-humid and continental monsoon climate making it ideal for observing the different seasons.

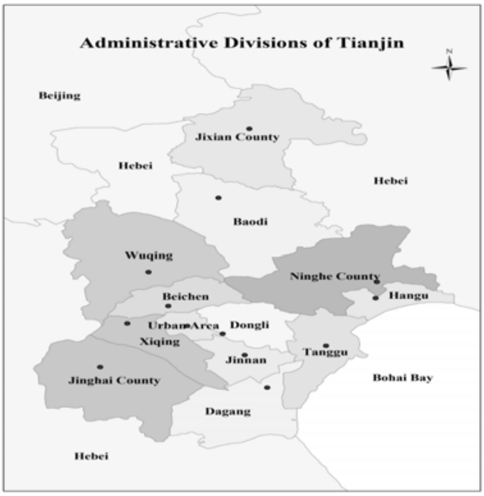

Figure 2: Administrative Division of Tianjin

2.2 Socio-economic conditions

Tianjin is one of four administrative units run directly by the central government, and acts as one of China's major ports and industrial centers. In 2002, the Tianjin municipality covered a total area of 11,919.7 km^2 with a permanent population of 10.0718 million, averaging a density of 769 people/ km^2. 58.88% of the population lives in the urban areas and 41.12% of households engage in agriculture. According to the projection of socio-economic trends, it was estimated by the Tianjin Water Conservancy Bureau that the population and gross output value of industry will increase steadily (see Figure 3).

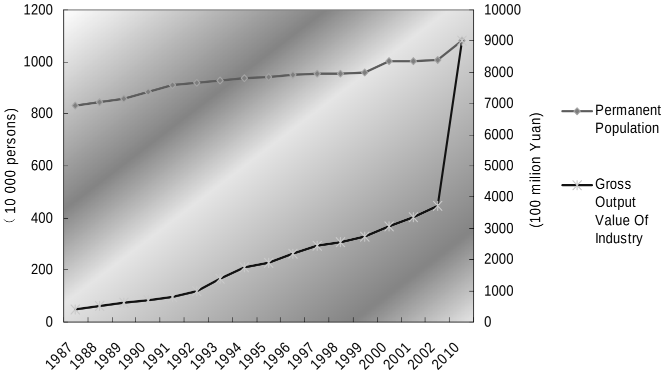

Figure 3: Trend of Population and Gross Output Value of Industry

Sources: from Tianjin Statistical Yearbook and Plan of Groundwater Resource Exploitation in Tianjin, 1997

Its Gross Domestic Product (GDP) was 244.766 billion Yuan in 2002, with a per capita GDP of 26,532 Yuan. As for the composition of GDP, secondary industry made a 50% contribution to the rise in GDP and tertiary industry has also been booming in recent years (*see Fig.4*).The main products produced in the municipality are steel, textiles, electronic equipment, and chemicals.

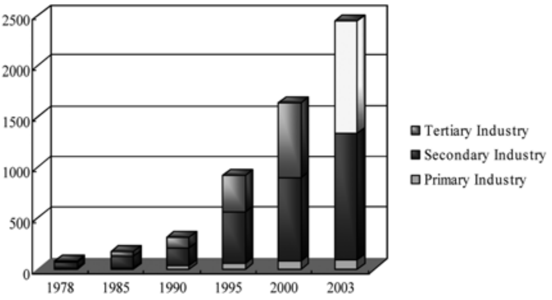

Figure 4: Composition of Gross Domestic Product in Tianjin

Source: Tianjin Statistical Yearbook

Note: Primary industry: farming, forestry, animal husbandry, and fishery
Secondary industry: industry and construction
Tertiary industry: service trade and other industries, except those mentioned above

The trends of economic and population growth suggest that socio-economic development will intensify the stress placed on the water resources and pose a huge challenge to water management.

2.3 Overview of water resources

Water resources in Tianjin are composed of surface water, transferred water, reused water, groundwater, and small amounts of seawater (See table 1, below). Based on the 1991~1995 data, the volume transferred from the Luan River was 1 billion m^3. The average total exploitable volume of groundwater is 0.827 billion m^3, 0.702 billion m^3 of which is of suitable water quality and it is mostly located in areas outside the urban center.

Table 1: Water supply reliability in Tianjin **Unit: 100 million m^3**

	F=50%	**F=75%**	**F=95%**
Surface Water	10.01	6.81	2.41
Transferred Water	7.50	7.50	4.13
Groundwater	7.02	7.02	7.02
Reused Wastewater	1.82	1.82	1.82
Others	0.54	0.54	0.54
Total	**26.89**	**23.69**	**15.92**

Source: Indicators for the Evaluation of Wastewater Discharge Policy in Beijing Tianjin Region

Note: Frequency=50%: Water inflow reliability for a normal year
Frequency =75%: Water inflow reliability for a moderately dry year
Frequency =95%: Water inflow reliability for a dry year
(Surface water volume is a variable. In probability statistics, a group of variable can be clearly described with frequency.)

Water resources in Tianjin are badly deficient, with per capita natural runoff volume of about 160m^3. This makes Tianjin rank as one of the most seriously water-deficient places in all of China. Tianjin is required to transfer water from the other watersheds, mainly from the Luan River in the adjacent Hebei province, and in emergency situations, water is transferred from the Yellow River.

Below is a projection of water demand and supply in Tianjin (See table 2). At present, the water demand and supply can hardly maintain a balance. However, it's estimated that supply and the demand could potentially maintain equilibrium in the future thanks to efforts such as the South-to-North Water Transfer Project, water saving schemes, wastewater recycling, and other measures that will be taken.

Table 2: Water demand and supply balance Unit: 100 Million m^3

Year	Reliability	F=50%	F=75%
2000	Demand	41.94	41.94
	Supply	29.92	29.92
	Shortage	**-12.02**	**-12.02**
2010	Estimated Demand	48.46	50.23
	Estimated Supply	50.23	45.64
	Shortage	**1.77**	**-5.48**
2020	Estimated Demand	54.21	56.87
	Estimated Supply	55.10	51.33
	Shortage	**0.89**	**-5.54**
2030	Estimated Demand	57.77	60.43
	Estimated Supply	62.61	59.66
	Shortage	**4.84**	**-0.77**

Source: Geological Survey and Research, 2005

Note: F=50%: Water inflow reliability for a normal year
F=75%: Water inflow reliability for a moderately dry year
F=95%: Water inflow reliability for a dry year

3 Groundwater Management in Tianjin

3.1 Characteristics of the groundwater

Based on the types of groundwater, there are two hydro-geological areas; the mountain areas with crevice water in bedrock and the alluvial plains, which can be divided into interstitial water (water between clay and sand) areas with whole freshwater and the interstitial water areas with deep freshwater, which are covered by salty water on the surface (see Figure 5).

(1) Mountain areas with crevice water distribute in the northern mountainous areas of Jixian County cover an area of 727km^2.

(2) The geological fracture zone divides the alluvial plains with two parts, the north which is a fresh water area, and the south which is a salty water area.

The exploitation and utilization of groundwater plays an important role in the economic development of Tianjin. Groundwater accounts for about 30% of the total water supply in Tianjin, and 50% of groundwater is used mainly for agriculture.

Figure 5: Geographical Demarcation of Groundwater in Tianjin

3.2 Overexploitation-induced problems

3.2.1 Ground subsidence

The main reason for ground subsidence is the long-term overexploitation of groundwater. There are several subsidence areas in Tianjin (See Fig. 6). Nowadays, some areas continue to subside because there are no alternative sources of water available. In contrast, the ground subsidence in Tanggu District and in urban areas has been greatly alleviated since 1983 by the transfer of water.

Figure 6: Land Subsidence Areas in Tianjin

3.2.2 Groundwater pollution

It is easy for the shallow groundwater to be polluted by surface water pollution and domestic and industrial sewage. Especially in Wuqing County, where wastewater irrigation has been practiced for a long time, the shallow groundwater is very polluted.

There are two reasons for the deep groundwater pollution. One is the poor quality of wells that allows the mixture of salty water and freshwater, and another is the abandonment of wells which then provide a natural entryway for pollutants and salty water to enter into the deep aquifers. Statistics shows that the total number of abandoned wells reached 35,746 by 1997 and 34,246 of the wells were located in the suburbs and designated for agricultural use. The use of groundwater for agriculture is free of charge in Tianjin and as a result there is no measuring device to measure exploited volume. The digging of wells in the suburban areas is at farmer's discretion and as consequently, the abandonment of the wells is at their discretion as well.

3.3 Policy response and effectiveness

Management of groundwater began in the 1970s. Later, the main regulation on groundwater management, the 'Temporary Regulation on Groundwater Resource Management in Tianjin', which is still in effect, was promulgated in 1987. Accompanying this regulation was a supporting regulation that came out at the same time, the 'Regulations on Levying a Groundwater Fee in Tianjin'.

These main regulations, enacted in 1987, regarding groundwater management have lagged behind the needs of groundwater management. Over the nearly two decades since the laws were passed, the groundwater and the municipality of Tianjin have changed a lot. There are certain reasons that these regulations have been unable to adapt with the changing situation. Firstly, the regulation is not comprehensive enough and it actually provided barriers for groundwater management. Another reason is that some articles are problematic in themselves. For example, it was prescribed that the groundwater for agriculture be free of charge. In fact, this regulation has been more beneficial to industry and not able to target agricultural needs. The Tianjin Water Conservancy Bureau has been amending the current temporary regulations since 2001, has submitted the revised regulations to the government in 2005 and is currently waiting for its approval and implementation.

4 Recommendations for Sustainable Groundwater Management

4.1 Optimal combination of different polices

The optimal combination of different policy measures can maximize the effectiveness of groundwater management. The review and adjustment of existing policy measures is crucial to adapting to the changes in the socio-economic and environmental context in Tianjin. Successful groundwater management is a function of the integration of different policy measures with local situations. It is also important that groundwater management be regularly reviewed and updated to meet the policy needs that can change over time (IGES).

4.1.1 Legislation

At present, the reality that laws and regulations are not exhaustive and specific is not only a problem in Tianjin, but also the rest of China. Take the “Temporary Regulation on Groundwater Resource Management” for example. This regulation has been in effect since the 1980s and has not been able to adapt to the new socio-economic conditions or the new state of groundwater resources. The need for river basin management in the future also highlights that there are no specific laws and regulations supporting this goal. The management of groundwater should be able to adapt and change in pace with the city.

4.1.2 EIA and SEA

The Environmental Impact Assessment (EIA) and the Strategic Environmental Assessment (SEA) should be implemented at all levels of water resource exploitation and utilization. EIA has been put into practice for years in China, while SEA just started.

4.1.3 Urban planning

A groundwater exploitation plan should be consistent with and an integral part of urban planning. Urban planning should incorporate measures to conserve groundwater.

4.1.4 Qualification Management on Groundwater Exploitation

Engineering construction standards of groundwater abstraction and the management of abandoned wells would benefit groundwater protection. The wells’ quality depends on the engineering and design so it must be assured that the construction companies are held to high standards.

4.2 Control the use of groundwater for agriculture

In the case of Tianjin, 50% of groundwater is used for agriculture. At the same time, agricultural activities have negative impacts on groundwater quality. Therefore an examination of the use of groundwater for agriculture will be a key factor in achieving sustainability.

In principle, groundwater use should be controlled to prevent the excessive extraction and its associated problems. However, control of groundwater extraction remains insufficient in the agricultural sector. A registration system for groundwater extraction has been implemented for sectors other than agriculture. The registration system should be encouraged for the agricultural sector as well. In addition, the use of alternative water resources should be encouraged.

4.2.1 Virtual Water Strategy

Due to the water scarcity in Tianjin, it has been very difficult to supply enough water for large plantation areas. A virtual water strategy may work as a way to solve this dilemma, which means the water-shortage region or country import water-intensive productions from water-rich region or country to gain local water security and food security.

4.2.2 Water Saving

Water saving is an effective measure to help mitigate the conflict between water supply and demand in Tianjin. Regulatory measures that support the introduction of water conservation technology should be promoted.

4.2.3 Fertilizer Reduction

Fertilizer use in agriculture is believed to be the main cause of nitrate contamination.. Measures to address this issue should be directed at the farmers directly but rather seek a longer term strategy. Capping the inputs of fertilizers may be one alternative as was done in Japan. In conjunction with the necessary technical improvements, a capping policy should be encouraged.

4.2.4 Alternative Water Sources

- Salty Water Utilization
- Desalted Seawater
- Reclaimed Wastewater
- Rainwater and Flood Utilization
- Transferred Water

4.3 Economic incentives

4.3.1 Comprehensive Water Fee

As we know, the rational water fee should be determined by market forces. However, the water fee structure should also reflect policy positions on water resources management.

4.3.2 Rationalized Groundwater Fee

At present, the groundwater fee is conspicuously low, which obscures the real value of the resource. The groundwater fee for industrial use is far lower than tap water, agricultural and rural domestic uses. Industry is levied a nominal fee or enjoy an exemption altogether all of which has undoubtedly encouraged groundwater extraction. Thus, it is necessary to set up a rational water fee system to assist water management comply with the rules of economics.

4.3.3 Different Purpose, Different Fee

In addition, water fees should differ depending on the user. For example, to encourage shallow groundwater and salty water utilization in salty water areas, fees on exploiting these kinds of water should be lowered, and the tap water fee for ground recharging should also be adjusted. Now tap water fees contain a wastewater treatment fee. This fee is 0.6 Yuan[1] per m^3 for domestic user and 1 Yuan per m^3 for the other users. Recharging is mainly dependant on the tap water, but users who use tap water for recharging has to pay the same as other users. Since they do not generate wastewater, they don’t have to pay the fee covering cost of wastewater treatment.

5 Recommendations for Overcoming Barriers to Implementation

5.1 Rational institutional framework

As we know, it is difficult to divide ground water from surface water. The rational use of groundwater is closely related to the management of surface water resources. There is a

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[1] Editor’s note: 1 Yuan=0.12458 USD, according to the currency exchange rate of 10 June 2006.

need for a unified approach to water management and this depends on a rational institutional framework. The rational framework can be separated into two sections, the implementation and administration section and the supervisory section and into three main levels, the national, river basin and provincial levels.

5.2 Unifying the water management

There is more than one institute that has different and sometimes overlapping responsibilities for groundwater management. In Tianjin, the *Tianjin Environmental Protection Bureau* is responsible for the qualitative side of water management while the *Tianjin Water Conservancy Bureau* is mainly responsible for the quantitative side of water management. Additionally, the surface water and groundwater is managed by the T*ianjin Water Conservancy Bureau* while the geothermal water resources with a temperature of more than 40 belong to the *Tianjin Planning and Land Resources Bureau*. There is very poor coordination between the bureaus. They seldom share information and instead blame each other for failures. This institutional arrangement becomes an obstacle to the implementation of holistic planning and implementation.

Therefore, there is a need to unify water resource management. An agency should be established and reinforced to direct the coordination and facilitation of groundwater policy-making and implementation.

5.3 Policy support

Lack of water resources in general makes it difficult to alleviate the ongoing abstraction of groundwater. Alternative water sources, such as transferred water, recycled water, and desalinated seawater, as well as others, are needed. Attempts to save water should be pursued simultaneously. Related policies encouraging these activities should be created. For example, governments encourage the use of shallow freshwater and salty water resources while providing no other policies to support this proposal. On the contrary, some policies actually serve to undermine the original policy. Policies should aim for preferential treatments, such as assigning preferential water prices that support policy goals.

5.4 Reliable information

Reliable information is essential for effective policy-making and implementation. However, the relevant information on groundwater is hard to obtain. Even if there is information available, it is not well organized and shared among relevant stakeholders. This situation concerning groundwater information makes groundwater management difficult.

Therefore, the monitoring of groundwater quality and quantity should be regularly conducted and properly organized so that the data can be readily used for policy-making and research. International cooperation in understanding more about the state of groundwater as a resource should be encouraged in order to improve the capacity to manage the knowledge.

5.5 Dialogues between relevant stakeholders

One of the reasons that problems arise in water resources management is the lack of intercommunication and proper understanding between relevant stakeholders. Different information results in different policy which could result in conflict. Thus, it is of great importance to communicate and harmonize departments and stakeholders.

The stakeholder meetings that were organized in Tianjin showed that such gatherings were helpful in enhancing awareness of groundwater issues and mutual understanding among the stakeholders. Therefore, stakeholder meetings should be used within the management process to overcome the many potential barriers to success.

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Rainwater for Karst Groundwater Replenishment in the Urban Development Area of Jinan City

雨水对济南城市开发区
喀斯特地区地下水的补充

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Abstract

Jinan is known as the city of springs. An integrated system of four groups of springs, connected via a channel to Daming Lake, forms a beautiful urban landscape. The springs are not only naturally beautiful but are also part of the cultural heritage. The Karst groundwater aquifers around Jinan have good storage formations which provide large amounts of high quality groundwater for domestic and industrial needs. However, the springs often stopped flowing during the 1980's and 90's due to overuse of the groundwater. Urban expansion increased sharply since the 1990's. Larger sealed areas reduced the infiltration of rainwater to groundwater, causing the increase of surface runoff and leading to increased pressure on the flood controls at the lower reaches of the river. The urbanization in the southern mountain area, which used to be a recharge area, has affected the underground water recharge This paper discusses different measures of limestone groundwater replenishment by rain water and the concomitant legal regulations to safeguard research, policy, planning, design, implementation and management of groundwater replenishment by rainwater.

摘要

济南以泉城著称。城区的四组泉水通过一个完整的系统构成了一道美丽的风景，它们通过一个渠道与大明湖相连。它们不仅是自然美景也是文化遗产。济南市有很好的喀斯特地下水含水层储水结构，给家庭和工业用水提供了大量优质的地下水。然而，由于地下水的过渡使用，这些泉水在20 世纪 80 年代和 90 年代经常断流。巨大的密封区域减少了雨水对地下水的渗透，地表径流的增加引起了河流下游防洪的巨大压力。南部山区过去是地下水的补给区，但这一地区的城市化影响了地下水的补充。本文讨论了利用雨水对石灰石地形进行地下水补充的不同方法及相关法规来保障雨水补充地下水的研究、政策、计划、方案、实施和管理。

1 Introduction

Water resource scarcity in the towns of Northern China is getting more serious. The availability of water resource is being further reduced by surface and groundwater runoff due to human activity. For example, variation in the underlying surface water of urban areas has changed the natural hydrological cycle. With an increase of sealed areas, the quantity of soil water and groundwater replenishment has decreased and surface runoff has increased. It is effective to use rainwater directly for the artificial replenishment of groundwater. Rainwater is lightly polluted, is easily treated, contains low levels of organic pollutants, dissolves oxygen close to saturation, and has a low calcium content and less total hardness. It can be used for drinking water, service water and industrial water after being treated. Compared with treated domestic waste water recycling, the cost of rainwater use and artificial replenishment of groundwater by rainwater is cheaper, the technical flow is simpler, the water quality more reliable, and has lower rates of bacterial and viral pollution. Furthermore treated, purified rainwater is even more publicly acceptable. Although air pollution and materials under the surface can affect the quality of rainwater, the quality is mostly quite good and it will be a reliable water source for groundwater as long as the problem of the initial flush of rainwater can be solved. Thus, rainwater plays an important role in urban sustainable water resource use and ecological restoration.

In general, there are two kinds of artificial groundwater replenishment. The first is the building of ditches, canals and ponds over highly permeable soil in which a layer of water enters the aquifer through infiltration by gravity. Another one is replenishment or injection by wells. The former is the simplest form of artificial replenishment of groundwater. The latter is suitable for less permeable soil layers on the earth’s surface, or where land prices are expensive or where there are no large stretches of land available to store water, or replenish water to deep aquifers. The technique of Aquifer Storage Recovery (ARS), which is used for ground aquifer replenishment and reuse, is generally recognized internationally. The basic process is rainwater or treated domestic waste water is harvested prior to pretreatment，replenishment，withdrawal and reuse. There is a long history of replenishing phreatic water aquifers through a highly permeable soil layer. But, artificial replenishment of groundwater has made great progress over the last twenty years and has accumulated experience in supplying drinking water and maintaining a high standard of waste water treatment. Dillon *et al.* analyzed over 70 cases of artificial replenishment of groundwater in ten countries with replenishment levels ranging from millions of m^3 to tens of millions m^3. According to the data, 38 of 40 cases were technically feasible. The core problems were the clogging of replenishment wells and guaranteeing that groundwater would not be polluted.

Australia, Germany, India, France and Japan are countries that have implemented artificial replenishment of groundwater in order to solve their water resource shortage. The share of artificially replenished aquifers is 20%, 15% and 10% of the total water supply in Sweden, The Netherlands and Germany respectively. The ASR program is being carried out in the U.S.A. There are a total of 100 ASR systems built and as of July 2002, 56 were in use. A study on rainwater harvesting and use in Beijing, Shanghai, Dalian, Harbin, and Xi’an was carried out. Beijing has taken the lead due to the seriousness of its water scarcity. The Chinese and German joint project on the use of storm water and groundwater replenishment in urban areas was carried out between 2000 and 2004. In the 1980’s and 90’s, the project studied urban rainwater harvesting as well as the engineering elements required in the application were examined on different scales. Some countries with more advanced technology have started the process of standardization and industrialization in these fields. For example, standards for rainwater use, called DIN1989, were published in Germany in 1989 which included the standards for design, construction, operation, management, filtration, storage, control and monitoring for rainwater use in residential and commercial areas. The second generation of rainwater technology appeared in 1992. After 10 years, the third generation of rainwater technology was developed. Artificial replenishment of groundwater was popular in China in the 60's and 70's. It was a main measure to prevent ground-subsidence and sea water intrusion in the coastal cities of eastern China. This technology was not extended throughout China due to wells being choked up with silt. The Chinese and German joint pilot study on artificial replenishment of groundwater by treated waste water through the Soil Aquifer Treatment system was carried out in the early 1990's.

The Sino-German joint scientific project on the sustainable use of urban water resources, particularly storm water harvesting and groundwater replenishment, started in Beijing in September 2001. The purpose of the project was to retain storm water on the ground or underground and to establish a compatible industry around this initiative. Germany has been foremost in the world in research on integrated rainwater use. The construction and measurement of a decentralized groundwater replenishment system by unpolluted rainwater was completed in 1990. The standard of the design, construction and operation for groundwater recharge by rainwater was then presented in 1999. Groundwater replenishment by rainwater is also protected by legislation and storm water use projects are encouraged in new estates (housing, factory and commercial areas). The government could impose a fee on storm water discharge as an incentive for reuse. In Japan, the technology for using rainwater for service water is well developed and groundwater replenishment is being enhanced.

Subsidence has been controlled by reducing groundwater withdrawal and increasing groundwater replenishment in Shanghai over the last 20-30 years. The study on the testing and prediction of artificial groundwater replenishment was carried out in Shenyang from 1987-1991. The study on groundwater replenishment through injection wells proved effective for agricultural irrigation and was carried out by the Institute of Water Resources and Hydraulic Power Research in the Daxing county of Beijing, with some success from 1986-1990. Testing and investigation of artificial deep groundwater replenishment in the Dechen district of Dezhou was carried out by the North Shandong Institute of Geological Survey in 2002.

So far, there has been little local research on the use of rainwater to replenish Karstic groundwater in urban, developed, semi-arid areas. Further research is needed on the artificial replenishment of limestone groundwater by rainwater because of the many issues involved, such as rainwater quality and quantity, the influences on rainwater runoff quality and quantity by underlying surfaces, hydro-geological formations and rainwater storage and replenishment wells. The purpose of this paper is to establish technical guidelines and/or standards. The following is an example of rainwater use and Karstic groundwater replenishment by rainwater in the city of Jinan, Shandong Province.

2 Analysis of Necessity and Feasibility of Karst Ground-water Replenishment by Rainwater in the Urban Development of Jinan

2.1 The important role of direct rainwater use for flood control

As the urbanization of Jinan has progressed, impervious surface area has increased. The statistics show that the urban area increased from 26 km^2 in 1949 to 278 km^2 in 2004. If the sealed area covers 70% of new urban developments, an increase of 470 thousand m^3 per new increment of 1 km^2 will be produced, more than the natural capacity can cope with. Natural gullies and river courses are now used for urban drainage in Jinan. All rainwater and a portion of domestic sewage are discharged into the Xiaoqing River. Presently, flood prevention tactics have not resulted in adequateflood protection for the past 50 years. In addition, many places are in gullies occupied by buildings and debris. If the gullies downstream are enlarged, the cost of flood control will be high and increasingly difficult to control. Thus, rainwater use is a primary measure needed to reduce downstream flooding in Jinan.

2.2 Karstic groundwater replenished by rainwater plays an important role in water supply and protection of the springs

The groundwater in the Karst regions of Northern China is mostly karst water fissure. The solution fissure is the main part of the karst fissure groundwater system and consists of an interdependent network. The aquifers belong to Ordovician and Cambrian systems. Karst fissure water has been a main source for the urban water supply in Northern China. Around half of the urban water supply comes from groundwater in Shandong Province. The area of limestone rock is 18,014 km^2, of which the exposed karst area is 15059 km^2 covering the cities of Jinan, Zibo, Tianan, Zaozhuang, Jining and Linyi. Karst groundwater plays a key role in supplying urban water in those cities.

The existing conditions for karst groundwater aquifers are good and there are excellent conditions for a groundwater feeder. The discharge from the four groups of springs to the urban area is originally sourced from rainfall infiltration into the groundwater in the southern mountainous area. Urban development has caused the rainfall infiltration to groundwater to be reduced by at least two-thirds, directly affecting the spring’s water flow. In the past, urban development expanded toward the southern mountainous area and many buildings were constructed. Although an extension of urban development towards the southern hills was controlled during Jinan’s overall development planning, it was not forbidden. The urban development continues to invade and occupy land near this area. So, in the groundwater replenishment area, rainwater is harvested and used for groundwater replenishment in the projects constructed as part of the new developments in order to fully utilize the improved groundwater feeder conditions, ease the conflict between controlled urban development and protection of the natural springs and strive for harmonious ecological, economic and social development. According to the analysis of rainwater samples, the quality of rainwater is comparatively better. The factories are located in northern Jinan and in the southern mountainous area, the direct groundwater replenishment area. In summer and autumn the prevailing winds are southwesterly and as a result there are few pollutants in the atmosphere. However, during the dry season, atmospheric pollutants accumulate on roofs and road surfaces. As long as the first flush of rainwater is treated well, the quality of rainwater can be managed.

2.3 The economic and ecological benefits of using rainwater

The project on groundwater replenishment by rainwater is small in scale and requires little investment, has a low operational cost and high ecological benefits compared with other large scale water sourcing options.

3 Objective and Concept

The objective is not only to use rainwater technology as a way to recycle water in order to meet the demands of urban production and living but also to play a part in the water recycling process, targeting urban areas with large populations and where impervious surface areas have increased. The overall concept is to use rainwater as a source of water. Rainwater will be retained and used to replenish groundwater so that the urban water supply will increase, urban surface runoff will be reduced and ease the pressure on flood protection facilities thus decreasing the need for investment in flood protection, resulting in lower flood-related losses. Rainwater use is important for sustainable development but the implementation of rainwater projects will need the support of policy and legal regulation as well as multi-disciplinary cooperation. Rainwater use is affected by many departments involved in urban development, such as different water authorities. A pilot study and demonstration project will be undertaken as a priority before 2010. As a result, a management regime will be put in place that combines existing provisions for Jinan water resources management with a development scheme in the southern mountainous area in order to control the overall city planning. The investment genesis, the types of projects and the construction, operation and management specifics of rainwater use for new developments or built projects will have to be stipulated. Until 2020, groundwater replenishment by rainwater in groundwater areas will account for 5% of karst groundwater withdrawal.

4 Planning of Project and Overall Arrangement

There are many potential approaches to rainwater use. In Jinan’s case, groundwater replenishment by rainwater project, the rainwater runoff reduced by infiltration and the rainwater directly used for service water are concentrated in the karst groundwater replenishment region.

4.1 Primary project approach

4.1.1 Project: karst groundwater replenishment by rainwater

Considering the geo-hydrological conditions of different urban development projects, a reasonable site must be selected. Planned or existing urban drainage systems will be combined with the project and in the developments, artificial groundwater replenishment wells will be constructed. The rainwater from roofs, after being processed through pretreatment and storage facilities, will be fed into the karst groundwater or into an injection well. Surplus rainwater exceeding the percolation ability of an injection well will be directed into the urban storm water drainage system.

4.1.2 Rainwater infiltration project

Artificial permeable pavement surfaces such as embedded grass brick, gravel roads and permeable concrete, as well as natural filtration surfaces, will be designed so that the rainwater can infiltrate into the soil and reduce storm water runoff. Natural vegetation normally has good permeability. So, the good natural permeability and water retention of green space will be taken advantage ofas well as artificial filtration facilities in order to increase the water being filtered into the soil. Green areas that are currently protruding will be converted to depressions within the groundwater replenishment areas. Better places for rainwater filtration will be designed or relocated for planned or existing parks, lawns and green areas in the front or back of houses. Shallow replenishment wells, canals and ditches and other depressions with filtration materials added will be constructed.

4.1.3 Project: Rainwater Harvesting, Storage and Use System

Rainwater is directly used independently by abuilding or buildings. Rainwater from the roofs enters the device through the mechanism of the discarded first flush, through a pipe. Then, the rainwater that passes through the discarded first flush mechanism is retained in the storage tank. After treatment, the rainwater passes through a distribution system and is used for service water needs including garden irrigation, toilet flushing, laundry and cool water circulation.

4.2 Layout and Procedures of Rainwater Use Project

The rainwater projects will be used in the developments built in the southern area and planned developments within the southern area as selected in the overall urban plan. The types and layouts of the rainwater projects are selected based on the covering stratum depth of the quaternary and properties of the underlying karst rock. The rainwater project will be implemented step by step. First, the rainwater soil filtration project will be implemented. Second, a comprehensive project of artificially recharging karst groundwater with rainwater will be carried out. Water quality control and results of the groundwater recharge should be assessed because the karst groundwater replenishment with rainwater directly influences the quality of urban drinking water. So the geo-hydrological investigation of suitable places to replenish karst groundwater and an assessment of the impact of rainwater on drinking water quality and control measures should be undertaken. Testing of pilot projects on deep replenishment wells for different geo-hydrological conditions will be implemented and the related technological standards will be established. Third, the extension and application of these findings will be implemented by 2020.

5 Establishing Policies and Regulations for Rainwater Harvesting and Karst Groundwater Water Replenishment by Rainwater in Jinan

Urban rainwater usage is just starting in China. Only Beijing has established a policy on rainwater use claiming "temporary regulation of intensified rainwater use in development project areas." The fourteenth regulations on Water and Soil Conservation Management Methods in Jinan stipulate that development should be limited to the main groundwater replenishment areas and to the northern hilly areas within the protection boundary. Sealed areas should not exceed 30% of the whole development area, as criteria for approval. The fifteenth regulations stipulate that squares, open park areas, yards, pavements and buffer zones should implement measures that favor rainwater filtration, and that sealed areas should be kept to a minimum. How to implement this was not stipulated and neither were the technological standards, funding or post-construction management plans. It is urgent for the city of Jinan, especially in its southern mountainous area, to enact regulations that allow for built or planned developments to reduce rainwater runoff and maintain groundwater replenishment that strives to mimic the natural conditions that existed prior to development. At the same time, the flood protection fee of 20 Yuan per m^2 and compensation for groundwater water percolation and replenishment reductions in urban development projects should be considered integral to the construction and management of rainwater usage projects.

6 Key Technological Problems for Karst Groundwater Replenishment in Developed Areas

Research on the early stages of artificial replenishment of groundwater by rainwater in the karst groundwater replenishment region is needed because it involves existing and future urban development projects, groundwater sources for urban areas and the very sensitive issue of the safety of urban water supplies. The purpose would be to solve the key problems and offer the technological basis governing rainwater use and karst groundwater replenishment by rainwater. The key concern regarding the replenishment of karst groundwater by rainwater is:

(a) Rainwater quality regime in the wet season and the laws of its variation;
(b) First stage rainwater flush treatment and rainwater filter treatment;
(c) Rainwater storage facilities;
(d) Geo-hydrological formations and the selection of locations for injection wells;
(e) Structure of injection wells and the storage ability of karst aquifers;
(f) Evaluation of the influence of replenished rainwater on groundwater drinking quality;
(g) Clogging of wells and surrounding karst formations because of the influences on its physical function and the chemical and microorganism activity in rainwater and Karst groundwater as well as Karst rock.
(h) Regulation and laws of karst groundwater replenishment by rainwater
(i) Risk estimation of karst groundwater replenishment by rainwater

7 Conclusion and Recommendations

Rainwater harvested from roofs is admitted into karst groundwater through replenishment wells in urban development areas in Jinan’s groundwater recharge area. This can make better use of the high permeability of carbonate rock, the short distance between the replenishment location and the springs or groundwater sources and the good quality of rainwater runoff on roofs to replenish rainwater into the limestone groundwater quickly. It will not only meet the objectives of protecting the water supply and the springs but also help to address the contradiction between the expansion of urban development towards the southern mountainous area and environmental protection and restoration. There are huge potential economic, environmental and social benefits. Much more research is required as well as cooperation between the public and private sectors in order to fully understand the role of rainwater in karst groundwater replenishment because of the many departments involved in policy making and the many technological implementations. Bringing this project to fruition will play an important role in the protection and restoration of Jinan’s natural springs.

Acknowledgements

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Use of Flash Floods for Artificial Recharge at Maan City, Southern Jordan, Cases from Arid Areas

约旦南部 Maan 城利用洪水进行人工回灌

——干旱地区的实例研究

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Abstract

In Jordan, the amount of rainfall is mainly governed by the topographic elevation of a location. Most parts of the desert areas and the southern Jordan valley receive less than 100 mm/year rainfall. Rain storm events, vary in duration and frequency in arid areas and have long term variability in time and space. Maan city is located at the southern part of Jordan, around 200 km south of the capital city of Amman. Both flat and hilly areas are located in an arid environment where the amount of precipitation is less than 150mm annually. In the early hours of the 11th March 1966, southern Jordan was affected by a severe storm which resulted in the partial destruction of Maan City. The peak discharge rate at the main flood survey site on Wadi Wuheida was 540m^3/sec. Floods of such a magnitude have not occurred again since 1966. The volume of the runoff produced during the thunder storm in 1966 is estimated at about 7 million m^3. Taking into consideration the infiltration to groundwater of the upper aquifer, water budgets of the rain storm events were estimated. To prepare more reliable figures requires more detailed field information than was available.Tahoona Well Field, located at Wadi Wuheida, supplied drinking water during the mid-1970s. Increases in groundwater extraction gradually exceeded the safe yield which caused a decline and fluctuation in the supply of the water table.The Wadi Wuheida dam and three other proposed artificial recharge sites were recommended in order to protect Maan city from the floods and aid water resource management in an arid environment.

The total of three recharge dams are planned to recharge the Campanian-Turonian upper Cretaceous calcareous aquifer called B2/A7. Furthermore these artificial recharge schemes will increase the safe yield and generally have a positive influence on the groundwater well-field that supplies the drinking water for Maan city. The recharge to the groundwater supply could occur through natural processes due to the dams especially due to the high permeability of the calcareous layers within the unsaturated zone.

摘要

在约旦，降雨量主要取决于地理位置的海拔高度。大部分沙漠地区和南部村庄的年降雨量在 100 毫米以下。干旱地区降雨的次数，持续时间和降雨的频率在时间和空间上都有很大的差异。Maan

城位于约旦南部，离首都阿曼约 200 公里。这里的平原和山区都处于干旱环境，年降雨量在 150 毫米以下。1966 年 3 月 11 日的清晨，约旦南部遭受严重的暴雨袭击，导致 Maan 城部分损毁。位于 Wuheida 旱谷的主要洪水监测站显示洪峰最大流量达每秒 540 立方米。自 20 世纪以来从没发生过规模如此巨大的洪水。这次暴雨确实非常剧烈，1966 年大暴雨之后 40 年洪水的变化能够支持这一结论。这次暴雨产生的径流量估计约为 700 万立方米。考虑到渗入上部含水层的地下水，这次降雨的水分平衡是可以估计的。想要得到更可靠的数据需要比目前更多的详细的现场信息。Tahoona 井区位于 wuheida 旱谷，在 70 年代中期作为饮用水供水系统。地下水开采的增加逐渐超过了安全出水率，从而导致了地下水位的下降和不稳定。为了保护 Maan 城免受洪水的侵袭以及加强干旱环境下的水资源管理，建议修建 wuheida 旱谷水坝和其它三项拟建的人工回灌站。这三个回灌坝计划回灌叫做“B2/A7”的坎帕尼亚-图罗尼亚地区晚白垩世时期的石灰质含水层。这些人工回灌工程将会增加安全出水率，并对过去作为 Maan 城饮用水供水系统的地下水井区产生积极影响。地下水回灌可以通过水坝的自然过程，特别是不饱和区内石灰质岩层的高渗透性来完成。

1 Background Information

Jordan is one of the arid and semi-arid regions where 90% of the country receives less than 200 mm of mean annual precipitation. Groundwater mining and groundwater quality degradation occurs in several upper groundwater systems.

Maan city had severe floods in 1966. It is located in the southern part of Jordan, around 200km South of Amman, the capital city. The area is either flat or hilly, and it is located in an arid environment where the amount of precipitation is less than 150mm/year. The existing population of Maan City is around 80 000 inhabitants.

The population of the town in 1966 had merely several thousand inhabitants with a considerable amount of sheep and chicken farms.

Flood losses reduce the asset base of households, communities and societies by destroying standing crops, dwellings, infrastructure, machinery and buildings.

2 Objectives of the Study

- To examine the influence of rainfall intensity and duration in order to create alternative protection methods for urban areas.
- To define the potential of artificially recharging groundwater through the floods in wadi systems.[1]

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[1] Editor’s note: Wadi—a mainly dry water course: a steep-sided watercourse in dry regions through which water flows only after heavy rainfalls.

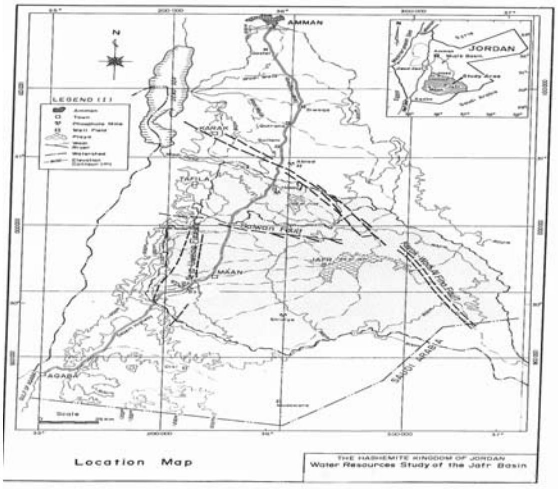

Figure 1: Location Map

3 Distribution of the Rainfall

In Jordan, the amount of rainfall is mainly governed by the topographic elevation of the location. Most parts of the desert areas and the southern Ghor receive less than 100mm/year of rainfall. Nearly all precipitation occurs between October and May.

Comparison of data analysis from adjacent stations reveals that rain storms are often very local events in Jordan. On the other hand, rainfall is highly variable from one year to another (up to 100% above or below the long term average). There are running averages of rainfall from the stations in the north, central and southern part of Jordan， which have been matched for comparison. Looking at the graphs on Figure 2 we can observe the long term averages of total rainfall as well as the rainfall variations for a period of fifty years since 1937.

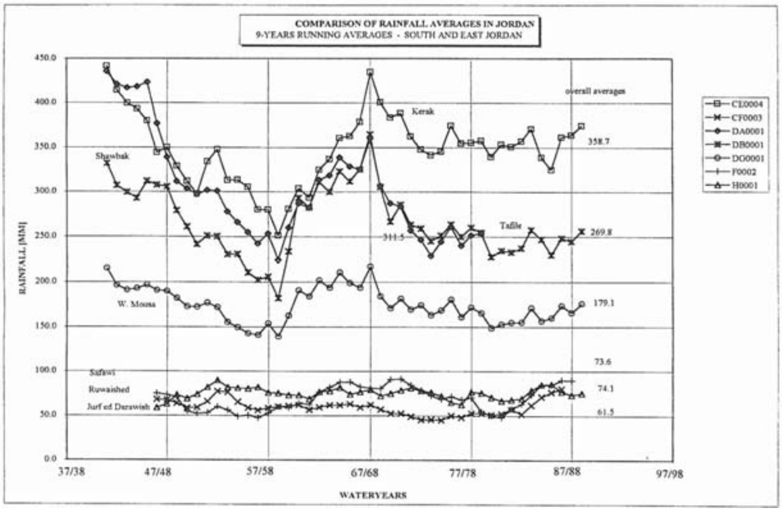

Figure 2: Comparison of Rainfall for Long Term Averages in Jordan

The study area is mainly composed of arid lands with average annual rainfall of 150mm. In the western part of the city lies a mountainous area as the extension of the catchment area. Here precipitation is higher, reaching up to 300mm annually. This main Wadi drains through several tributaries towards the city. The highest elevation of the Wadi Wuheida catchment at the western part reaches to 1700 meters above sea level. The catchment area and daily distribution of rainfall on the 11th of March 1966, the flooding day, is depicted in Figure 3.

Rain storm events and their duration and frequency in arid areas have long term variability in time and space. These parameters influence the flood's volume, flow and velocity; cause significant effects on the environment, land use, soil, cultivation and finally on development activities, investment programs and population.

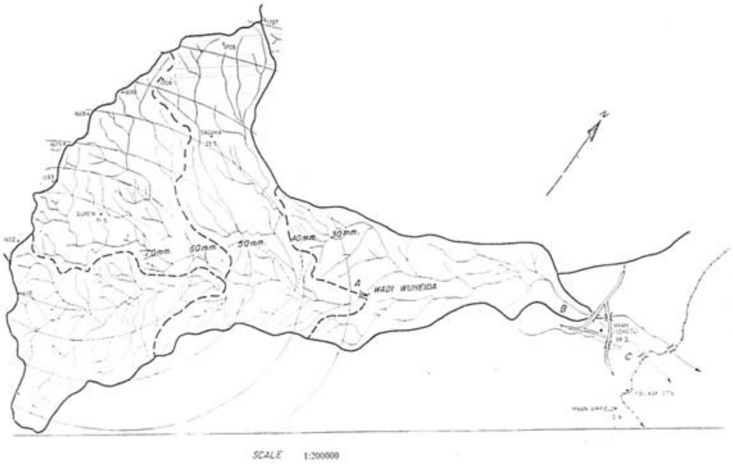

Figure 3: Catchment Area and Daily Distribution of Rainfall on March 11, 1966, the Flood Day

4 Flash Floods at Maan Town

In the early hours of March 11, 1966, southern Jordan was affected by a severe storm which resulted in the partial destruction of Maan town, current location of Maan City, with a considerable loss of life and widespread damage to the main road. During the storm, widespread thunder storms occurred along the cold front when it reached southern Jordan, so the area south and southeast of Maan received heavy rainfall. Neighboring areas in Saudi Arabia were also affected.

The following photo represents a view from the east. The arrows show the path of the flood through the town on March 11, 1966.

Figure 4: Maan Town View from the East, Post- Disaster

A flood gauging station exists near the outlet of the Wadi Wuheida and at the intersection of the Wadi with the main road of Amman-Aqaba at the bridge intersection. The monitoring station measures the variability of flash floods when flash floods occur and there is no base flow in the Wadi system.

The following photo shows the main bridge upstream of Maan Town. The branches in the embankment were backfilled. The estimated peak flow of 540m^3/sec overflowed over the bridge.

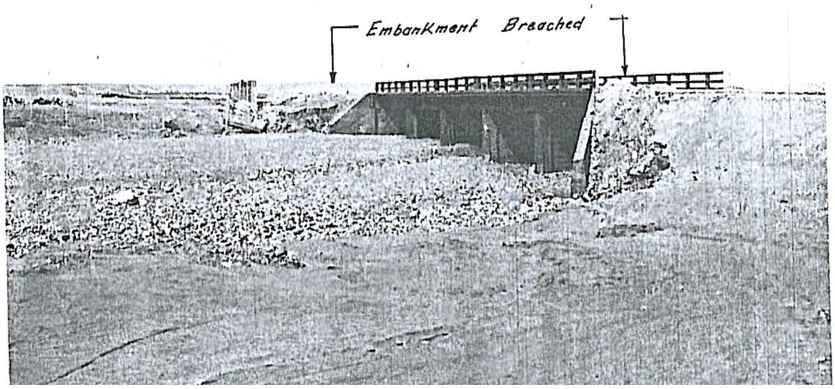

Figure 5: View of the Bridge at the Main Road of Maan Town Post- Disaster

The total rainfall amount and the time distribution of rainfall which falls during the storm were tabulated in 8 rain gauges, which clearly indicate that the rainfall level was at the degree usually associated with large thunderstorms. Sediments were also deposited in some locations on the Maan-Aqaba main road.

The flood which destroyed part of Maan occurred in the Wadi Wuheida, which flows eastwards through Maan Town. The peak discharge at the main flood survey site on Wadi Wuheida was 540m^3/sec. Since the monitoring station is located at the bridge/main road, and it has been estimated that the bridge sluice can only handle a capacity of 40m^3/sec, the remaining 500m^3/sec overflowed over the road embankment, and eventually breaching the road on both sites sides of the bridge, resulting in damage to the walls of the bridge. The location of the bridge is shown in Figure.4 as well as a general view of Maan Town after the disaster.

The occurrence of such a flood has not been recorded since before the 20th century. This storm was certainly of unusual severity, and despite the variability of floods four decades afterwards, none matched the 1966 flood.

The total runoff volume during this storm event was estimated at about 7 million m^3. The water budget of the rain storm event could be estimated by taking into consideration water infiltration to the groundwater of the upper aquifer. To prepare more reliable figures further detailed field information is required.

Rainfall intensity, duration and frequency were estimated by the Ministry of Water and Irrigation (MWI) in Jordan at several precipitation stations covering almost the whole country. Figure 6 illustrates the results collected from long term basic data monitored with an automatic recorder at a Maan precipitation station.

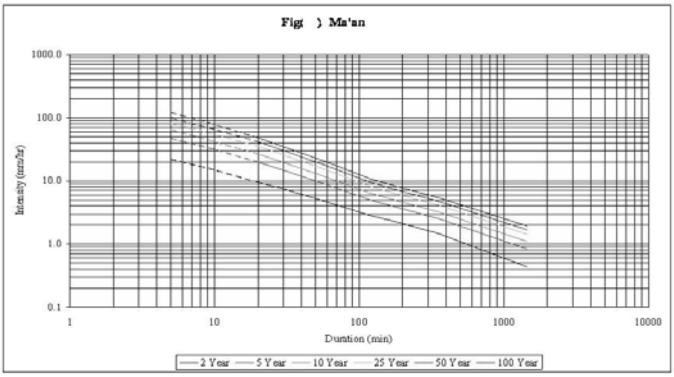

Figure 6: Rainfall Intensity, Duration and Frequency Curves for Maan Station

5 Geology and Hydrogeology

This water resources study indicates that the extension of the catchment areas of the Wadi Wuheida and Wadi Jurdhan, towards the Jafr basin depression of the Wadi, fills in the east. Actually, the Jafr basin depression is flooded from tributaries surrounding the basin, where the ponds are subjected to evaporation due to a dry environment and high temperatures in summer that exceed 35^oC. Also, the floods recharge the groundwater of the upper aquifer system (B4) at Jafr depression. This aquifer system is mainly formed from calcareous layers of chalk and marly limestone and clays with chert intercalation called B4 of Terciary age.

Also, the location map mentioned in Figure 1, indicates minor and major fault systems surrounding Maan City such as the Arja-Uweina Flecture, east of the city, which extends towards the north.

The main aquifer system named B2/A7 is comprised mainly of limestone, chalk, marl and sequential chert beds. This aquifer dates from the Campanian and Turonian ages. These units are connected hydraulically as one karstic fractured and free aquifer system, almost parallel with the surface drainage. The average hydraulic conductivity (K) of this aquifer in the area is 6* 10^{-6} m/s.

The groundwater flow of the (B2/A7) aquifer is recharged from the mountainous areas west of Maan along the Wadi Wuheida and Wadi Jurdhan towards the east, and run almost parallel with the surface drainage until the main Arja-Uweina Flecture. This flecture acts as a main barrier boundary and sharply reduces the groundwater velocity towards the Jafr depression in the east.

The Tahoona well- is located at Wadi Wuheuda. It supplied drinking water in the mid-seventies, and as a result groundwater extraction gradually increased, exceeding the safe yield and consequently led to a decline of the water table. Figures 7 and 8 depict the Tahoona dynamic water level fluctuation.

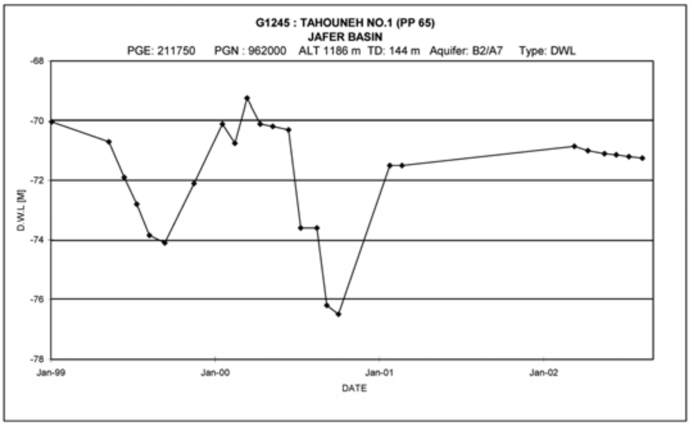

Figure 7: G1246 Dynamic Water Level Monitoring Well

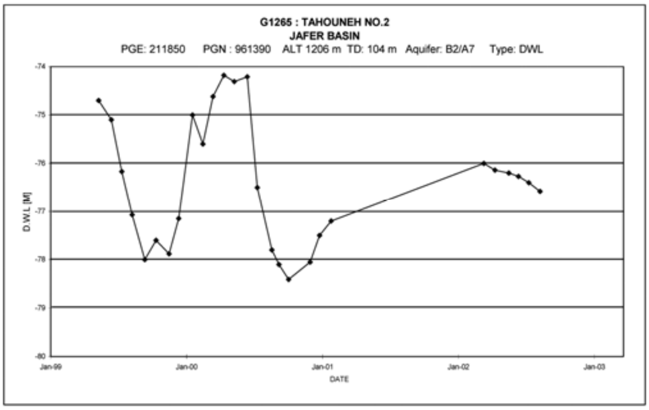

Figure 8: G1286 Dynamic Water Level Monitoring Well

6 Rainfall Basic Data Evaluation

It is understood that there is little fluctuation in the annual rainfall at Maan station within the past 69 years (1937-2006) of water monitoring. Also an approximate stability of the trend for the period (1962-2006) exists for the Basta precipitation station that represents the highland areas at the western part of the catchment (Figure 9 and Figure 10).

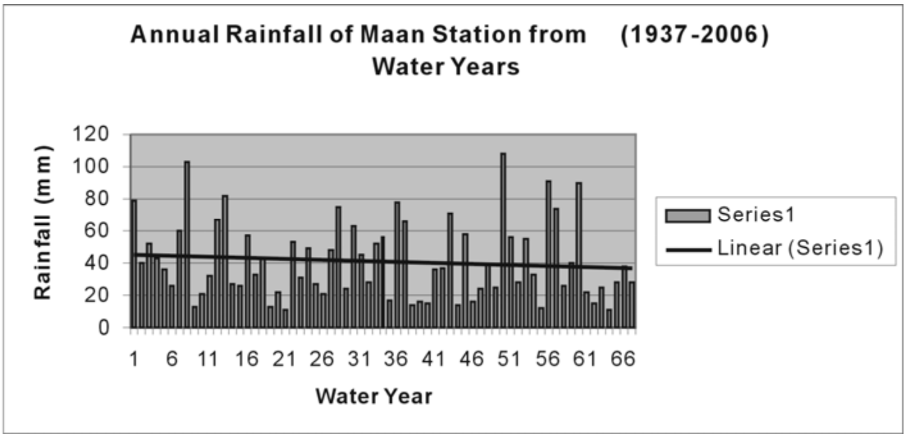

Figure 9: Annual Rainfall of Maan Precipitation Station

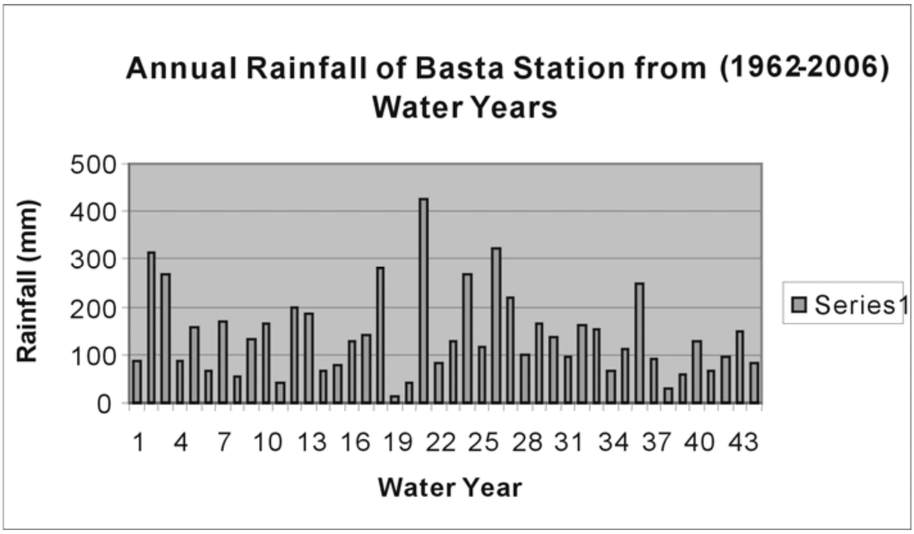

Figure 10: Annual Rainfall of Basta Precipitation Station

The daily precipitation for Maan and Basta precipitation stations, recorded over 10 years, indicates 150-165 rainy days. These findings reflect the variability of rainfall and stream flood flow that fluctuated depending on the rainfall intensity, duration and frequency (Figure 11 and Figure 12).

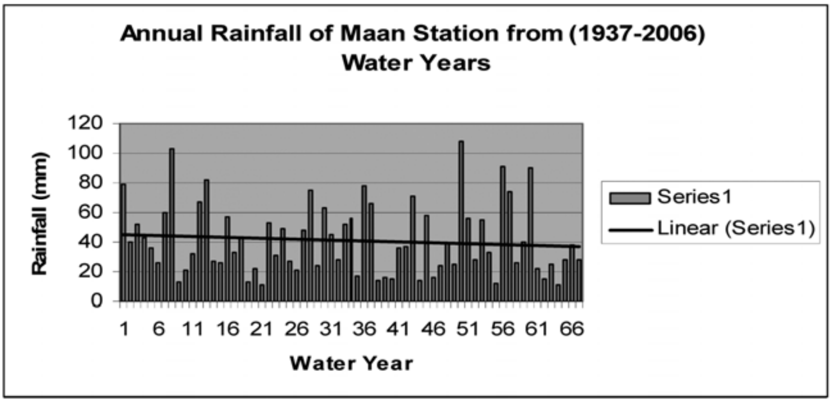

Figure 11: Daily Rainfall of Maan Precipitation Station

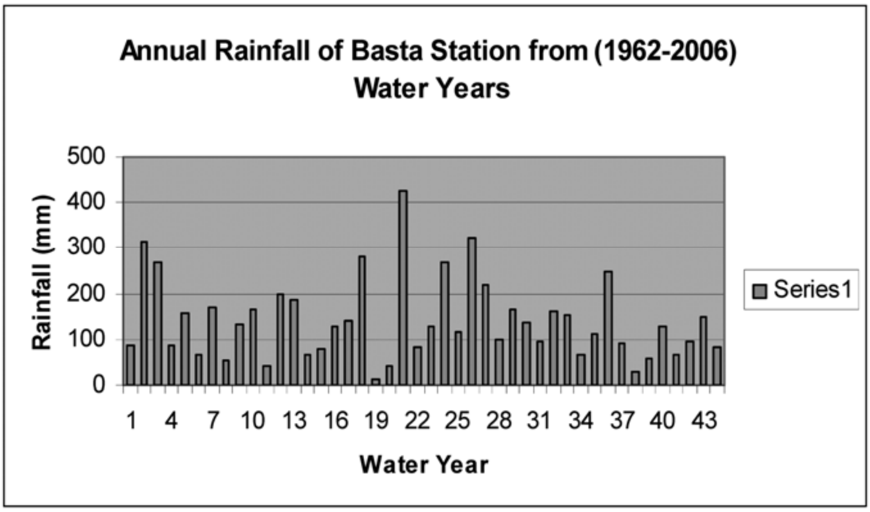

Figure 12: Daily Rainfall of Basta Precipitation Station

This is also reflected in the stream flow of Wadi Jurdhan gauging station located at a catchment neighboring Wadi Wuheida catchment area about 10 kilometers northeast.

The daily isoheytal rainfall distribution map for the catchment area that recorded the flooding event on March 11, 1966 ranges from 70mm at the western highlands areas and decreases gradually within the catchment area tributaries towards the east to about 20mm at Maan Town. The catchment area and daily rainfall distribution on March 11, 1966 is depicted in Figure 3.

The mean daily stream flow of the flood from the Wadi Jurdhan gauging station within the 20-year recording period from 1963-1982 ranged from 1-11 m^3/sec. Figure 13 illustrates where the peak flood flow intensity reached maximum levels at Wadi Wuheida, specifically on March 11, 1966 as the flood proceeded towards Maan Town. The peak discharge at the main flood survey site at Wadi Wuheida was 540m^3/sec.

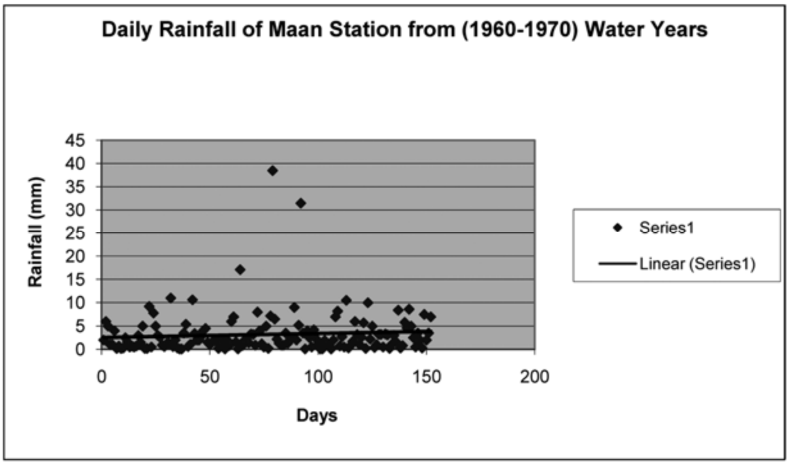

Figure 13: Daily Flood Volume of Wadi Jurdhan Gayging Station

7 Recharge Dams

Taking into consideration the water resources development and management in the basin, the recommendation is to construct either a Wadi Wuheida storage dam or three artificial recharge dams at locations B1, B2 and B3. These sites are located at the main tributaries about 15 kilometers southwest of Maan City, as shown in the location map.

Usually the recharge to the groundwater occurs by natural infiltration along wadis in the western highlands. The proposed recharge dams mentioned above could serve both purposes: to store water from floods and to protect the existing Maan City from future rain storm events. The recharge to the groundwater system could occur through natural processes from the dams especially due to the high permeability of the calcareous layers within the unsaturated zone.

The artificial recharge locations mentioned in the table will recharge the principal groundwater system B2/A7, which is made of limestone and cherts. Also, the artificial recharge schemes will increase the safe yield and have a positive influence on the Tahoona groundwater well-field that is used to supply drinking water to Maan City.

The catchment area, annual average runoff, gross storage capacity, effective storage capacity and dam height of the recharge dams are estimated as follows: Table 1.

Table 1: Recharge dams: component

Dam No.	Catchment Area (km^2)	Average Annual Inflow (mcm/year)	Maximum Annual Inflow (mcm/year)	Gross Storage Capacity (mcm/year)	Effective Storage Capacity (mcm/year)	Dam Height (m)
B1	55.7	0.8	3.6	2.4	2.1	20
B2	135.9	1.6	8.9	4.2	3.7	19
B3	71.7	0.9	4.8			

8 Conclusions and Recommendations

- Need for emergency management during the flood (e.g. flood warnings, emergency works to raise or strengthen dikes, flood-proofing, evacuation)
- Create emergency plans in cooperation with governmental and non-governmental organizations including and particularly community based institutions is required
- The three recharge dams proposed in Wadi Wuheida storage dam could serve to integrate water resources management as well as recharge the upper aquifer that supplies drinking water and protect Maan city from potential flash floods

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Sustainable Urban Water Management for Cities Dependent on Local Aquifers: Making the Most of a Valuable Resource
充分利用宝贵的资源：针对依靠本地含水层的城市的可持续用水管理

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Abstract

By 2030 it is estimated that more than 60% of the world's predicted population of 8.4 billion will live in towns or cities. Cities large and small depend on aquifers for their water supply; about half of the world's megacities are groundwater-dependent, as are hundreds of smaller cities worldwide, including two-thirds of China's more than 500 cities. Many cities are sited on unconfined or semi-confined alluvial aquifers which possess abundant, but fragile, groundwater resources. Urbanisation has a major influence on these aquifers. These include impacts on the urban water balance, affecting recharge to, and groundwater flow within, underlying aquifers. These result from factors which include the import of large quantities of water for supply, modifications to pluvial drainage, extensive use of the ground for effluent discharge and waste disposal and large-scale intra-urban groundwater abstraction. The consequences include problems of aquifer depletion, saline intrusion, and land subsidence or, at the other extreme, locally troublesome rising groundwater levels.

Less easy to quantify are the impacts on water quality, which arise from the nature of wastewater and pluvial drainage disposal, from interaction with urban watercourses and from the effects, both intended and accidental, of intensified industrial, residential, commercial and transport land uses. Together these usually lead to widespread contamination of shallow groundwater by domestic and industrial effluent. Given the large storage of most aquifers and their long residence times, there is often a major time lag before the problems and magnitude of groundwater pollution become fully apparent. Without the foresight of informed urban water management which takes into account the rather different perspectives of water-supply provision, wastewater/solid waste disposal and engineering infrastructure development and maintenance, the net outcome will be increasing water scarcity. This will be accompanied by escalating long-term marginal costs for water-supply, especially if local aquifers need to be supplemented or replaced by those from the hinterland. These three legitimate but different and potentially conflicting functions need to be reconciled if sustainable city development is to be achieved.

摘要

估计到 2030 年世界人口预计达 84 亿，其中超过 60%的人口将居住在城镇。城市的大小取决于为他们供水的含水层；全世界大约一半的大城市和许许多多的小城市依靠地下水供水，其中包括中国 500 多个城市中 2/3 的城市。许多城市坐落在敞开或半封闭的冲击含水层上，这些含水层拥有丰富但脆弱的地下水水源。城市化对这些含水层产生了重大影响，如对城市水平衡，含水层回灌，地下水在含水层中的流动以及潜水层的影响。产生这些影响的因素包括大量输入补给水，改建雨水管，为排水和污水处理而大量占用土地，以及城市内部大规模的开采地下水。这些共同导致的问题包括含水层损耗，咸水入侵，地面沉降，或者当地地下水水位上升等某些极端的情况。

比较不容易量化的是对水质的影响，这来自于污水与雨水处理的类型，来自于城市河道的相互作用，来自于不断加剧的工业、居住、商业、和交通用地带来的有意和无意的影响。这些通常会导致生活和工业污水引起的浅层地下水的大范围污染。由于多数含水层贮藏量大，存留时间长，通常在问题出现和地下水被完全污染之前有一个很长的时间间隔。

先进的城市用水管理要考虑城市供水，污水/固体废弃物，以及基础设施的开发与维护，没有这样的远见会导致越来越多的水荒。这还将伴随着供水系统的长期边际成本上升，特别是当地含水层需要从边远地区补充或替代时。如果要实现可持续的城市发展，这三种合理但有区别，并存在潜在冲突的功能需要协调一致。

1 Background: Conflicts over Use of the Urban Subsurface Water Resources

Cities may require water for public use, private domestic use, industrial and commercial use. Whatever the mix of use and users, there is no doubt that urbanisation drastically affects local aquifer systems in terms of both quantity and quality. The first and most important factor to consider is whether the aquifer in question is located in a rural catchment relatively remote from urban activities, whether it is peri-urban and likely to be encroached upon in the near future or whether it actually underlies the city. In the first case, the resource will be affected by rural issues (which are covered in a later chapter), but for the two latter cases and for cities that depend on water from both settings, read this chapter.

Cities overlying aquifer systems use the subsurface for three main purposes:

- As a source of water supply
- For the disposal of wastewater
- For urban engineering infrastructure; pipes, tunnels and foundations, as a source of building material (stone, sand, aggregate) and as the receptor for solid waste

The first two of these functions directly affect the underlying groundwater system. The *benefits* of such use are apparent from the outset, but the *costs* are long-term, and may not be appreciated at early, typically unplanned, stages of development (Table 1).

Table 1: Benefits and costs of using the urban subsurface

Function Of Subsurface	Initial Benefits	Long-Term Costs
Water-Supply Source	- Low capital cost - Staged development possible - Initial water quality better - Private and public supply can develop separately	Excessive abstraction can lead to: - abandonment/reduced efficiency of wells - saline intrusion risk in coastal cities - subsidence risk in susceptible environments
On-site Sanitation Receptor	- Low-cost community-built facilities possible - Permits rapid expansion under sanitary conditions - Uses natural attenuation capacity of subsoil	- Sustainability of groundwater abstraction threatened if contaminant load exceeds aquifer assimilation capacity
Pluvial Drainage Receptor	- Low capital costs - Conserves water resources - Less flood risk along downstream watercourses - Roof runoff provides dilution of urban contaminants	- Contamination from industrial/commercial area and most highways
Industrial Effluent/Solid Waste Disposal	- Reduced manufacturing costs	- Noxious effluent may prejudice groundwater quality - System favours irresponsible attitude to waste stream management

The perspectives of different users performing these vital urban infrastructure functions are dissimilar, and this in turn colors what they consider to be unacceptable groundwater degradation (Figure 1):

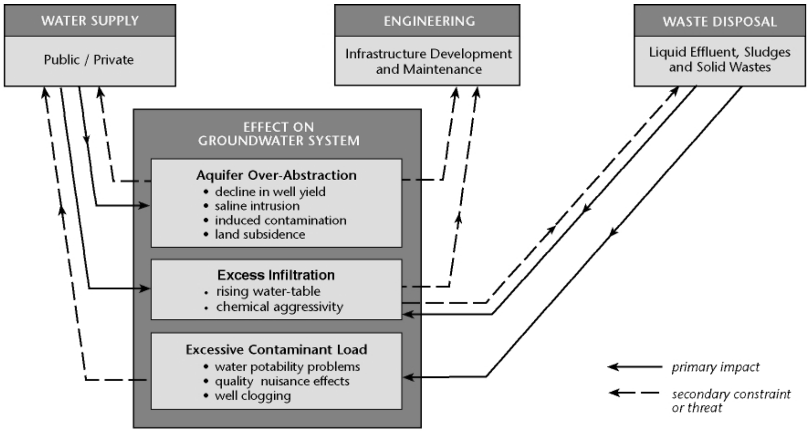

Figure 1: Facets of degradation of groundwater system underlying a city, resulting from interaction between urban services

Water-supply: Groundwater is frequently a significant source both for the municipal water utility (typically operating relatively few high-yielding wells or wellfields) and for the private sector (dispersed, ranging from individual domestic wells to large industrial supplies). In general terms they have similar interests. For both, groundwater degradation concerns centre on decreasing availability and deteriorating raw water quality, since they lead to rising water production costs, customer complaints about water quality nuisance factors, and/or to public health risks. Both sectors may also be anxious to establish or protect legal rights to abstract groundwater. However, their priorities on these problems and on the options for tackling them differ.

The municipal water-supply utilities can afford to take a broad view, and although affected by site-specific problems are most concerned about overall resource scarcity and about water quality problems that are costly or impossible to treat. They can consider developing alternative water supplies from beyond the city nucleus, into peri-urban areas and the rural hinterland. However, for many cities, public water supply price controls are as much a political as an economic issue, and this may constrain the required investment to bring in out-of-town supplies. Moreover, development of groundwater from beyond city limits may lead them into conflict with other major groundwater users, especially agricultural irrigators.

Private residential and industrial abstractors inevitably have to take a narrower view. They are primarily concerned about decreasing performance and deteriorating quality of the well(s) on the land they own or occupy. Their options for dealing with any problems that arise are limited, since they are generally restricted to the specific site concerned. They may be able to treat the groundwater supply (at least for some quality problems) or deepen their wells (in efforts to overcome problems of yield reduction due to falling water levels). Ultimately, the decision on continued use will depend upon the cost and reliability of the supply, compared with that available from the municipal water-supply utility.

Wastewater & solid waste disposal: A very different perspective comes from those concerned with wastewater elimination, even where this function is also the responsibility of the municipal water-supply company and even more so where it is organised separately.

The first issue that arises is whether it is physically possible to dispose of liquid effluents to the ground, which may not be the case where soil infiltration capacity is low, due to shallow water-table or to relatively impermeable superficial strata. This may prevent the installation of on-site sanitation units, especially water-flush systems that need to dispose of large quantities of wastewater through infiltration structures (for example septic tanks). A second set of issues is the impact of wastewater discharge and waste disposal on groundwater quality. In particular, whether:

- the type and density of on-site sanitation units is such as to seriously affect groundwater quality
- the location and quality of downstream wastewater discharge from a mains sewerage system, together with its reuse for agricultural irrigation, is such as to prejudice the interests of groundwater users
- the site location, design and operation of municipal/industrial solid waste disposal facilities is acceptable in terms of leachate impacts on groundwater quality.

For those planning and operating solid and liquid waste disposal facilities, their functions would be regarded as adversely affected if on-site sanitation systems became hydraulically dysfunctional (due either to excessive loadings or to the water table rising towards the ground surface) or if disposal activities unacceptably prejudiced downstream groundwater uses/users. These issues rarely receive adequate consideration in the absence of a properly-resourced and adequately-empowered regulatory body.

Engineering infrastructure: Municipal engineers responsible for developing and maintaining urban buildings and infrastructure need to consider changes in subsurface properties as a result of long term trends in groundwater levels. Issues include:

- falling water-table (due to heavy abstraction for water-supply): physical damage to buildings and to underground services, such as tunnels and sewers, as a result of land settlement and subsidence
- rising water-table (due to increased infiltration rates): damage to subsurface engineering structures as a result of hydrostatic uplift or reduced bearing capacity, inundation of subsurface facilities, excessive ingress of groundwater to sewers, chemical attack on concrete foundations, subsurface facilities and underground structures.

For this group of users either a high or a low water table can be designed and engineered for, but stability (or at least predictability) of variations is a prerequisite; unanticipated changes/rates of change would constitute groundwater system degradation.

Faced with unexpected structural deterioration, those responsible for maintaining the urban buildings and infrastructure want to minimize such damage or try to recover remedial costs. This is rarely achieved, since unstable water levels may be due to several factors, so attribution to individual abstractors or polluters is difficult. Typically, and unsatisfactorily, the resultant costs have to be borne by the community at large, through urban taxes or rates, or even more unjustly by the owners of the damaged properties themselves.

Managing urban groundwater degradation: So those planning and managing urban aquifers need to recognise not only that groundwater degradation can take various forms depending on the infrastructural function under consideration but also that they are strongly interrelated (Figure 1) and compromises will need to be reached. In reconciling the demands of waste disposal and urban subsurface engineering as well as those of water supply, some degree of degradation will be unavoidable. Examining the effects each have on the subsurface can help develop the integrated approach so necessary to avoid serious long-term degradation and to encourage sustainable use of the aquifer system.

2 Pattern and Stage in Evolution of a City Underlain by a Shallow Aquifer

All cities developing local groundwater resources differ in detail but for many the typical stages of development are as shown in Figure 2.
As the growing city's demand for water (and for safe disposal of wastewater) rises, so the changing combinations of supply source (from local to peri-urban to hinterland) are matched by new urban sources of recharge (losses from the piped infrastructure, on-site sanitation and pluvial drainage).

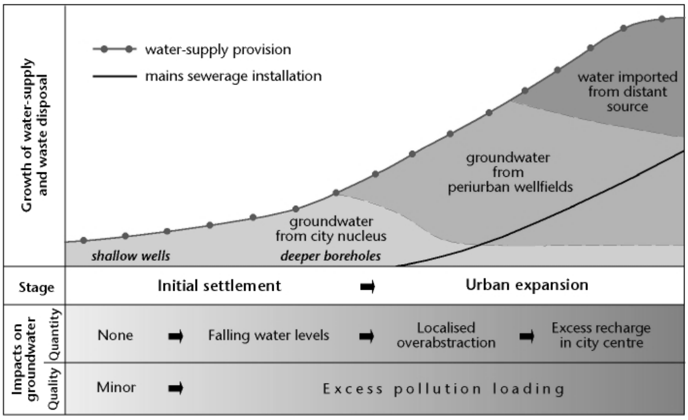

Figure 2: Stages in evolution of water infrastructure of a city overlying productive aquifer

Subsurface water levels both within the city and outside undergo major changes as the twin pressures of competing demand for water and quality concerns shift supply emphasis from city centre to peri-urban areas (Figure 3).

Although this pattern can be observed in many of the world's cities, the extent and rate of change will be highly variable, depending on the particular conditions of geology, the water supply and sanitary arrangements adopted. Nevertheless, as a general observation, the radical changes in frequency and rate of subsurface infiltration caused by urbanisation tend overall to increase the rate of groundwater recharge.

If the underlying aquifer system is not utilised, or the shallow subsurface is not sufficiently permeable to transmit away the extra water, then groundwater levels will rise. Initially as the water-table rises towards the land surface, tunnels and service ducts may suffer structural damage or be flooded, followed later by hydraulic and corrosion effects on building foundations and tunnel linings. In extreme cases, where the water-table reaches the land surface, there may be a health hazard because septic tanks malfunction and water polluted with pathogens may accumulate in surface depressions.On the other hand, where the city is underlain by a productive shallow aquifer and groundwater abstraction is significant, a declining water table will mask the presence of increased urban infiltration rates and indeed in some unconsolidated aquifers the geotechnical problems associated with pumping-induced subsidence can result.

However, as cities evolve, intra-urban abstraction often declines, either as a direct result of groundwater quality deterioration or as a consequence of unrelated economic factors. In these circumstances, the water table begins to recover and may eventually (over decades) rise to levels higher than pre-urbanisation, as a result of the additional urban recharge. This can provide a widespread threat to a well-established urban infrastructure constructed when foundation and cabled/piped services design did not need to take account of a near-surface water table. Thus the hydrogeological regime continues to exert a major control over an urban infrastructure, even when the city in question has ceased to depend significantly on local groundwater for water-supply.

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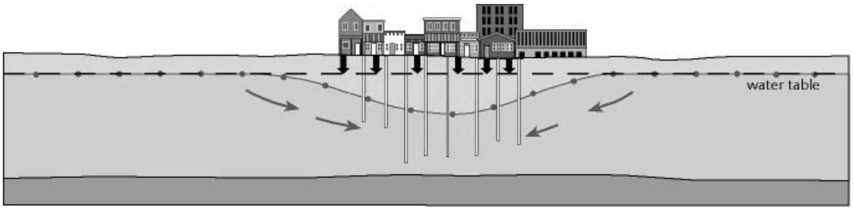
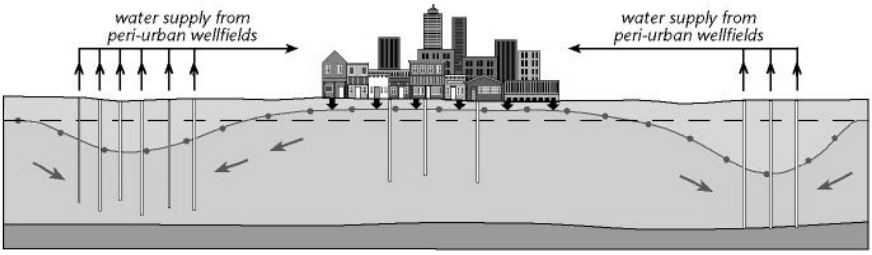


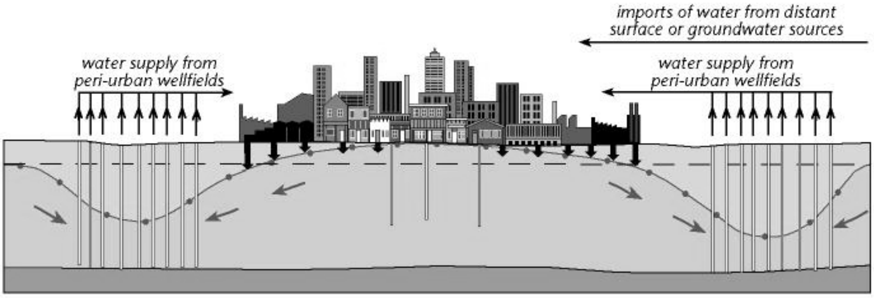
(a)
town becomes a city

- Water table lowered beneath city, wells deepened.
- Wastewater discharged to ground.
- Shallow groundwater in city centre becomes polluted.
- Subsidence can occur if aquifer is unconsolidated and interbedded.
- Expansion of pluvial drainage to ground and local watercourses.



(b)
city expands

- Aquifer beneath city largely abandoned because of contamination.
- Water table begins to rise beneath city due to cessation of pumping and high urban recharge.
- Significant water table decline in city periphery due to heavy abstraction from wellfields.
- Incipient contamination of urban wellfields by groundwater recharged beneath city centre.



(c)
city expands further

- Wellfields unable to cope with increased demand and threatened by outward growth of city.
- Expensive water imports from distant sources or conjunctive use schemes necessary.
- Water table rises beneath city nucleus - problems of flooding, wastewater disposal etc.
- Scope reduced for (low cost) pluvial drainage to ground.

Figure 3: Evolution of water supply/waste disposal in a typical city underlain by a shallow aquifer

3 Urbanisation Processes that Affect Groundwater

Urbanisation affects both the quantity and quality of underlying groundwater systems by:

- Radically changing patterns and rates of aquifer recharge
- Initiating new abstraction regimes, which may be cyclic in the long-term
- Adversely affecting the quality of groundwater.

4 Changes in Recharge Patterns

The effect on recharge arises both from modifications to the natural infiltration system, such as surface impermeabilisation and changes in natural drainage, and from the introduction of the water service network, which is invariably associated with large volumes of water mains leakage and wastewater seepage. The effects in terms of rates, area and duration are shown in Table 2. The extension of the water infrastructure may also be accompanied by the import of large volumes of water from outside the city.

Table 2 : Impacts of urban processes on infiltration to groundwater (from Foster et al, 1993)

Urbanisation Process	Effect On Infiltration		
	Rates	Area	Time base
Modifications to the Natural System			
Surface impermeabilisation & drainage:	Reduction	Extensive	Permanent
Stormwater soakaways*	Increase	Extensive	Intermittent
Mains drainage*	Reduction	Extensive	Intermittent-continuous
Surface water canalisation *	Marginal reduction	Linear	Variable
Irrigation of amenity areas*	Increase	Restricted	Seasonal
Introduction Of Water-Service Network			
Local groundwater abstraction	Minimal	Extensive	Continuous
Imported mains water-supply leakage	Increase	Extensive	Continuous
On-site (unsewered) sanitation **	Major increase	Extensive	Continuous
Piped sewerage: (leakage in urban areas)* (downstream disposal)**	Some increase Major increase	Extensive Riparian areas	Continuous Continuous

Also has (**) major and (*) minor impact on groundwater quality

The net effect for many if not most cities is a rise in the total volume of recharge, the land sealing effects of paving and building being more than compensated for by the enormous volume of water circulating through (and lost from) the city's 'water infrastructure' of pipes and from soakaways draining the built area (Figure 4). In this way for instance groundwater recharge in the city of Moscow has tripled.

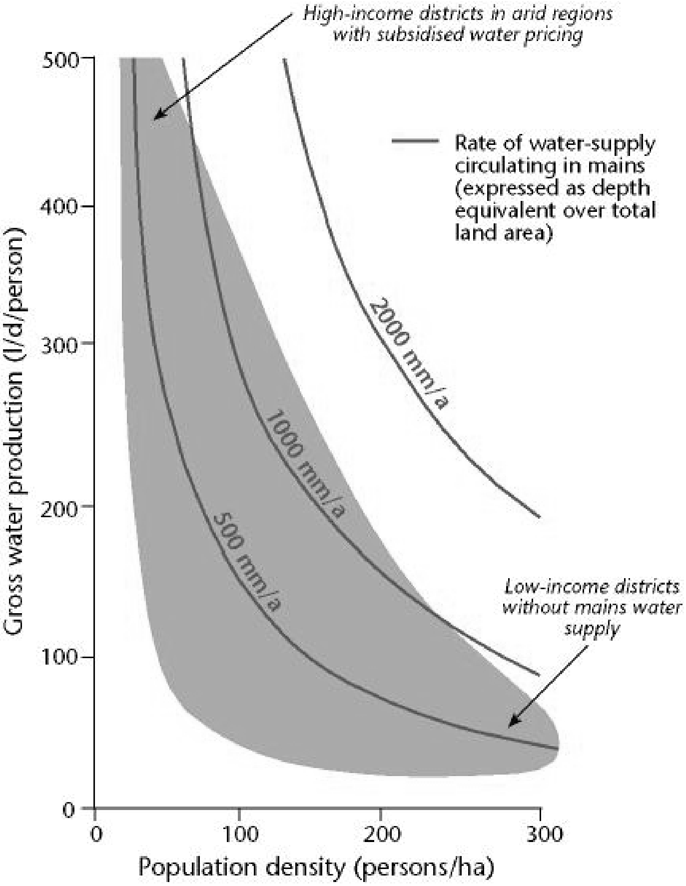


Figure 4: Hydrological equivalent rates of circulation in water supply mains in urban areas

Note: typical range indicated by shading

Several city case-studies show that the effect is most pronounced in cities where on-site sanitation and/or amenity watering is important and in arid and semiarid climates, where the new sources may increase the total infiltration several times over the pre-urban situation (Figure 5). Environmental degradation and health problems can then occur if local geological or topographic conditions impede drainage and result in groundwater flooding (Box 1).

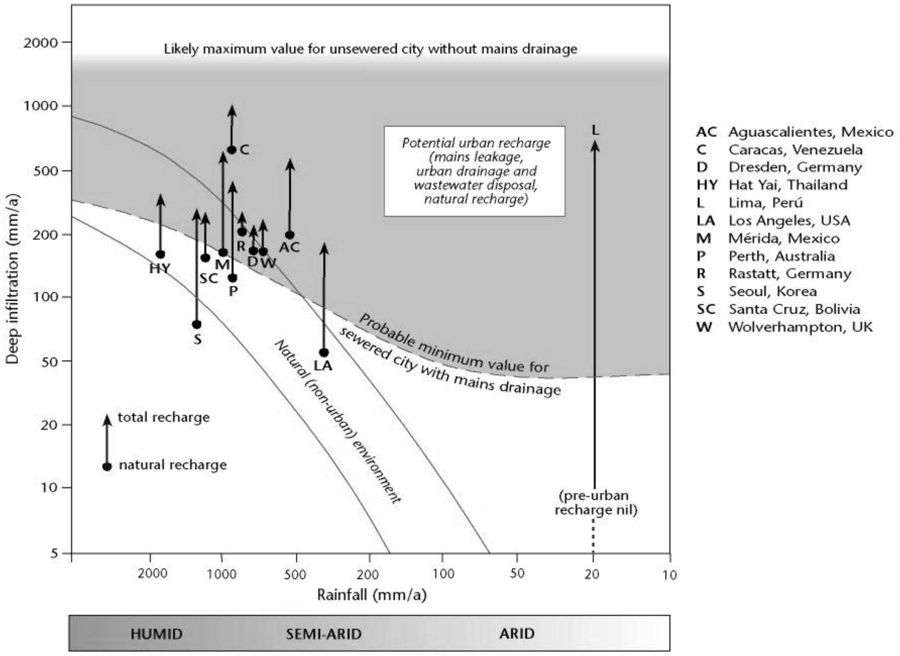


Figure 5: Increase in groundwater recharge due to urbanisation (modified from Foster et al 1993, Krothe et al 2002, Eiswirth et al 2002)

BOX 1 Patterns of urban groundwater: rising water levels

The water balance of an aquifer once its catchment is urbanised becomes much more complex due to the presence of both new potential sources of recharge and of new abstraction. This effects water levels, which rise and fall to maintain a balance between inflow and outflow. In many aquifer systems, these changes will not be immediately obvious due to the large volume of available storage, and it may be many years before they reach equilibrium with the hydrological changes induced by urbanisation. Disregard of the lag in response time between cause and effect in aquifer systems can unwittingly compound aquifer degradation effects, which can arise from changes in inflow and outflow components. An example of the problem is one of the paradoxes of arid-zone hydrology, and is seen in the waterlogging problems experienced by several Arabian cities due to increased urban recharge.

The city of **Riyadh**, Saudi Arabia grew from a town of 20 000 in 1920 to more than 1.2 million in the 1990s. Per capita consumption rates also rose, to more than 600 l/person/day in 1990. By the early 1980s, the high water demand was met by long-distance imports of desalinated water. This coincided with reduced pumping from a deep underlying limestone aquifer, abandoned due to serious pollution. New urban recharge sources have arisen from high water mains leakage rates (over 30 per cent), underground storage tank losses, percolation from septic tank systems and over-irrigation of amenities such as parks, road verges, gardens.

Waterlogging has occurred because much of the city is underlain by a shallow aquitard and adequate drainage through it cannot occur. The vertical permeability is low and there is now insufficient pumping by users from the deep aquifer system to provide a vertical hydraulic gradient to induce leakage from the overlying aquitard. The waterlogging has caused deformation of basements and pipe networks, and dewatering equipment was required to alleviate flooding. Horizontal drains have been demonstrated to be ineffective, and the problem has required more complex and expensive pumping of the aquifer underlying the aquitard to induce drainage. (Rushton and Al-Othman, 1993).

Thus for Riyadh an urban water management strategy to control the waterlogging problem would need to include not only control of mains and tank leakage, and over-irrigation (inputs), but also a means of coping with the large volume of imported water, for example local groundwater pumped from the deep aquifer system could be substituted for non-sensitive uses such as amenity irrigation.

Another Arabian example shows that rises in level do not have to be more than a very few metres before degradation effects become serious. Both Kuwait and Doha share with Riyadh the pattern of much increased recharge due to a rapid growth in population, an increase in per capita water consumption and water imports from desalination plants, high water mains leakage, amenity over-irrigation and on-site sanitation returns. But in addition both are low-lying coastal areas with underlying evaporite deposits, and evaporative salinisation of the near-surface adds serious water quality deterioration to the geotechnical effects described for Riyadh. The percolating desalinised water dissolves salts and makes shallow groundwater much less attractive for other, non-potable uses as well as making it more aggressive and harmful to concrete and steel reinforcing materials.

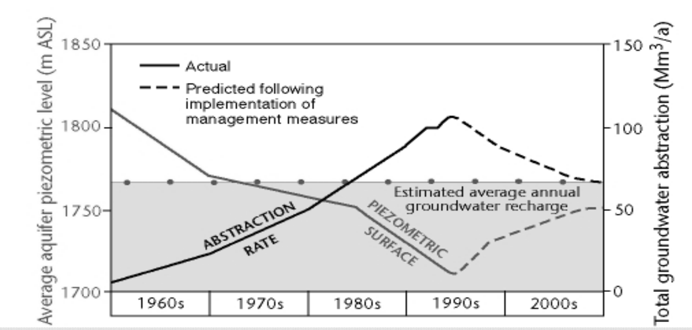
A typical groundwater budget from one of these arid-zone cities shows how insignificant the contribution of recharge from rainfall is in comparison with human sources. The corollary is that urban planning and control policies, if effective and enforced, can be very influential in controlling the extent and rate of groundwater degradation. For instance, hydrographs from monitoring wells confirm the groundwater budget calculation that garden irrigation is a very important new recharge source. Control of such domestic and municipal over- irrigation could be put in place very quickly and comprise either financial (metering and increasing block tariffs, drip irrigation incentives) regulatory (sprinkler/hosepipe bans) or operational (supply restrictions, pipe resizing) measures.

Groundwater budget for a typical Arabian Gulf coastal city (from Walton, 1997)

Groundwater recharge source	**% total**	**Groundwater outflow source**	**% total**
Seepage from amenity over-irrigation	45	Seepage and channelling to coast	46
Mains supply leakage	30	Groundwater abstraction	21
Septic tank/soakaway seepage	22	Drainage into sewerage system and stormwater drains	25
Effective recharge from rainfall	3	Groundwater flow inland	6
-	-	Groundwater evaporation	2
Total recharge inflows=29.8 $\times 10^6$ m^3/a	100%	*Total discharge outflows=28.9 $\times 10^6$ m^3/a*	100%
Addition to storage= 0.9 $\times 10^6$ M m^3/a, resulting in typical annual water table rise of 0.3-0.4m			

Box 2 Patterns of urban groundwater: falling water levels

Many cities worldwide experience the effects of falling water levels. The city of Querétaro is typical of many in Mexico trying to manage demand and supply in an arid climate. The city (population 700 000) draws most of its water supply from 55 production boreholes supplying 175 Ml/d. However, over-exploitation of the Valle de Querétaro aquifer for both urban water supply and agricultural irrigation has depressed the potentiometric surface by more than 100 m, requiring borehole depths of up to 350 m and pumping lifts of 130 to 160 m. The steadily falling water levels (3.5 m/a) have increased energy costs for water production and forced a regular up-rating of borehole pumps and reorganisation of the distribution system.



Change in groundwater abstraction and aquifer water level,
Querétaro valley, Mexico

Over-exploitation of the aquifer has also resulted in compaction of the valley-fill sequence which is alluvial, volcanic and lacustrine in origin and shows 0.4 to 0.8 m of differential subsidence along faults. Serious building and infrastructure damage has resulted (for example ruptured water-mains and municipal/industrial sewers), while opening of vertical fissures at the ground surface has increased groundwater pollution vulnerability.

The municipal water-supply undertaking (CEAQ) uses about 70 per cent of the groundwater abstracted from the Valle de Querétaro aquifer and in the mid-1990s implemented a 10 year aquifer stabilisation plan. Measures are comprehensive and include reduction of mains leakage, improved operational efficiency, demand management and the innovatory approach of financing irrigation technology improvements, water use efficiency, and changes in cropping practice in the agricultural sector in return for voluntary surrender of water rights. By providing secondary treated waste water in exchange for peri-urban irrigation well water-rights, CEAQ have planned to limit importation of scarce groundwater from aquifers in neighbouring valleys up to 50 km away to less than 45 Ml/d.

5 New Groundwater Abstraction Regimes and Their Consequences

Groundwater abstraction necessarily results in a decline in aquifer water-levels. Where such abstraction is limited, groundwater levels stabilise at a new equilibrium such that flow to the area balances groundwater pumping. However, where groundwater withdrawal is heavy and concentrated, such that it greatly exceeds average rates of local recharge, water-levels may continue to decline over decades. Serious declines reduce well yields, which can provoke an expensive and inefficient cycle of borehole deepening to regain productivity, or even premature loss of investment due to forced abandonment of wells.

In some unconsolidated aquifers groundwater quality also may suffer as an indirect result of pumping-induced subsidence. Differential subsidence causes damage not only to individual buildings and roads, but also to piped services routed underground, by increasing water mains leakage and rupturing sewerage systems, oil pipelines and subsurface tanks. This can cause serious contamination of underlying aquifers (Box 2).

Major changes in hydraulic head distribution within aquifers can lead to the reversal of groundwater flow directions, which can in turn induce serious water-quality deterioration as a result of ingress of sea water beneath coastal cities, up-coning/intrusion of other saline groundwater, as in the case of Bangkok, Jakarta, Madras, Manila and Barcelona, and induced downward leakage of polluted water from the surface elsewhere. Thus severe depletion of groundwater resources is often compounded by major water-quality degradation.

Some cities that have previously pumped extensively from an underlying aquifer system experience groundwater level rebound if the pumping regime moderates. This has already been observed in Europe and the USA (e.g. Barcelona, Berlin, Birmingham, Budapest, Houston, Liverpool, London, Milan, and Moscow) and most typically has been observed in industrial cities where earlier periods of expansion resulted in heavy pumping for manufacturing and/or for public supply.

Particular problems occur where aquifer water levels have been depressed over many years, during which time foundations, tunnels and other subsurface structures are constructed in the unsaturated upper aquifer. Subsequently, for various reasons, abstraction rates decline and water levels start to recover, sometimes at a rate accelerated by new sources of urban recharge such as water mains and sewer leakage. Such leakage can occur for instance as the pipe infrastructure ages and renewal rates fail to keep pace, or from natural events such as seismic tremors. Problem arise as water levels recover to depths which would start to affect deep urban infrastructure (metro tunnels, high-rise building foundations), presenting problems not only of stability (subsidence hazard) and flooding but also of corrosion if the water is chemically aggressive (Box 3).

BOX 3 Patterns of urban groundwater: groundwater rebound

The groundwater level rebound problem is well illustrated in several English cities. The rate and magnitude of rise is most striking in central London, where between 1967 and 2001 water levels had risen steadily by over 50 m at a rate of about 1.5 m/year (see Figure A). This rise threatens the underground railway system, constructed at various dates since the 1890s, particularly the deeper lines, and the stability of building foundations. As water levels rise through overlying pyrite-bearing sands and silts above the top of the limestone aquifer (the Chalk) there are also water quality concerns from increasingly aggressive pH-reduced water.

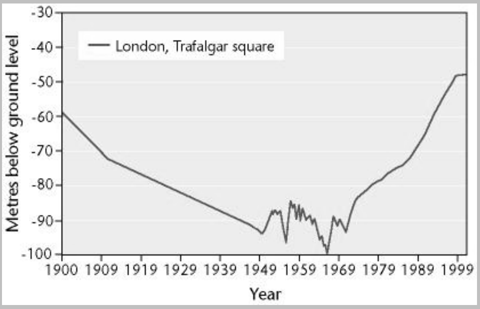


Figure A Rising water level in the Chalk limestone aquifer below central London, UK

Rising groundwater in the Triassic sandstone aquifer underlying the port of Liverpool demonstrates the effect rebound can have on coastal cities (Figure B). There, deterioration in groundwater quality due to saline intrusion and diffuse urban pollution together with diminished water use by heavy industry have greatly reduced pumping since the 1970s. Rebound has affected most notably transport tunnels,including the Liverpool Loop railway tunnel, which was constructed in the early 1970s to enable trains from the Mersey Tunnel to turn around beneath the city centre via several stations before re-entering the tunnel. The circular section, single track, permeable tunnel was excavated in the unsaturated zone at a time when water levels were below the tunnel and groundwater ingress was minimal.

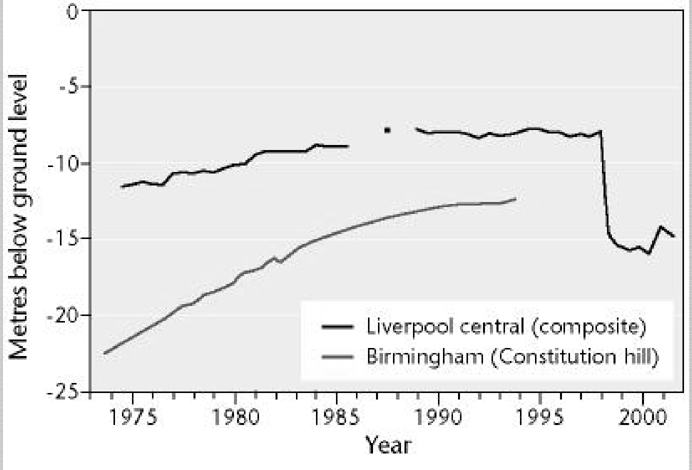


***Figure B** Rising water levels in the Permo-Triassic sandstone aquifer below Birmingham and Liverpool, UK*

Unfortunately the rising water table in central Liverpool not only progressively increased dewatering requirements but also the brackish water caused track corrosion and interfered with the automatic failsafe signaling systems in the tunnel, stopping trains even when the track was clear. The length, location and depth of the tunnel serves to intercept groundwater and protect many other shallower structures at risk. The composite hydrograph from two monitoring wells charts the growth of this problem (which necessitated major remedial engineering works) and shows the impact of remedial extra dewatering of the tunnel in 1998.

In Birmingham, the rise is about 10m between 1974 and 1994 and only localised dewatering boreholes in the unconfined sandstone aquifer have averted flooding of factory basements and tunnels.

In the cases of both Birmingham and Liverpool, the high available storage of the aquifer (storage coefficient typically about 15 per cent) has kept rebound rates modest, but it disguises the fact that very large volumes of water are involved, such that dewatering operations need to be both timely and large scale.

An additional problem of salinity may affect those cities located on the coast or on tidal estuaries because saline intrusion of the aquifer, induced under former heavy pumping conditions, may have caused sufficient deterioration in water quality to pose a corrosion hazard to reinforcing materials in subsurface structures e.g. Liverpool UK or an ecological hazard to surface water habitats in urban parks or river amenity areas once the water table approaches ground level.

For the correct design of mitigation measures, it is important to understand the relative contribution made by each component of the groundwater budget. For instance, in Moscow water mains and sewer leakage are important contributors to groundwater rebound, whereas in Barcelona, recovery was much controlled by the very steep reduction in industrial abstraction between the 1960s and the mid 1990s as industry moved out of the city. Although losses remained sufficiently large to contribute to the problem, during the same period mains supply leakage was reduced by over 40% and piped sewerage systems replaced.

A variation in the pattern can arise in cities with a history of underground coal mining, where water levels can rebound once extraction declines or ceases and tunnel dewatering ceases e.g Glasgow and Wigan in the UK. The act of mining usually renders the formation that is coal-bearing much more permeable, while the effects of subsidence and other displacements can provoke lateral or vertical migration of rising saline or acidic mine drainage into adjacent or overlying aquifers still used for potable water supply.

6 Effects on Groundwater Quality

The net effect on the quality of recharge is generally adverse, especially if wastewater is an important component (Box 4). Urbanisation processes are widely the cause of extensive but essentially diffuse pollution of groundwater by nitrogen and sulphur compounds and rising levels of salinity. These compounds may not be of serious health significance in themselves, but can serve as indicators of more widespread groundwater contamination by industrial chemicals, petroleum products, solvents and non-readily degradable synthetic compounds, most of which may not be analyzed for on a regular basis in resource surveillance programs due to constraints of cost and capacity (Table 3).

Table 3: Groundwater quality impacts from various sources of urban aquifer recharge (from UNEP 1996)

Recharge Source	Importance	Water Quality	Pollutants/Pollution Indicators
Leaking water mains	Major	Excellent	Generally no obvious indicators
On-site sanitation systems	Major	Poor	N, B, Cl, FC, DOC
On-site disposal/leakage of industrial wastewater	Minor-to-major	Poor	HC, diverse industrial chemicals, N, B, Cl, FC, DOC
Leaking sewers	Minor	Poor	N, B, Cl, FC, SO_4, diverse industrial chemicals
Pluvial drainage from surface by soakaway drainage	Minor-to-major	Good-to-poor	N, Cl, FC, HC, DOC, diverse industrial chemicals
Seepage from canals and rivers	Minor-to-major	Moderate-to-poor	N, B, Cl, FC, SO_4, DOC, diverse industrial chemicals

Note:
FC Faecal coliforms Cl chloride & salinity generally DOC dissolved organic carbon
N   nitrogen compounds (nitrate or ammonium) B boron SO_4 sulphate HC hydrocarbons (fuels, oils and greases)

Box 4 Composition of urban waste waters

Urban waste water is comprised mainly of water (99.9 per cent) together with relatively small concentrations of suspended and dissolved organic and inorganic solids. Among the organic substances present in sewage and its microbiological load are carbohydrate, lignin, fat, soap, synthetic detergent, protein and its decomposition products, as well as various natural and synthetic organic chemicals from process industries. Concentrations of these synthetic compounds tend to be much higher in developed countries compared with developing countries, reflecting the nature and degree of industrialisation. The table below shows the concentrations of the major inorganic constituents of urban waste water in both humid and semi-arid climates. In many arid and semi-arid countries, such as Jordan and Mexico, water use can be relatively low and sewage therefore tends to be more concentrated. In wetter countries such as Thailand and Bolivia, sewage tends to be more dilute.

Inorganic components of urban waste water from developing cities

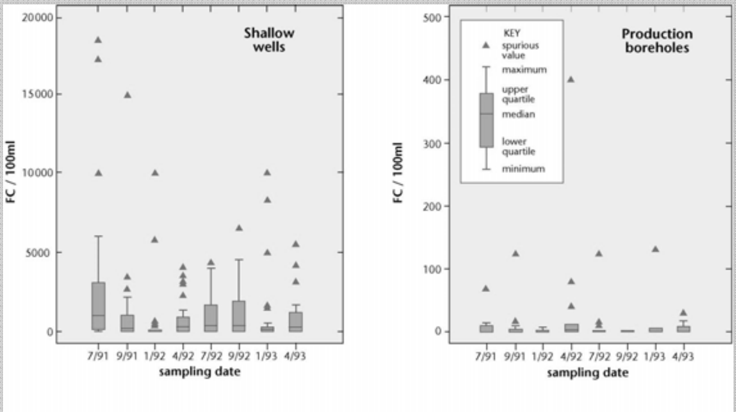
		Concentration (mg/l except SEC)			
	WHO-dwgl*	**Humid**		**Semi-arid**	
		Hat Yai, Thailand	**Sta Cruz, Bolivia**	**León, Mexico**	**Amman, Jordan**
Electrical Conductivity (SEC) µS/cm	-	345	890	2500	2350
Dissolved organic carbon	-	10	35	96	40
Sodium	200	35	73	111	235
Potassium	-	13.5	19.3	16.2	37
Bicarbonate	-	130	440	685	830
Sulphate	250	12	40	81	35
Phosphate	-	1.5	6.1	4	19
Chloride	250	45	57	310	530
Nitrogen	11.3** 0.9***	11	39	40	93
Boron	0.5	0.05	0.08	0.26	0.56

* Drinking water guideline value, WHO, 1998** as nitrate NO_3^- *** as nitrite NO_2^-

Box 5 Groundwater contamination by pathogens: a case study from Mérida, Mexico

The city of Mérida lies on the karstic limestone Yucatán peninsula of Mexico. It has no mains sewerage, and most of the waste water is disposed directly to the ground via septic tanks, soakaways and cesspits which are completed in the karstic limestone and are commonly sited only 1 to 3 m above the water table. The limestone is highly permeable and provides the entire water supply for the city. Most of the water comes from well fields located on the city periphery, but in the early 1990s around 30 per cent was extracted from boreholes within the urban area.

The fissured nature of the limestone and shallow depth to the water table mean that water movement to the aquifer is frequently rapid. The unsaturated zone provides virtually no attenuation capacity, as the aperture of the fissures is many times larger than the pathogenic micro-organisms. Not surprisingly, gross bacteriological contamination of the shallow aquifer occurs, with faecal coliforms (FCs) typically in the range 1000 to 4000/100 ml; permitted concentrations in drinking water of is less than 1/100 ml.



Faecal coliforms in groundwater, Mérida

The faecal coliform counts fluctuate seasonally; lowest values are observed in the drier season (January to April) and the highest in the wet season (June to September). This variation suggests that there is less attenuation during the rainy season, presumably because the increased hydraulic surcharge (due to urban stormwater entering the aquifer) causes the fissures to transmit water, including polluted surface run off. The contamination is much more pronounced in shallow dug wells than in deeper boreholes that typically tap depths of 18 to 38 m but are also significantly affected. The presence of faecal coliform indicator bacteria at depth may be due to vertical fractures, or to the malfunction of a small number of deep waste-water disposal systems which inject into the underlying saline aquifer.

On a more localized basis pollution by pathogenic bacteria, protozoa and viruses is also encountered (Box 5), but the ability of many aquifers to eliminate, or at least attenuate, these contaminants should not be underestimated (Box 6). The maintenance of sanitary well and borehole construction standards and proper well abandonment practices can contribute hugely to the containment of microbial contamination in all but the most vulnerable aquifers.

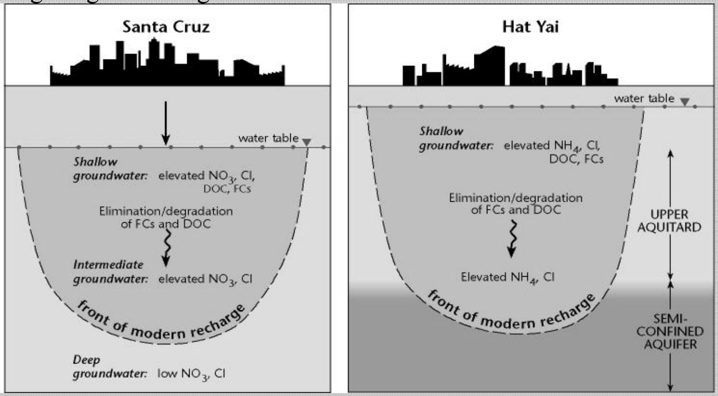
The occurrence of more serious contaminants in aquifers tapped at depth for urban supply will depend on:

- The characteristics of the contaminants (physical properties, mode of disposition to the urban subsurface, intensity and duration of the load)
- The attenuation capacity of the intervening strata (Table 4)
- The way the aquifer system responds geochemically to the imposed contaminant loads in urban recharge (Boxes 7, 8 and 9).

Box 6 Contaminant attenuation at work: effects on urban aquifers in Thailand and Bolivia.

The effects of attenuation on some contaminant classes can be seen in the processes of waste-water infiltration below the cities of Hat Yai in Thailand and Santa Cruz in Bolivia. Large areas of both are unsewered*, so that significant quantities of domestic and some industrial wastes are discharged to the subsurface. Principal contaminants entering the subsurface in this way include nitrogen, chloride, long-chain organic compounds and microbiological waste including faecal pathogens. Shallow groundwater beneath both cities is contaminated, and indicators show elevated concentrations of nitrogen (as ammonium beneath Hat Yai where the water table is shallow and as nitrate beneath Santa Cruz, where it is deeper), chloride, faecal coliforms and dissolved organic carbon (DOC). See figure below.

Both cities are dependent on groundwater obtained from deep semi-confined aquifers, but pumping has induced downward leakage. Although nitrogen and chloride indicators show penetration of the front of modern recharge, faecal coliforms (FC) and elevated levels of DOC were generally not recorded in the deeper groundwaters, where water quality is excellent. The processes of attenuation and elimination are thus well illustrated in both cities, which have distinctive hydrogeological settings.



Impact on water quality from penetration of urban recharge in Santa Cruz and Hat Yai

Since the case-study in Santa Cruz in the mid-1990s, piped sewerage has been significantly extended

Similarly, the impact of such contaminants on the supplies will depend on both the end-use and the relative acceptability in terms of toxicity, purity etc as represented by water standards.

Table 4: Transport characteristics of the common urban contaminants/contamination indicators

CONTAMINANT	SOURCE	ATTENUATION MECHANISM				PERMITTED DRINKING WATER CONCENTRATION	MOBILITY	PERSISTENCE
		Biochemical Degradation	Sorption	Filtration	Precipitation			
Nitrogen (N)	Sewage	✓	✓[1]	✗	✗	Moderate (10-20 mg N/l)	Very High	Very High
Chloride (Cl)	Sewage, industry, road de-icer	✗	-	✗	✗	High	Very High	Very High
Faecal pathogens (FCs)	Sewage	✓✓✓	✓✓	✓✓✓	✗	V. Low (<1 Per 100 ml)	Low-Moderate	Generally Low
Dissolved organic carbon (DOC)	Sewage, industry (esp. food processing, textiles	✓✓✓	✓✓✓	✓	✗	Not Controlled	Low-Moderate	Low-Moderate
Sulphate (SO_4)	Road-runoff, industry	✓[2]	✓	✗	✓	High	High	High
Heavy metals	Industry	✗	✓✓✓	✓[3]	✓✓	Low (Variable)	Generally Low unless pH low (except Cr [VI])	High
Halogenated solvents (DNAPLs)	Industry	✓	✓	✗	✗	Low (10-30 µg/l)	High	High
Fuels, lubricants, oils, other hydrocarbons (LNAPLs)	Fuel station spillages, industry	✓✓✓	✓✓	✗	✗	Low (10-700 µg/l BTEX[4])	Moderate	Low
Other synthetic organic	Industry, sewage	Variable	Variable	✗	✗	Low (Variable)	Variable	Variable

KEY ✓✓✓ highly attenuated ✓✓ significant attenuation ✓ some attenuation ✗ no attenuation

[1] Ammonia is sorbed

[2] Can be reduced

[3] where occur as organic complexes

[4] Aromatic compounds with health guideline limits

Box 7 Secondary water quality changes

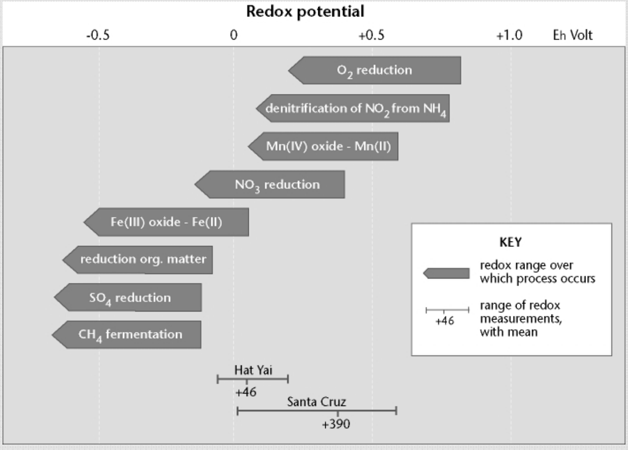
Secondary water quality changes are an effect only recently recognised in aquifers underlying cities or large industrial complexes. These are caused by a combination of the increased contaminant load at the urban land surface/shallow subsurface and its penetration as city boreholes induce downward leakage of urban recharge. Both the industrial and the domestic components of urban waste water have a high organic content. This organic content is relatively easily oxidised under aerobic conditions and where the water table is deep, oxygen and micro-organisms in the unsaturated zone of the aquifer may remove (degrade) much of the organic content.

Below the water table, any further degradation (of organic matter) will consume the dissolved oxygen present in the groundwater:

$$CH_2O + O_2 = CO_2 + H_2O$$

$$CO_2 + H_2O = HCO_3^- + H^+$$

Oxygen in this reaction is termed the electron acceptor. The quantity of oxygen dissolved in groundwater is much less than that present in the unsaturated zone and is less rapidly replaced. Thus depletion of dissolved oxygen is possible whenever the oxygen demand for the degradation of organic matter exceeds supply. When this happens the oxidation-reduction (or redox) potential of the groundwater declines and further degradation of organic matter continues utilising other ions (electron acceptors) that are progressively more difficult to reduce. These include, in order of disappearance, nitrate (NO_3^-), ammonium (NH_4^-), manganese (Mn^{4+}), ferric iron (Fe^{3+}), and sulphate (SO_4^{2-}) (see figure). These compounds often occur naturally either in the mineral grains of a rock or in the cement that binds the grains together. Significant water quality changes result which, depending on the aquifer setting, can be adverse (leading for instance to increases in the dissolved metals content in pumped groundwater) or beneficial (as denitrification can reduce otherwise unacceptable nitrate concentrations). Box 16 describes these effects studied in the two cities of Santa Cruz Bolivia and Hat Yai Thailand, but the process is likely to be much more widespread in susceptible aquifer settings. A similar set of reactions for instance often occurs around municipal refuse disposal sites and beneath farm waste slurry pits



Sequence of microbially mediated redox processes

High iron and manganese concentrations, although not a threat to health, do represent a water quality problem, as they may be unacceptable for domestic purposes (because they impart an unpleasant taste and can stain laundry) and for some industrial processes. Removal of these ions by treatment is expensive. A more serious concern in health terms is the presence of naturally occurring arsenic in some rock formations, apparently associated with iron oxide minerals. Concentrations in excess of 20 times the WHO guidelines have been observed in shallow groundwater as arsenic is mobilised under changed redox conditions, caused by seepage to the ground of urban effluent containing a high organic load. Mobilisation of arsenic in deeper aquifers has also been confirmed. The implications are serious firstly because of the health implications of excess arsenic in drinking water and secondly because arsenic is a relatively abundant element in alluvial sediments. The mobilisation of arsenic by iron oxide dissolution could occur more generally beneath unsewered cities and therefore urban groundwaters need to be monitored for arsenic especially where strongly reducing conditions prevail such as those produced by the disposal of waste water to the subsurface. The presence of high concentrations of dissolved iron and manganese and of low concentrations of nitrate and sulphate in groundwater is indicative of reducing conditions.

Box 8 Secondary water quality changes in urban aquifers

Secondary water quality changes are illustrated by the effects of waste-water infiltration below the cities of Hat Yai in Thailand and Santa Cruz in Bolivia where on-site waste-water disposal has been widespread. The constituents of waste water in aquifers react with each other, with subsurface gases and with the porous medium of the aquifer matrix itself. Most geochemical changes in waste water occur as a result of the reactions of a few major components that, in turn, affect redox potential and pH, the master variables of aquifer geochemistry. For example, nitrogen present in organic form in infiltrating waste water can be transformed and volatilised as it undergoes bacterially mediated processes but only under certain circumstances.

Across much of the city centre in **Santa Cruz**, organic nitrogen entering the shallow aquifer has been oxidised via ammonium on its passage through the oxygen-rich unsaturated zone. It reaches the aquifer relatively unattenuated, mainly as nitrate. The conversion of ammonium to nitrate generates acidity, which, in the case of Santa Cruz, is buffered by the calcium carbonate present in the rock matrix, and so little or no change in pH is detected. At a few sites where oxygen has been fully consumed in the breakdown of organic carbon, denitrification occurs and a proportion of the nitrogenous leachate is converted to nitrogen gas (see Figure A). This mitigating effect only occurs however where the loadings are so high that the system has become anaerobic, so although the nitrate content in the saturated aquifer is significantly reduced, it may still be higher than is acceptable according to water quality norms.

These changes in the forms of compounds present in groundwater can convert chemicals from nontoxic to toxic forms, and vice versa; for example, the change from the potentially toxic nitrate and nitrite to nitrogen gas. Making an aquifer more reducing can either increase the solubility of toxic compounds (arsenic, manganese) or reduce them (nitrate, chromium, selenium). It can also increase the dissolved iron and manganese content, making the water unacceptable for some purposes.

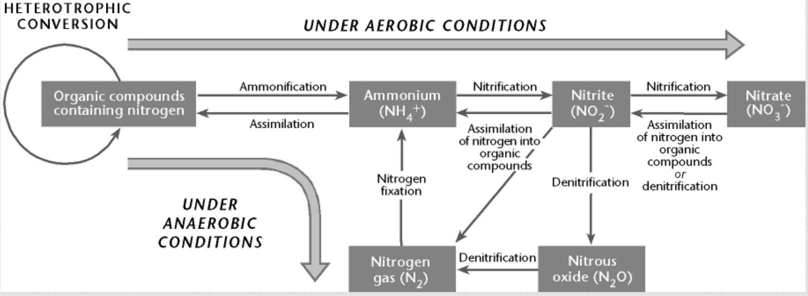


Figure A Transformations of nitrogen from waste water during groundwater recharge

In Hat Yai the groundwater system has become more reducing than in Santa Cruz, due in part to the very shallow water table. Little carbonate is present in the rock matrix, so during oxidation of the ammonia the tendency is for the pH to fall. At a lower pH, heavy metals have a greater mobility and are more likely to go into solution. In the city centre, the nitrate has been entirely consumed and naturally occurring micro-organisms are likely to utilise manganese or iron present in the rock matrix (or sulphate in urban recharge) to break down organic food sources. This increases the concentrations of manganese and iron in solution as they are more soluble in their reduced form (an effect also observed in the centre of Santa Cruz). In addition, any naturally occurring arsenic, which may be loosely bound to iron oxide in the matrix or on grain surfaces, is also released into the groundwater. Concentrations up to 1.0 mg/l arsenic were found in the most reducing zones of the aquifer and, in general, high arsenic and iron concentrations were found to be associated in Hat Yai (Figure B).

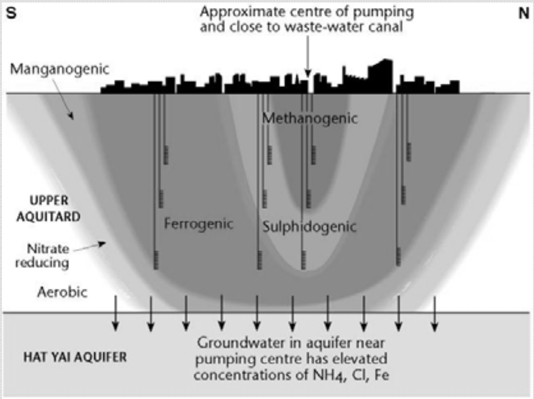


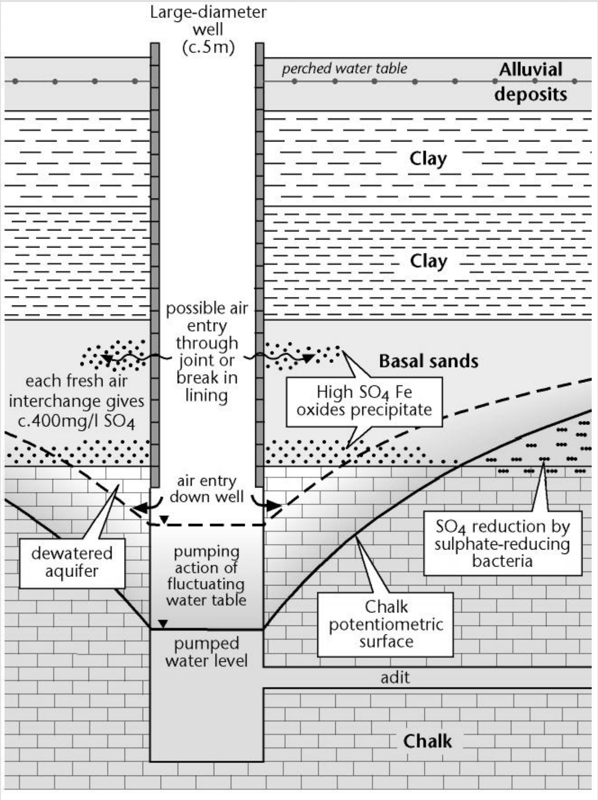
Figure B Cross-section through Hat Yai showing redox zones

This lowland alluvial aquifer setting is common throughout much of southern Asia, and an example from a water quality study in the densely populated marginal housing area of Dattapara north of Dhaka city in Bangladesh shows how the impact of heavy nitrogen loading from pit latrines on shallow groundwater can be self-mitigated in these conditions of shallow water table and poorly permeable clay soils. The very high population density (about 620 persons/ha) generates a high nitrogen loading estimated at 3000 kg N/ha/annum yet nitrate concentrations in shallow domestic supply tubewells, 10 to 20 m deep, were surprisingly low at less than 20 per cent of the WHO guideline of 11.3 mg/l NO_3-N. Anaerobic conditions (evidenced by negligible dissolved oxygen and redox potential of –250 mV) favour denitrification and the formation of ammonium, which is either volatilised to the atmosphere as ammonia, sorbed to sediments or remains in solution.

Box 9 Pyrite oxidation in ‘reducing’ aquifers

Sometimes the effects of pollution can be indirect and unsuspected. The most dramatic effects relate to redox effects. The potential secondary effects arising from on-site waste-water disposal in the cities of Hat Yai, Thailand and Santa Cruz, Bolivia were illustrated in Boxes 6-8. These illustrated the impact of making the aquifer more reducing but the reverse can also occur. Entry of oxidants, principally oxygen and nitrate, into previously reducing aquifers can also have serious repercussions on groundwater quality. This occurs most commonly in sandy alluvial aquifers containing pyrite (FeS_2), a common minor mineral that can occur where such aquifers are overlain by a confining layer of silt or clay. For example, excess fertiliser nitrate infiltrating into sandy alluvial aquifers in Germany has led to excessive concentrations of sulphate in groundwater. Although dissolved oxygen can also oxidise pyrite, the limited solubility of oxygen (about 8–10 mg/l for the typical range of groundwater temperatures) means that the amount of pyrite able to be oxidised in this way is relatively small. Much larger quantities can be oxidised when air is allowed to enter the aquifer. This results most frequently when the water table is lowered following extensive groundwater abstraction. A large quantity of sulphate then accumulates in the unsaturated zone, where it is relatively immobile, and is only detected in pumped groundwater when the regional rate of abstraction is reduced and the water table rises.

Such an effect has been found in north London, where a succession of sand and clay overlies and confines the nationally important Chalk aquifer. Following proposals to develop the aquifer for artificial recharge, pilot investigations found poor quality abstracted water following recharge. In some areas, the Chalk water level oscillates around the top of the aquifer due to seasonal changes and to cycles of pumping and non-pumping. The resultant saturation and drainage pulses air through the pyrite-bearing sandy beds overlying the Chalk, and the resulting oxidation has produced porewater concentrations of up to 30 000 mg/l sulphate in the sandy beds. Leakage from these sands can produce sulphate concentrations in excess of the WHO guideline value of 250 mg/l in water pumped from the underlying Chalk (see figure).



Schematic diagram showing how localised oxidation and reduction could occur around a large-diameter well, north London artificial recharge scheme (after Kinniburgh et al., 1994)

Pyrite oxidation also releases large amounts of acidity and the groundwater may become quite acid where the aquifer has no minerals, such as calcite ($CaCO_3$), which can be readily weathered to neutralise the acidity. This reaches an extreme situation in many mines where the drainage water can be extremely acidic. Acid mine drainage can also contain high concentrations of iron, zinc, lead, arsenic and other trace constituents which either arise directly from the dissolution of pyrite or indirectly from the dissolution of other minerals as a result of the acidity produced.

Unlike the protection measures employed in traditional aquifers, for example nitrate protection zones or restrictions on the siting of on-site sanitation, aquifer protection measures in reducing aquifers involve maintaining as a high a water table as possible in order to prevent air entry and oxidation.

7 Implications of Urban Processes for City Water Resources

Pollution of urban aquifers is a widely-recognised phenomenon, and the typical response is the abandonment of at least the shallow zone for public water-supply, water utilities either opting for deeper wells or relocation to periurban or rural areas as an operational alternative to extensive treatment. While these are perfectly valid operational responses, the long-term implications need to be taken into consideration:

- In multiaquifer systems, extensive pumping from deeper strata will depress the potentiometric surface, and the resultant head differences between shallow and deep aquifer water levels may induce downward leakage of (usually polluted) water into the lower aquifer if the intervening beds are sufficiently permeable. The long timescales typically involved in leakage to the deep aquifer mean that only the most persistent pollutants will reach supply intakes, which will also benefit from the effects of dilution by pristine deep groundwater (Boxes 10A, 10B). In such circumstances, maintenance of high quality deep groundwater can depend on effective prioritisation of the deeper aquifer use. For instance, high quality water would be squandered if used for non-sensitive industrial supply, cooling or amenity irrigation where these demands could be met by from continued use of the shallow aquifer. Matching quality to end use in this way has the triple advantage of intercepting and recycling poorer quality water to a less sensitive function, reducing leakage hazard and conserving scarce high quality deep groundwaters for the highest value use (typically potable supply).

- Another problem that is likely to occur if depressed water levels rebound after a long period of intensive pumping is that pollutants, such as LNAPLs, that have entered the aquifer in the past can be lifted and carried to springs or wells. An example of this is New York, where oil spilled in the 1950s was mobilised by a rising water table, rebounding as a consequence of reduced pumping. The oil rose with it until in 1978 it began to enter a tributary of the East River.
- Total or near-abandonment of an urban aquifer for supplies from the hinterland will put into the water and wastewater systems large volumes of imported water. The detailed response will depend on the geology and city circumstances, but they may include negative effects such as waterlogging of lowland areas if the near-surface strata are poorly permeable or the water table is already high or positive results such as the regeneration of urban watercourses and springs long dewatered by historic pumping.

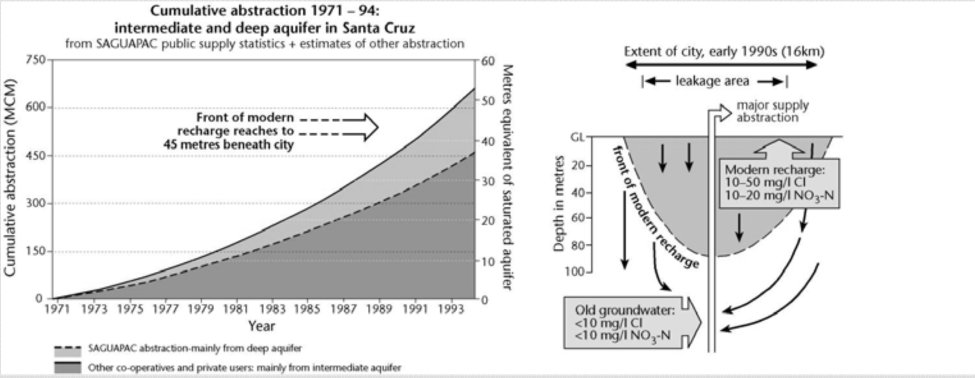
For some urban areas the abandonment of a shallow aquifer due to progressive contamination is not socially or economically an option. For instance, many cities in the developing world have middle- and high-income areas on a reticulated supply but low income/socially deprived districts partially or completely dependent on the underlying shallow aquifer for handpump/public standpipe community water supplies and for on-site sanitation. In such situations the users may not have the luxury of abandonment of the resource and their planning/public health representatives instead need to consider how to manage the twin demands of supply and waste disposal in such a way that both functions can continue without incurring unacceptable community health risks. There will not be easy general prescriptions for such conflicting demands because different aquifer settings vary in their pollution vulnerability and will require different solutions (Box 11). One measure for instance could be to use urban housing density controls to limit contaminant loadings and enforcing spatial separation criteria between supplies and latrine units.

BOX 10A: The engine driving water quality change: deep penetration of urban recharge in Santa Cruz

Santa Cruz de la Sierra, Bolivia, is a low-rise, relatively low-density fast-growing city located on the plains to the east of the Andes. Its municipal water supply is derived entirely from well fields within the city limits, extracting from deep semi- to unconfined alluvial aquifers. Mains water is provided by cooperatives of which the largest is SAGUAPAC. The supply in 1994 was 98 Ml/d from about 50 boreholes (90 to 350 m deep). There are also many private wells (some 550 in 1991) used to supply small business and some homes. These wells are generally less than 90 m deep and draw water principally from the shallow aquifer. The city has relatively good coverage of piped water supply, but until the 1990s only the older central area had mains sewerage; most domestic and industrial effluent and pluvial drainage were disposed to the ground. The main additions to groundwater recharge over the natural infiltration of excess rainfall were the on-site disposal of waste water and leakage from the mains water supply. Seepage from the nearby Rio Piray is also believed to be significant, but is difficult to quantify precisely. There is no pattern of falling water levels; this is due to the abundance of recharge and the ease with which water can enter the subsurface and percolate to the shallow aquifer.

Groundwater in the deeper aquifer, below 100 m, is of excellent quality, similar to the shallow aquifer upgradient of the city, and this represents the natural condition. However, the uppermost aquifer, above 45 m, shows substantial deterioration, with elevated nitrate and chloride beneath the more densely populated districts. These are derived from the disposal of effluent to the ground, mainly the products of on-site sanitation. This represents a major source of urban recharge that is then drawn downwards in response to pumping from the deeper semiconfined aquifers. The front has penetrated to over 90 m in the most intensely pumped area (1994) although the average depth of penetration beneath the city is probably closer to 45 m.

Deep groundwater abstraction first started in about 1970; by 1994 the cumulative withdrawal was equivalent to the volume of water stored within the upper 50 m of the aquifer beneath the city. This shows that the front of modern recharge is moving down at a rate of about 2 m per year and that downward leakage from beneath the city may account for the bulk of the local recharge to the deeper aquifers.



Development of abstraction and vertical leakage in Santa Cruz aquifer system, 1971–1994

Box 10B Primary and secondary water quality effects on deep groundwater in Santa Cruz

The penetration and travel time of this new urban recharge can be tracked by the chloride, which acts as a tracer (Figure A) and by nitrate (Figure B). The diagrams below show how incipient contamination is starting to affect the older production wells, which have shallower depths to the top of their screened sections. By 1994, a steady rises in concentration could be observed in those wells with screens starting above 90 m depth. In a few of these shallower screened wells the nitrate content is approaching or has exceeded the WHO guideline, reflecting a trend that is likely to be occurring even more strongly in most of the (unmonitored) private boreholes in the city centre because their screens are at even shallower depths.

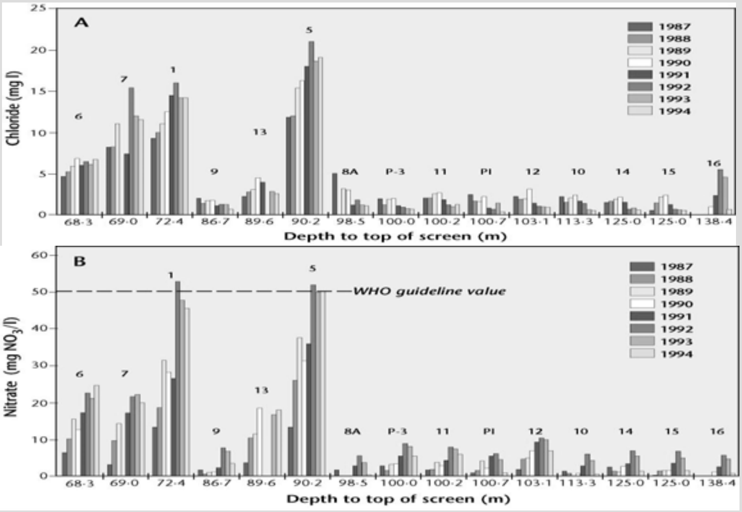
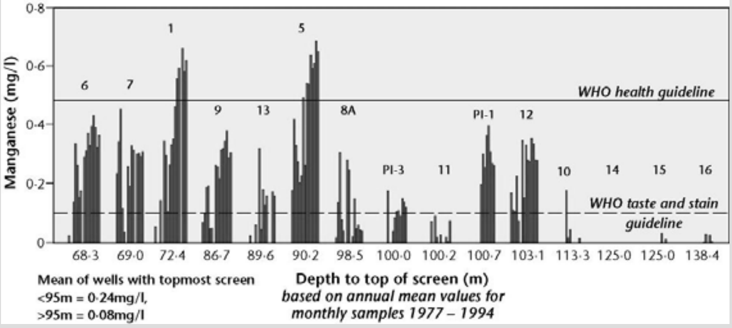


Figure Chloride (A) and nitrate (B) trends in deep public supply boreholes in Santa Cruz, Bolivia

Dissolved oxygen in the urban recharge is low, having been consumed as the carbon in the organic load is oxidised to carbon dioxide, which in turn reacts with carbonate minerals in the aquifer matrix to produce bicarbonate. The oxidation of the high organic load also reduces naturally occurring manganese from the aquifer matrix, making it more soluble. By 1994, the average manganese concentration in wells tapping intermediate levels of the aquifer had tripled (Figure C), with some of the older production boreholes, which have screens above 100 m, starting to show concentrations above 0.5 mg/l, leading to laundry-staining problems and an unpleasant taste to the drinking water.



Mean of wells with topmost screen
<95m = 0·24mg/l,
>95m = 0·08mg/l

based on annual mean values for monthly samples 1977 – 1994

Figure C Rising manganese in shallower public supply wells due to urban recharge-induced geochemical changes, Santa Cruz, Bolivia

Box 26 Urban water supply from basement aquifers; experience from Uganda

The city of Kampala and the provincial town of Iganga in Uganda obtain their water supply from weathered basement rocks. Both make extensive use of on-site sanitation. In Iganga (population 50 000), the public supply is supplemented by a large number of shallow boreholes in town, fitted with hand pumps. These wells tap an aquifer comprising an upper deeply weathered zone, some 10 to 20 m thick, overlying a more permeable fractured zone. Most of the boreholes are screened opposite the lower fractured zone (Figure A). Water sampled from these boreholes shows moderate to high nitrate concentrations but bacterial faecal indicators are largely absent. This is attributed partly to the generally low aquifer vulnerability (a consequence of the upper deeply weathered profile) and partly to the design of the boreholes; the intakes tap the deeper fractured zone where water has had a longer residence time and so had greater potential for microbial attenuation. Only the more persistent contaminants (for example nitrate and chloride derived from on-site sanitation systems) are able to reach the borehole screen. Shallower dug wells showed more frequent contamination by faecal indicator bacteria and pronounced seasonality.

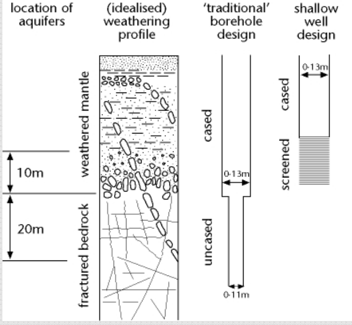


Figure A: Urban aquifer setting in the town of Iganga, Uganda (from ARGOSS, 2002)

By contrast, in Kampala (population about 1 million), the hilly topography has produced differential weathering, with thin mantles of weathered material on high ground discharging to springs formed at geological boundaries on the lower slopes. The aquifer supplying the protected springs thus lacks the deeply weathered zone and is characterised by shallow flow through fractured rock. There are more than 300 springs in the city and many residents who are without a domestic tap connection, use these for part or all of their domestic water needs, including drinking and cooking. The aquifer is extremely vulnerable, and tests have showed that contamination by faecal bacteria was widespread even for protected springs. The springs are replenished by local recharge, but short travel time from the ground surface to the spring outflow allows little opportunity for attenuation (Figure B).

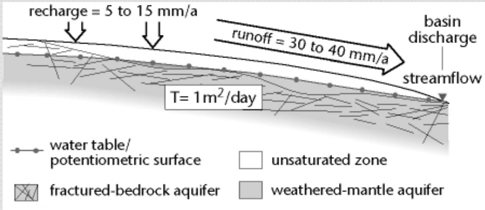


Figure B Groundwater flow system feeding urban water supply springs in Kampala (from ARGOSS, 2002)

Although both urban areas rely on the same aquifer type (weathered basement) the hydrogeological setting is quite different in detail and this will affect future design of safe water and waste disposal facilities. For instance, in Kampala, an effective and well-maintained disinfection treatment stage would be obligatory rather than precautionary if the springs are to provide a bacteriologically safe water supply to the local community of low-income residents who comprise most of the users of this source of domestic water.

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Watershed Management: A Tool to Aid Groundwater Management for Large Cities with an Example from California, USA
流域管理:美国加利福尼亚州为代表的大城市地下水管理方法

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North Coast Regional Water Quality Control Board

Abstract

The emphasis of this paper is on groundwater management for large cities. However, groundwater management depends to a great extent upon management of surface water. This paper focuses on the role of surface water management as it relates to groundwater. We review inseparable relationships between groundwater and surface water and the efficiency in managing surface waters to improve and augment groundwater. We illustrate some of the methods of restoring the natural functions of streams to improve both water quality and quantity using an example of sediment management in California, USA. This paper is focused on water quality rather than water quantity but they are dependent on each other.

Considered on the scale of a continent, our future is to manage fresh water as one water system. Part of this system is on the land surface as streams and lakes, while part is below the surface, but it is all part of one interacting system (Figure 1). The water above and below the surface are generally treated as different systems for several reasons: Surface water is visible, but we seldom see the groundwater, and the two parts of the system require vastly different engineering to be acquired and managed. Yet the quantity and quality of each affects the quantity and quality of the other, so in the big, long-term picture, both form one intertwined and integrated system.

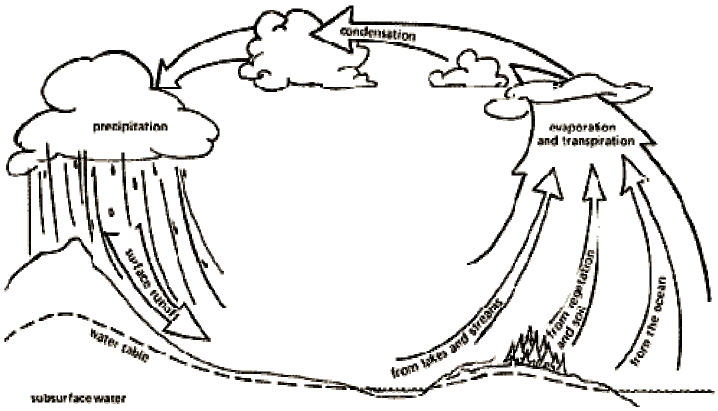

Figure 1: The hydrologic cycle provides a continuous supply of clean water to the continental water system.

Within this system the hydrologic cycle continually provides a source of clean water back to the land through precipitation. And this source of clean water is free. For that reason it makes economic sense to change the practices of civilization to collect and maintain this water in a usably clean state, rather than allow it to become polluted and then bear the huge economic and social costs of dealing with contaminated water. There are many ways of approaching these avoidable problems and still more solutions.

In this paper we discuss strategy for maintaining the quality of surface water as a means of improving and conserving groundwater. The quality of water at any given point in a watercourse is the product of all that happens in the watershed above that point. For this reason, it is obvious that water quality and pollution must be addressed at a watershed scale. Creating a healthy watershed is a natural, sustainable, and inexpensive way to preserve high quality waters and to improve water that may already be polluted.

In the long term groundwater quantity and use are limited by infiltration rates, but high quality surface water pays off economically by reduced access cost, reduced demand for groundwater, and higher quality recharge water entering the groundwater system.

摘要

本文重点论述大城市的地下水管理。然而，地下水的管理在很大程度上取决于地表水的管理。本文强调与地下水相关的地表水的管理，考查了地下水和地表水之间不可分割的联系以及通过地表水管理效率来改善地下水水质和增加地下水水量。本文以美国加利福尼亚州沉积物管理为例，阐述了几种通过恢复河流的自然生态功能来改善水质和增加水量的方法。尽管本文更多的将重点放在水质而不是水量上，但这二者是相互依赖的。

考虑到陆地的范围，将来应该把淡水作为一个整体水系来管理。这个系统的一部分存在于地表的河流湖泊，而另一部分存在于地下，但他们都是一个相互作用的系统的组成部分（表 1）。地表水和地下水通常被作为不同的系统对待，基于几个原因：地表水是可见的，我们却很少看见地下水，这两部分水需要大量不同的工程来获取和管理。然而，地表水和地下水的水质和水量是相互影响的，因此，从宏观和长远来看，这两方面共同构成一个相互交织的完整系统。

在这个系统中，水分循环以降雨的形式为陆地持续提供清洁的水源。这种清洁水源是免费的。因此，改变社会习惯，收集水和保持水的清洁可用性，而不是在它污染后花费巨额的经济和社会成本处理污染就具有经济上的意义。有很多方法来避免这些问题并找到解决之道。

本文探讨了将保护地表水水质的策略作为改善和保存地下水的一种手段。一个河道任何已知点的水质是那个点之上全流域的所有因素共同作用的结果。因此，水质和污染的问题显然必须在流域的范围来解决。创造一个健康的流域是保持水质优良和治理水体污染的一种自然、可持续、便宜的方法。

从长远来看，地下水的水量和利用受渗透率的限制，但高质量的地表水能够取得经济上的回报，因为它减少了设备成本，减少了对地下水的需求，而且可以用优质的水来补充地下水系统。

1 Development and Water

Many countries have gone through stages in the development of water usage as one of many interrelated components of economic development. In this paper approaches to watershed management as it is evolving in one part of the United States, is used as an example. Although the details of particular methods and approaches described may not apply to China, the fundamentals are applicable anywhere.

First, in order to maintain water quality, we must think and manage on a watershed scale, because degradation of the watershed has an impact on quality of water originating from any source in the watershed. Impacts in the headwaters affect the whole system, and impacts in the lower watershed can pollute even high quality waters as they pass through that area.

Second, for long term water quality improvement to occur, the population in the watershed must participate in the process of planning, management, and maintenance of watershed conditions and improvements. Where large numbers of people live in a watershed, it is very tempting for people to ignore the basic principles of good water management for personal convenience or profit, especially if society as a whole accepts the practice. It is a very common human trait to not worry about what is out of sight. So when something is placed in the watercourse and it flows away, only clean water is seen and it is easy to forget the downstream impacts. Flush the toilet, and the problem is gone. If management is to be effective, good practices must be the accepted norm throughout society and must be rewarded. The polluter must be shunned by society as a whole or regulated by laws and fines if necessary. In a densely populated watershed, a small change by many people can produce an enormous improvement of the watershed and water quality.

Point-source discharges, as from mills and factories, are relatively easy to identify and control through regulation. However, non-point sources of pollution, such as sediment from roads, agricultural chemicals, animal waste, and human waste are harder to pinpoint and too widespread and decentralized to control with regulations. To effectively control these sources, the public must be educated in the reasons and benefits of the actions that are necessary to keep downstream water users and water sources protected.

Educating and involving the population is a difficult task for many reasons. In some cases watershed improvements must depend on people changing traditional ways of doing things; in other cases it may be a matter of equity or scale of impact. For that reason, public discussion and public participation have been found to be more effective than making regulations that are difficult to enforce and which may contribute little to public understanding. Educating students is a very effective means of accomplishing changes in society. As students are made aware of impacts, they can aid in changing society’s attitudes.

This paper discusses approaches that have been found effective in the USA. Approaches that might be effective in China may be different in important ways, but we believe that the principle of involving the population in the problem-solving to achieve buy-in from a maximum number of people has been demonstrated to be more effective than top-down regulation alone. When there is public support for change, proper care of the land is agreed to and enforced by the community.

Because much of the printed literature and agency reports used in our studies in California may not be readily available in China, we refer almost entirely to literature and reports that are available online. Many of these online reports contain extensive bibliographies of literature in print, so the interested reader can find reference to printed literature through the online reports.

We do not cite a large number of publications in this paper. However, a large body of literature is easily available online describing the methods, details, and results of TMDL studies done in California. We direct the interested reader to the home page of the California State Water Resources Control Board (http://www.swrcb.ca.gov/). This site contains links to the sites of each of the nine Regional Water Quality Control Boards in California, and each of these sites has links to every TMDL study that has been done in its region. Thus the whole body of TMDL literature in California is easily available, and within these reports are links to relevant reports of the US Environmental Protection Agency and water protection agencies in other states.

2 An Approach to Watershed Analysis

Faced with managing both quantity and quality of the water supply amidst economic development, both the federal government and the states in the USA have developed systematic means of approaching the problems. In this approach the beneficial uses of water bodies are defined, and the different sources of impairment are defined. With the beneficial uses and the impairments defined, the next step is to determine the greatest rate of loading for a given impairment at which the water body can still maintain its beneficial uses. This rate of loading is called the Total Maximum Daily Load (TMDL). An implementation plan is then developed to reduce the impairment to the TMDL.

Beneficial Uses of water are defined in law as the uses of water necessary for the survival or well being of humans, plants, and wildlife. These uses of water serve to promote the tangible and intangible economic, social, and environmental goals. Beneficial Uses of the waters of the State that may be protected include, but are not limited to, domestic, municipal, agricultural, and industrial supply; power generation; recreation; aesthetic enjoyment; navigation; and preservation and enhancement of fish, wildlife, and other aquatic resources or preserves. Existing beneficial uses are legally defined as uses of surface or ground water that were in effect on or after November 28, 1975 when the laws went into effect; and potential beneficial uses are defined as uses that would probably develop in future years through the implementation of various control measures.

Common impairments include excess sediment, excess nutrients, elevated temperature, pathogens, and a great variety of toxic materials including pesticides, hydrocarbons, and heavy metals among others.

Watershed Analysis is the tool used to address pollution on a watershed scale.
A Total Maximum Daily Load (TMDL) study is a system to:

- Assess the condition of an entire watershed
- Evaluate the factors that contribute to the water quality problems in the waterbody (river or lake)
- Develop a plan to restore water quality conditions.

The TMDL process consists of three major steps:

- The water body is officially listed as impaired.
- A technical analysis is done to determine the TMDL.
- An implementation plan is developed to address impairments.

The technical analysis and the implementation plan are presented to the Regional Water Quality Control Board and State Water Quality Board in open hearings and debated publicly on their merits. Stakeholders are invited to participate in the debate and their information and opinions are taken into consideration. This is a public process that leads to regulation.

The website of the North Coast Regional Water Quality Control Board, http://www.waterboards.ca.gov/northcoast/programs/tmdl/Status.html, contains a list of all TMDLs done in the North Coast Region or in 303(d) listed to be done. The documents of TMDLs that have been done and approved are available on that website.

3 An Example of Watershed Analysis: The Scott River Sediment TMDL

3.1 Components of the TMDL

As an example of watershed analysis, we review a Sediment TMDL that was approved by the North Coast Regional Water Quality Control Board, The California State Water Resources Control Board, and the U.S. Environmental Protection Agency in 2006. This TMDL was the result of about three years of technical analysis and public involvement. The objectives and components of a Sediment TMDL are as follows:

Sediment TMDL objectives:

1. Assess the water body conditions.
2. Quantify sediment sources.
3. Determine how much sediment the stream system can handle and still support existing and potential beneficial uses.
4. Identify whether and how much the different sediment inputs need to be reduced in order to support desired conditions.
5. Develop an Implementation Plan (Action Plan) that will restore the health of the body of water.

Sediment TMDL Components:

1. Problem statement, which defines the conditions in the watershed, and characterizes the impairment.

2. Numeric targets, which are quantitative or narrative measures of desired conditions. These can vary by place or season.
3. Source analysis, which determines and quantifies the natural and human-related sources of sediment delivered to the stream system.
4. Linkage analysis, which defines connections between human activities and land use and sediment delivery.
5. Determination of loading capacity, which is how much sediment the stream system can handle and still support its beneficial uses.
6. Allocations of how much sediment will be permitted from different sources, which allows calculation of reductions needed to achieve desired water quality.

3.2 The Scott River sediment TMDL process

In 1992 the U.S. Environmental Protection Agency (USEPA) listed the Scott River as impaired with sediment under Section 303(d) of the federal Clean Water Act. This listing was made on the basis of a 1990 study showing poor substrate conditions in the Scott River and some of its tributaries and the judgment of water quality professionals familiar with the Scott River watershed.

The study had shown that excessive sediment in the river and it tributaries had filled pools and covered the natural streambed of gravel with sand and silt that prevented spawning of salmon and steelhead trout, which are a major economic resource. In addition, the resulting shallow wide streams gathered more sunlight resulting in warmer water, and excess sediment interfered with use of the water for agricultural and household use.

The North Coast Regional Water Quality Control Board, an agency of the State of California, had the task of determining the Total Maximum Daily Load (TMDL) of sediment that the river system could receive and still function in an unimpaired manner. Experience has shown that in the Coast Ranges, rivers generally can operate in a manner that is satisfactorily unimpaired with as much as 25 percent more sediment than in a natural state. For that reason, in this region we set the TMDL at 25 % above natural levels.

3.2.1 Existing beneficial uses for the Scott River are:

1. Municipal Water Supply
2. Agricultural Supply
3. Industrial Service Supply
4. Groundwater Recharge
5. Freshwater Replenishment
6. Navigation
7. Hydropower Generation
8. Water Contact Recreation (e.g. swimming)
9. Non-Contact Water Recreation (e.g. boating, fishing)
10. Commercial or Sport Fishing
11. Cold Freshwater Habitat
12. Wildlife Habitat
13. Rare Threatened or Endangered Species
14. Migration of Aquatic Organisms (salmon and steelhead trout)

15. Spawning, Reproduction, and/or Early Development (salmon and steelhead trout)
16. Aquaculture (Scott Valley Hydrologic Subarea)

3.2.2 Potential beneficial uses are:

1. Industrial Process Supply
2. Aquaculture (AQUA) (Scott Bar Hydrologic Subarea)

3.2.3 Water quality objectives

The Basin Plan (NCRWQCB, 2005) identifies both numeric and narrative water quality objectives for the Scott River. The water quality objectives applicable to the Scott River Sediment TMDL are listed below. These are legally defined objectives and have been applied in TMDLs for other bodies of water as well.

Suspended or Settleable Material:

> Waters shall not contain suspended material in concentrations that cause nuisance or adversely affect beneficial uses.

Turbidity:

> Turbidity shall not be increased more than 20 % above naturally occurring background levels. Allowable zones of dilution within which higher percentages can be tolerated may be defined for specific discharges upon the issuance of discharge permits or waiver thereof.

Sediment:

> The suspended sediment load and suspended sediment discharge rate of surface water shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses.

The object of the TMDL process is to set in motion courses of action that will allow the body of water to be removed from the 303(d) list. There are three different ways in which the Scott River could be de-listed:

1. If sediment conditions in the stream system are found to meet water quality standards the stream would be de-listed. This would mean that either conditions improved between the time the stream was listed and the time of the study or that closer evaluation shows that the listing was not justified. This did not happen in the case of the Scott River.
2. If it is found that the desired water quality standards are not achievable for the river as a whole, then site-specific standards may be developed and adopted. This was not the case for the Scott River.
3. An achievable implementation plan is developed and adopted to specifically address the sources and actions that cause pollution in the Scott River basin. This is the process that was followed in the Scott River.

3.2.4 Approach to sediment analysis

Source assessment: determines the sources of the sediment that is causing the impairment to the listed water body. The assessment needs to include, at a minimum, the type of sediment (e.g., sand, silt, clay, gravel) and rate at which sediment is being delivered to the water body, and the sources of the sediment (e.g., stream banks, roads that parallel or cross the water body, including sources from outside the riparian zone, such as land development in the source watershed, increased erosion from timber harvest or agricultural areas).

Specific guidance is provided in the protocols for performing this assessment. Critical factors include not only land use, but underlying geology and topography.

Linkage of water quality indicators/targets and sources: determines the linkage that defines the cause-and-effect relationship between the identified sediment sources and the impairment caused by the sediment. This step also includes estimation of the loading capacity. The protocols include guidance on deciding the appropriate level of analysis, and if modeling is required, further detailed guidance is provided on which type of model(s) should be used.

3.2.5 Key points in the Scott River sediment TMDL

- The sediment source analysis addresses both natural and human-caused sources of sediment.
- Road-generated sediment rates that were calculated from road inventories and modeling in one sub-watershed, the South Fork, were applied to other parts of the Scott River watershed.
- Granitic bedrock and decomposed granite soils were considered separately in the load-generated sediment estimates, because this material creates unique problems.
- Large mass-wasting features – landslides, debris flows, earth flows – were inventoried through the entire watershed from aerial photos.
- Streamside sediment source estimates were based on inventories of stream banks and streamside features contributing sediment in sample reaches that were chosen using a stratified random sampling approach. The results were then extrapolated to other stream reaches based on underlying geology.
- The largest sediment sources are from stream sides and have cumulative effects resulting from multiple interacting human activities, primarily agriculture, timber harvest, and construction and use of roads.
- Results estimate current sediment delivery to be 167% of natural sediment delivery.
- The TMDL is set at 125% of natural sediment delivery.
- The sediment TMDL for the Scott River watershed is 560 tons of sediment per square mile per year.

3.2.6 Sampling approach and rationale

The sediment source inventory and analysis is divided into three components:

- Road-generated sediment was calculated based on road erosion inventories and modeling using the program SEDMODL2.
- Large mass-wasting features were inventoried on aerial photos.
- Streamside sediment sources were calculated from inventories of stream banks and discrete erosion and mass-wasting features contributing sediment.

For the purpose of the analysis, the Scott River watershed was divided into seven subareas, primarily on the basis of subwatershed boundaries, to characterize the different subregions.

3.2.7 Combined geologic units

The geologic material and structure underlying a particular area is a primary factor in determining not only sediment delivery under natural conditions but also the change in sediment delivery in response to human activities. For this reason we chose bedrock composition as the factor on which to stratify sampling. The GIS geology map coverage used (Saucedo et al., 2000) shows no less than twelve geologic units mapped in the Scott. Because applying all of these units would create too many strata for a practical sampling program, mapped units having similar properties of weathering and erosion were combined. For the purposes of the streamside sampling program, we combined the mapped units into four geologic units:

- Quaternary Deposits.
- Granitic Bedrock.
- Mafic and Ultramafic Bedrock.
- Sedimentary and Metamorphic Bedrock.

Table 1 summarizes the four geologic units in the Scott river watershed.

Table 1: Areas and stream miles underlain by different geologic units in the Scott River watershed derived from the GIS geology layer of the Geologic Map of California (Saucedo et al., 2000).

Geologic unit	Area (acres)	Area (sq miles)	Area (by percent)	Stream Miles
Quaternary	51218	80	10%	199
Granitic	54938	86	11%	259
Mafic	87370	137	17%	401
Sed & Met	326657	510	63%	1641
TOTALS	***520184***	***813***	***100%***	***2500***

Areas of granitic bedrock pose a particular problem. During weathering of the granitic rock, cohesion between grains is lost, leaving the material as a mass of separate grains ranging in size from fine sand to small pebbles and lacking enough clay to bond it together. Consequently, the decomposed granite is highly susceptible to dry ravel, rill and gully erosion, debris slides, and debris torrents. In addition, disturbance of the surface, or an increase in the degree of slope, tends to accelerate these processes. The problems of stability and sediment contribution associated with decomposed granite are sufficiently severe, widespread, and costly that a conference dedicated to these problems and their solutions was convened in Redding, California in 1992 (Sommarstrom, 1992)

3.2.8 Roads

Most roads, including skid trails (crude temporary roads along which logs are dragged from where they are cut to where they are loaded onto trucks), cross ephemeral or perennial streams. Crossings are built to capture the stream flow and safely convey it through, under, or around the roadbed. However, stream crossings can fail, adding sediment from the crossing structure (i.e., fill) or from the roadbed directly into the stream. Stream crossing failures are generally related to culverts that are undersized, poorly placed, plugged, or partially plugged. When a crossing fails, the total sediment volume delivered to the stream usually includes both the volume of road fill associated with the crossing and sediment from collateral failures such as debris torrents that scour the channel and stream banks.

Diversion potential is the potential for a road to divert water from its intended drainage system across or through the road fill, thereby delivering road-related sediment to a watercourse. The potential to deliver sediment to the stream can be eliminated from almost all stream crossings by eliminating inboard ditches, out sloping roads, or installing rolling dips (USEPA, 1998). Generally, less than one percent of stream crossings have conditions where modification is inappropriate because it would endanger travelers or where modification is impractical because of physical constraints (USEPA, 1998).

3.2.9 Stakeholder participation and coordination

In the public process in this TMDL we sought input and participation from farmers, timber companies, and other stakeholders in the Scott River watershed; from State and federal agencies that have regulatory responsibilities in the region; from public interest groups; and from other interested individuals. The object of this effort was to be as open as possible during the process so that groups using the watershed would not feel, or be, left out. At the time the Sediment TMDL study was being done, a Temperature TMDL was in progress also. The studies were done together and TAG meetings discussed both TMDLs. For this report, however, we discuss only the sediment part of the process.

A key section in the Scott River Sediment TMDL Staff Report (NCRWQCB, 2005) reads:

- The public has had many opportunities to comment on and participate in the development of this Draft Scott River TMDL Action Plan and Staff Report.
- The Scott River TMDL Technical Advisory Group (TAG) has provided input and advice to Regional Water Board staff.
- Staffs have responded to many questions and comments raised by the TAG.
- A public Scoping Meeting was held to solicit public comment on the scope of the environmental review.
- Status updates and presentations on the Scott River TMDL have been made to the Regional Water Board and members of the public.
- There will be many more opportunities for public input and comment on the Scott River TMDL Action Plan.

The chapter introduced by that section describes some of the opportunities that have been made available to the public for comment on and participation in the development of the Scott River TMDL Action Plan.

The Scott River Sediment TMDL Technical Advisory Group (TAG) was formed to provide input and advice to staff of the Regional Water Board during development of the technical TMDL for sediment. Although forming a TAG is not a requirement of the Basin Plan amendment process, the existence of the TAG engaged members of the community and helped to produce a more robust TMDL Action Plan. Inviting public input is not what the engineers and scientists who undertake a technical project think of first, and we found the process time-consuming and at times frustrating. However, by the time the project went to the Regional Water Board for discussion and the processes that would lead to adoption had begun, most of the hard questions and objections had been answered and the adoption process went fairly smoothly.

Members of the TAG included representatives from the California Department of Fish & Game, the California Department of Forestry & Fire Protection, the California Department of Water Resources, the County of Siskiyou, the Farm Bureau (a cooperative farmers' organization), Fruit Growers Supply Company (a timber company), the National Oceanic & Atmospheric Administration, the Natural Resources Conservation Service, the Quartz Valley Indian Community, the Scott River Watershed Council, the Siskiyou Resource Conservation District, Timber Products Company, the United States Fish & Wildlife Service, the University of California Cooperative Extension, the Karuk Tribe, several members of the local communities, and contractors working on behalf of the Regional Water Board to assist with the development of certain sections of the TMDL.

Six meetings were held over the course of the TMDL development period. During this time, Regional Water Board staff presented the following documents for TAG review and comment:

- In response to an overarching concern about the field and analytical methods proposed for use in the Scott River Sediment TMDL analysis, Regional Water Board staff agreed to prepare a pilot study for the South Fork Scott subwatershed, and designed, implemented, and prepared a report on the results of the Pilot Study.
- TAG input on the Pilot Study indicated a need to consider granitic areas separately from areas underlain by other geologic units. This approach was developed and forms the basis for the proposed TMDL.
- Best efforts were made to separately describe and account for distinct land uses, such as forestry and mining.
- Significant additional explanation of methods and procedures was developed for the streamside features analysis.
- Many comments and suggestions received from TAG members on an early draft of the Scott River TMDL Action Plan and Staff Report were incorporated.

3.2.10 CEQA scoping meetings

The California Environmental Quality Act (CEQA) requires that a meeting be held to solicit public comments to help staff assess the potential environmental scope of the environmental analysis. Such a Scoping Meeting was held on June 28, 2005, in Yreka, California, which is very near the Scott River watershed. Many of the comments received at that meeting are concerned technical aspects of the initial proposal rather than the scope of the environmental review. Many of the public comments involved objections to having to change land management practices and fear that the proposed requirements would financially impact residents of the watershed.

A second CEQA Scoping Meeting was held in the town of Arcata near the lower part of the Klamath River, to which the Scott River is a tributary. Here we received quite different input from those affected downstream residents. In Arcata, salmon fisherman complained that poor quality water from the upper river had impacted the salmon population by reductions of 90 %or more over the last 60 years. This was attributed largely to dams that block migration and degrade water quality especially when combined with timber harvesting and agricultural activity. People at the meeting in Arcata felt that their needs were not being addressed in the TMDL as it was not strict enough on the sources of pollution. Hundreds of commercial fishermen and their families were suffering from the decreased fish population and saw the reason as the combination of activities in the watersheds upstream. In addition, the native tribal people, whose religion, diet, and way of life center on the salmon, were suffering from their scarcity.

This second meeting was a lesson on the importance of looking downstream for the effects on other areas and people.

3.2.11 Presentations to the regional water board

Periodically, Regional Water Board technical staff presented updates and status reports to the Regional Water Board and interested members of the public on the Scott River TMDL and related efforts in the Klamath River Basin. Presentations were made on February 10, 2004, on May 4, 2005, and on August 10, 2005. The presentations were opportunities for the public and Board members to hear status updates and background information. At each of these meetings, the public had the opportunity to comment before the Board, and all such comments become part of the public record.

3.2.12 Other activities

On October 12, 2005, Regional Board staff made a presentation to the Siskiyou County Board of Supervisors. Regional Water Board staff maintained regular contact with County staff regarding the status of TMDL development throughout the process.

On October 3, 2002, Regional Water Board staff presented the TMDL program and schedule for the Scott River TMDLs to the Siskiyou Resource Conservation District Board in the town of Etna in the Scott River watershed. On January 9, 2003, Regional Water Board staff made a presentation to the Statewide Coho Recovery Team convened by the California Department of Fish and Game. Regional Water Board staff also attended, as members of the public, a series of meetings by the Scott-Shasta Recovery Team, a separate effort associated with the statewide Coho Recovery Team aimed specifically at developing elements of recovery plans for these watersheds. This coordination identified areas of overlap between the TMDL and Coho Recovery efforts, aligned Coho Recovery recommendations to minimize conflict with TMDL goals, and provided an opportunity for ongoing discussion with individuals and organizations also involved in the TMDL process.

Regional Water Board staff gave regular updates on the status of TMDL activities in the Klamath Basin to the Klamath Basin Fisheries Task Force and its subgroups. Presentations were made to the full Task Force on June 24, 2004, June 15, 2005, and October 19, 2005, and to the Task Force’s Technical Working Group on December 7, 2004.

The USEPA and the Regional Water Board initiated an informal consultation process with the U.S. Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration, Fisheries (NOAA Fisheries) on Klamath River TMDLs. Regional Water Board and USEPA staff used this process to provide information and updates on the TMDLs in the Klamath River Basin, namely the Salmon, Scott, Shasta, Lower Lost, and Klamath River TMDLs. In addition, both NOAA Fisheries and the USFWS attended the Scott River TMDL Technical Advisory Group meetings.

The USEPA held regular meetings with representatives of tribes in the Klamath River Basin watershed in California and the Regional Water Board to provide updates on the TMDL process, as part of USEPA’s tribal trust responsibilities. These meetings have been held approximately quarterly for the last several years.

In addition, there has been and continues to be informal contact with many individuals and organizations active in the Scott River watershed.

3.2.13 Public draft of the Scott River sediment TMDL

- The Scott TMDL and Action Plan released for public comment, September 20, 2005
- Public Comment Period, September 20 to November 3, 2005
- Public Informational Workshop at Regional Water Board in Santa Rosa, CA, October 12, 2005
- Public Informational Workshop (Yreka), October 18, 2005
- Public Informational Workshop (Arcata), October 19, 2005

Additional opportunities for public comment came at the Regional Water Quality Control Board meeting in April 2006 at which the Board approved the plan subject to revision by the board staff; and in June 2006 when the revised plan was presented to the State Water Quality Control Board it was approved.

We discuss the large number and sources of public participation to emphasize that the stakeholders were sought out and kept advised of the project and that their comments and ideas were taken seriously and acted upon. This is not the usual course for a technical project, but most technical projects do not depend on public participation of the majority of a population to achieve success. In this case, getting the right technical answers was not sufficient. Implementation of the plans to improve the watershed depended on the active involvement and cooperation of the large majority of the people, agencies, and corporations that have activities in the watershed. In order to achieve buy-in, it was necessary that people participate in the process and be educated in the reasons changes were needed, what those changes needed to be, and how their participation is required to bring about the changes.

3.2.14 Scott River TMDL and load allocations

In accordance with EPA regulations, the loading capacity (TMDL) is allocated to the various sources of sediment in the watershed, with a margin of safety. That is:

TMDL = sum of the wasteload allocations for individual point sources
+ sum of the load allocations for nonpoint sources
+ sum of the load allocations for background sources.

The margin of safety is discussed below. As there are no point sources of sediment in the Scott River watershed, the wasteload allocation for point sources is set at zero.

In addition to ensuring that the sum of the load allocations equals the TMDL, the Regional Water Board considered several factors related to the feasibility and practicability of controlling various nonpoint sources of sediment. The load allocations for nonpoint sources reflect professional judgment as to how effective best management practices are in controlling these sources. For example, techniques are available for greatly reducing sediment delivery from roads (Weaver and Hagans, 1994). In the Scott River watershed, the effectiveness of mitigation measures with respect to roads has been demonstrated in one major sub-watershed and in improved road design in other areas.

For the Scott River TMDL, source categories that are more controllable receive load allocations based on a higher percentage reduction from current levels. For example, failures of road stream crossing are more readily controlled than road-related mass wasting, particularly in weathered granite. Therefore, the load allocation for road stream crossing failures is based on a loading reduction of 75 %, whereas the load allocation for road-related mass wasting is based on a loading reduction of 42 %.

The table showing the load allocations for the Scott River watershed is too large and complex to include here but it may be viewed online as Table 3.23 in the Scott River TMDL technical document (NCRWQCB, 2005). The allocations depend upon the relative emphasis and magnitude of erosion control programs that need to be developed during implementation. The load allocations are expressed in terms of yearly averages (tons/sq mi-yr). They could be divided by 365 to derive daily loading rates (tons/sq mi-day), but the Regional Water Board is expressing them as yearly averages, because sediment delivery to streams is naturally highly variable on a daily basis. In fact, the Water Board expects the load allocations to be evaluated on a ten-year rolling average basis because of the natural variability in sediment delivery rates. In addition, the Water Board does not expect each square mile within a particular source category to necessarily meet the load allocation; rather, the Water Board expects the average for the entire source category to meet the load allocation for that category.

3.2.15 Margin of safety

The federal Clean Water Act, Section 303(d) and the associated regulations require that a TMDL include a margin of safety that takes into account any lack of knowledge concerning the relationship between the pollutant loads and the desired receiving water quality.

The margin of safety may be incorporated implicitly by making conservative assumptions in calculating loading capacities, waste load allocations, and load allocations (USEPA, 1991). The margin of safety may also be incorporated explicitly as a separate component in the TMDL equation. For the Sediment TMDL analysis, conservative assumptions were made that account for uncertainties in the analysis.
Specific conservative assumptions used to account for margin of safety:

- In estimating sediment delivery by soil creep it was recognized that the hydrography used directly affected the estimated delivery from this source. Because no available hydrography GIS layer shows all streams, as established in field studies, the delivery from this natural source is underestimated. This underestimation affects the allocation of anthropogenic sediment, as the allocation is calculated as a percentage of the natural delivery.
- Ages of small features tended to be estimated low. The majority of small features described and estimated were along streams and the majority of these were natural. This would tend to result in higher yearly rates of sediment delivery for these features and is therefore conservative. If features attributed to the near-catastrophic 1997 flood event actually were initiated before this event, yearly rates of sediment delivery estimated for these features would be higher and are therefore conservative in the context of calculating the TMDL.
- The estimation of cumulative watershed effects is a part of the margin of safety. Some human-caused features are not accounted for in their proper category. For example, the GIS layer of roads used under-represents roads and does not include skid trails. In some areas only major haul roads are included, which means that many temporary roads and skid roads that can increase erosion remain

unaccounted for in that road survey. Addition of the cumulative watershed effect factor accounts for roads and skid trails that are not documented in the survey.

3.2.16 Seasonal variation and critical conditions

The TMDL must discuss how seasonal variations were considered. Sediment delivery in the Scott River watershed has considerable annual and seasonal variability. The magnitudes, timing, duration, and frequencies of sediment delivery events fluctuate naturally depending on variations in storm patterns throughout the year and between years. Because the storms and the mechanisms of sediment delivery are largely unpredictable from one year to the next, the TMDL and load allocations are designed to apply to the sources of sediment, not the movement of sediment across the landscape, and to be evaluated on the basis of a ten-year rolling average.

The Water Board assumes that by controlling the sources to the extent specified in the load allocations, sediment delivery will be controlled within an acceptable range for supporting aquatic habitat, regardless of the variability of storm events. The TMDL must also account for critical conditions for stream flow, loading, and water quality parameters. Rather than explicitly estimating critical flow conditions, this TMDL uses indicators that reflect net long term effects of sediment loading and transport for two reasons. First, sediment impacts may occur long after sediment is discharged, often at locations downstream of the sediment source. Second, it is impractical to accurately measure sediment loading and transport, and the resulting short term effects, during high flow events that produce most sediment loading and channel modifications.

4. Discussion

In the State of California the waters of most rivers, lakes, and wetlands are defined by law as a public trust, which means that they are the property of the people through the agency of the State government. Legally, this means that the government of the State is responsible for managing the waters for the best use of the people and in such a way that the waters are not degraded. This is the legal foundation on which State government management of the water is built.

Before industrialization and high population growth, when the amount of waste was small, a saying among some engineers was “The solution to pollution is dilution.” This is not, and never was, a good concept: dumping waste into a river simply transports the waste to the communities downstream. When the amount of waste is small the practice of dumping has been generally accepted in many parts of the world. Beginning in the late 19th century, however, in the USA many rivers became so degraded by industrial and municipal waste that mechanisms had to be developed to clean them up in order for progress and development to continue. Not only did surface water pollution make the surface water unfit to use and expensive to treat, it both contaminated groundwater through the recharge process and increased the demand for groundwater.

A more modern approach is: “Never dilute what is already concentrated.” because treating concentrated waste is less expensive and easier than treat a pollutant without having to concentrate it first. One of the principles of watershed management is to recognize and treat pollutants at the source before they get released to the environment.

5 Summary

Improvement of groundwater usage for large cities depends on more than one approach. Proper and innovative engineering for extraction, usage, and recharge of groundwater in the region of a city is necessary to make efficient and long term use of this resource. Most of the papers in this volume are concerned with this set of challenges and solutions as related to the large cities of China.

However, another set of challenges relates to the bigger picture of managing water at a regional level. Groundwater management at the local scale cannot be efficient unless it is accompanied by a program of watershed management in the source areas upflow from the city. Recharge from local drainage is an important part of the recharge system, but much of the recharge also comes from rivers that flow through enormous drainage basins before they enter the region of the large city. Such a river carries whatever contaminants have been discharged into the drainage throughout this collection area. As pumping of groundwater allows recharge from the river, some contaminants are not filtered out and inevitably contaminate the groundwater.

The economic consequences for the city are twofold. First, the cost of treating groundwater for domestic or industrial use rises as contamination rises. Second, as the desirability of groundwater decreases, more surface water is used at high treatment cost.

As one example, the rapidly growing city of Shanghai lies at the mouth of the Yangtze, which drains some 1,800,000 sq km of land. This drainage basin supports about 400 million people, has large areas that are densely populated and under intense agricultural cultivation, and includes many cities. As the Yangtze arrives in Shanghai, it carries a significant portion of the waste and pollution generated in this enormous watershed. During the present and foreseeable rapid industrialization and intense farming, the waste load carried by the river can only be expected to increase if agricultural, industrial, and waste disposal practices remain the same. In order to avoid increasing the flood of pollutants now reaching downstream cities, agricultural practices, industrial waste-disposal practices, urban water and sewage treatment processes, and even small-scale human waste disposal practices will have to change.

One way to approach such change is through regulation. But we suggest that such regulation alone would have little chance of being effective because it would be asking huge numbers of people to change the way they live on the basis of rules that they would not understand well, and attempting enforcement would overwhelm the capacities of government.

A more effective way to bring about change may be through education and through involving as many people as possible in the process. This type of public effort is not what comes first to the mind of the engineers and scientists who recognize and quantify the problems. Such specialists are more inclined to depend on a technical solution to the problems. The technical solutions are absolutely necessary, but getting them carried out and lessening the need for them, depend on the population as a whole. A team of engineers cannot change the way of living and thinking of the 400 million people in the Yangtze watershed: only education can accomplish that. It is necessary to involve people in the problem-solving itself so that they achieve buy-in toward solving the problems and realize that they are stakeholders and have something to gain.

6 Key Points

6.1 In the big picture

- Groundwater for cities is part of a much broader set of conditions and problems.
- Improvement of water quality through watershed management is more cost effective in the long run than paying ever more to purify water that has already become polluted.
- The natural water cycle delivers a continuous supply of clean water to the continent, free of cost. Therefore to the extent that water quality is degraded the pollution is largely the result of human actions.

6.2 At the level of developing solutions

- While groundwater is an essential part of the water supply for cities, surface water also is essential as surface water supplies recharge to groundwater and is itself a major part of the municipal supply.
- Management of surface water quality and quantity is a function of society as a whole and the values and viewpoints of people as they use, misuse, and reuse water.
- The use of waterways to “dispose of” waste is no longer a viable option in a densely populated, economically developing country.
- Water supply, especially in the field of water quality, is at least as much a social problem as a technical problem, and changes in social attitudes toward water are essential before the technical solutions can become effective.
- Watershed management involving contribution and buy-in by stakeholders rather than relying only on engineering and regulation has been shown to be effective.
- In California, education and participation by stakeholders is an evolving process that is having considerable success.
- The means and processes of effective stakeholder involvement depend greatly on the culture, attitudes, and history of the stakeholders and on the processes of government agencies involved. Therefore, watershed management in China may work quite differently from watershed management in California and it will have Chinese characteristics.

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Cost-Benefit Analysis of Jinan’s Water Supply and Groundwater Protection
济南市地下水保护和供水保泉成本效益分析

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Abstract

Jinan city is well-known for its many springs. The water supply in Jinan used to depend on underground sources of water. In order to protect the springs in this city, the water supply system started to absorb various water sources mainly including water from Yellow River transfer project, reservoirs water and underground water. Water from the Yellow River contributes the greatest proportion; however this water has a low quality and a high cost. The imbalance between the costs and benefits of different water sources ultimately negates efforts to protect the springs. Therefore, a Cost-Benefit analysis of Jinan’s water supply is important. In this paper, the costs per m^3 of different water sources are analyzed and calculated. The benefit of each water source is then calculated. Finally, the paper discusses the costs and benefits of different water sources and groundwater protection efforts in Jinan.

摘要

目前，为实现保泉目标济南市供水系统从过去主要依赖地下水改为多水源供水格局。市区水源主要有引黄工程黄河水、地表水库蓄水、地下水 3 个主要部分组成。这其中黄河水占的比例较大，但其水质差、成本高。保泉的成本、效益不成比例，供水企业入不敷出，从长远来看，这对保泉极为不利。因此，要实现供水保泉目标，进行供水成本效益分析具有很重要的意义。本文首先对市区各水源供水成本与供水效益进行了分析与计算，在此基础上，进行了不同方案的供水保泉的成本效益分析。结果对济南市供水保泉方案的选择以及地下水保护的远期规划具有很好的参考意义。

1 Introduction

Jinan, also named “Spring-City", is famous for its springs. Since 1980, the unsustainable use of underground water sources and the lack of effective management and protection resulted in the continual depletion of groundwater levels**.** In March 1999, the Baotu Spring stopped flowing, and became the focus of widespread attention.

Jinan City’s water shortage and wider damage to the local environment also hamper the sustainable development of the economy. To solve these problems and restore the environment, Jinan City carried out a groundwater protection plan that seeks to achieve harmony between human needs and environmental protection, restore the flow of the springs, natural lakes and rivers as well as promote the development of the economy in

Jinan City. It is also a part of the 'National Underground water Protection Action Plan'. In order to realize the targets of Jinan City's groundwater protection plan, Jinan city should use the Yellow River and Changjiang River. It is also helpful for industry to use surface water and limit groundwater for domestic use. Agricultural irrigation should seek to save water overall and mainly use surface water and grey water. All water used for ecological and environmental purposes should be surface water.

The composition of the Jinan water supply has also changed. When groundwater use is reduced, surface water may be increasingly used to compensate. Costs of water from different sources, per m3, are also different, and surface water is more expensive than groundwater. If we change the structure of the Jinan water supply, costs will increase if more surface water is used. The economic viability of the water supply plan should be discussed. It is necessary to do cost-benefit analysis of the Jinan water supply with a focus on groundwater protection.

2 An introduction to Jinan's Major Water Sources

The Jinan City water supply system has multiple sources. The three major sources are the Yellow River, reservoirs in the south and groundwater in the urban area. The Yellow River water reservoir, Queshan and Yuqing supply water to the city through the Huanghe and Yuqing water plants. Among the surface water reservoirs, only the Wohushan reservoir and Jinxiuchuan reservoir supply water to the city. The Wohushan reservoir transports water to the Nanjiao water plant, one of the two main water plants in Jinan, using Culverts. Jinxiuchuan reservoir transports water to the Fenshuiling water plant using Nullah, an open channel. The Dongjiao, Xijiao and Shiqu water plants supply the city with groundwater. 'Self-Supply Wells' that belong to companies also exploit a part of the groundwater supply.

The urban water supply is mainly used for industrial and domestic use. Between 2002 and 2004, the usage of each source of water for Jinan City is calculated and given (See table 1).

Table 1: 2002～2004 years water supply in Jinan city

Year	Water from The Yellow River (10^4m^3)	Water from reservoir (10^4m^3)	Underground water (10^4m^3)	Total Num (10^4m^3)
2002	15958.3	2737.7	15213.0	33909.0
2003	14008.1	4132.9	15430.0	33571.0
2004	12876.8	6410.2	17881.0	37097.0

In the table, the water from the Yellow River reservoir was removed through evaporation, seepage and transmission losses. Also, the Self-Supply wells' capacity is about 200,000 m^3 per day (73 million m^3/Year).

3 Calculating the Cost of the Water Supply in Jinan City

The purpose of the calculation is to obtain the cost per m^3 of each water source. The water supply of Jinan City is managed by the Jinan Water Supply Company. Therefore, the water management cost to pipeline cost is the same and calculated first. Other costs such as water purchasing costs, power costs, manufacturing costs, loan interest and other costs should be calculated according to water sources respectively.

According to the data provided by Jinan Water Supply Company, in 2002 the pipeline manufacturing cost was 68.523 million Yuan. There was little change in 2003 and 2004 so we take the same value for those years. The water supply in 2002 was 266.09 million m^3, so the cost for water management is 0.25 Yuan per m^3. Similarly, it was 0.26 Yuan in 2003 and 0.22 Yuan in 2004. The other individual costs of each water source are calculated as follows:

3.1 Yellow River water projects

The projects mainly consist of Yuqinghu reservoir, Queshan Reservoir, and their water plants. Yellow River Diversion Project costs for the year 2002-2004 were analyzed and calculated:

(a) Costs in 2002:

The cost of the Yuqing Lake Reservoir, Queshan Reservoir and Yuqing Water plant includes: the depreciation of fixed assets was 64.4222 million Yuan. Reservoir construction loan interest was 59.4771 million Yuan. Power fees were 29.5772 million Yuan. Water resources fees were 8.287 million Yuan and Others costs such like flood control, water treatment is 6.1963 million Yuan. The Yellow River water plants had a 12.849 million Yuan production cost and a 9.958 million Yuan manufacturing cost. The total cost in 2002 was 190.7668 million Yuan (1.44 Yuan per m3).

(b) Costs in 2003:

The depreciation of fixed assets and the loan interest were the same as 2002. Power costs, water resources fees and other expenses, such as water treatment cost are calculated according to Yuqinghu reservoir by water volume.

The cost of Yuqing Lake Reservoir, Queshan Reservoir and Yuqing Water plant includes: depreciation of fixed assets: 64.4222 million Yuan. Reservoir construction loan interest: 59.4771 million Yuan, power fees: 25.9628 million Yuan, water resources fees: 727.43 million, others: 5.4391 million Yuan. The costs of the Yellow River water plant are given below: production cost,12.849 million Yuan and manufacturing cost, 9.958 million yuan.

The total cost in 2003 was 185.3824 million Yuan (1.58 Yuan per m3).

(c) Costs in 2004:

Similarly, the water supply costs in 2004 as follows.

The costs of Yuqing Lake Reservoir, Queshan Reservoir and Yuqing Water plant include: depreciation of fixed assets: 64.4222 million Yuan. Reservoir construction loan interest: 59.4771 million, Power fees: 23.8658 million Yuan, Water resources fees: 668.68 million. Other costs such as flood control and water treatment: 4.9998 million Yuan. The cost of the Yellow River water plant: production cost is 12.849 million Yuan. Manufacturing cost: 9.958 million Yuan. The cost of The Yellow River water plant is given below: production cost is: 182.2587 million Yuan (1.63 Yuan per m3).

3.2 Surface water

In 2002, Nanjiao water plants purchased 3.404 million m^3 of water from Wuhushan reservoir. The production-costs this year (including power fees. wages, and so on) were 626.9 million Yuan. Manufacturing-costs (including depreciation, wages for workers, repairing-costs, etc.) were 3.535 million Yuan.

Other surface water mainly comes from the Fenshuiling water plant, and brought from the Fenshuiling reservoir. Due to a lack of data, the cost analysis of the Fenshuiling water plant is taken as the same as the Nanjiao plant. TheNanjiao water plant's current daily water producing capacity is about 47,000 m^3, and the Fenshuiling water plant is more than 52,000 m^3 per day. According this proportion, Fenshuiling water production costs is 7.7 million Yuan in 2002 and manufacturing cost is 3.9 million Yuan.

Therefore, the surface water production cost in 2002 was 13.969 million Yuan and manufacturing costs was 7.435 million Yuan. For 2003 and 2004 year, production cost and manufacturing costs are also calculated. See table 2.

Table 2: Costs of surface water supply

Year	Water 10^4m^3	Price of Water before treatment Yuan	Costs for purchasig water 10^4Yuan	Water production costs 10^4Yuan	Manufactur-ing costs 10^4Yuan	Total costs 10^4Yuan	Costs per m^3 Yuan/m^3
2002	2737.7	0.26	711.8	1396.9	743.5	2852.2	1.29
2003	4132.9	0.26	1074.5	2108.8	743.5	3926.8	1.21
2004	6410.2	0.26	1666.6	3270.8	743.5	5680.9	1.10

3.3 Groundwater

The Jinan Dongjiao water plant, Xijiao water plant and the urban water plant supply the city with groundwater. In 2002, the costs including water production costs were 28.515 million yuan; Manufacturing costs: 9.733 million Yuan). The data is given in the following table. The water supply costs of 2003 and 2004 year are also calculated.

The average annual water supply of Self-Supply wells of the enterprises is about 7,300 m^3. for this part of water, water resources costs for government is 1.80 m^3 and production costs is about 0.7 Yuan/m^3, so the price of Self-Supply wells water is 2.5 Yuan. The average annual cost of Self-Supply wells water is about 182.5 million Yuan (Table 3).

Table 3: Groundwater supply costs for Jinan city

Year	Production costs (10^4 Yuan)	Manufacturing costs (10^4 Yuan)	Total costs (10^4 Yuan)	Costs per m^3 (Yuan/m^3)
2002	2851.5	973.3	3824.8	0.73
2003	2929.7	973.3	3903.0	0.74
2004	3917.5	973.3	4890.8	0.68

4 The Calculation of the Benefits of Jinan's Water Supply

The benefits are calculated according to the actual water price. According to information provided by the Jinan City Water Supply Company, current water price for domestic use is 2.35 Yuan/m^3, theprice for services is 3.5 Yuan / m^3, the industrial water price is 2.4 Yuan/m^3.

Water use efficiency is 65%. There have been no major technological improvements to the water supply in recent years, so the water use efficiency takes the same value from 2002 to 2004. The water supply benefits of each water source in Jinan city are calculated and given in Table 4.

Table 4: Water supply benefits of Jinan city

Year	Benefits（10^4 Yuan）		Total benefits（10^4 Yuan）	Water Use Efficiency (%)
	Industrial Water	Urban domestic water		
2002	19835.4	24240.7	44076.1	65
2003	21804.1	19964.62	41768.7	65
2004	23259.6	23981.4	47241.1	65

The above calculation does not include "self-supply wells". The water price of "self-supply wells" is 2.55 yuan per m^3. Self-Supplywells, on average, produce 186.15 million Yuan a year.

5 Cost-benefit Analysis of Jinan Water Supply and Groundwater Protection

5.1 2002 to 2004 cost-benefit analysis

Firstly, the calculated the cost andbenefits from 2002-2004. The total cost over three years was 146428.19 million Yuan andhe benefits were 1.11408 billion Yuan. "Self-supply wells" produced 558.45 million Yuan. The total benefits amounted to 1.67253 billion Yuan.

2002 had a total cost of 508.56 million Yuan, of which68.523 million Yuan were management and pipeline fees. For the Yellow River part, the cost is 190.767 million Yuan and the reservoirs part was about 28.522 million Yuan. Groundwater cost 220.748 million Yuan (including 182.5 million Yuan for self-supply wells). The total benefit for 2002 is 626.911 million Yuan (Self-supply wells is 186.15 million yuan).

The cost for 2003 was 514.70 million Yuanof which 68.52 million Yuan was management and pipeline fees. For the Yellow River part, the cost was 185.382 million Yuan and for the reservoirs part was about 39.27 million Yuan. Groundwater costs 221.53 million Yuan (including 182.5 million Yuan for self-supply wells) and the total benefits for 2002 were 603.84 million Yuan (Self-supply wells is 186.15 million yuan).
The cost for 2004 was 508.56 million Yuan of which 538.999 million Yuan was for management and pipeline fees. The Yellow River part cost 182.259 million Yuan and the

reservoirs part was about 56.81 million Yuan. The groundwater part cost 231.41 million Yuan (including 182.5 million Yuan for self-supply wells). The total benefits for 2002 were 658.56 million Yuan (Self-supply wells is 186.15 million yuan).

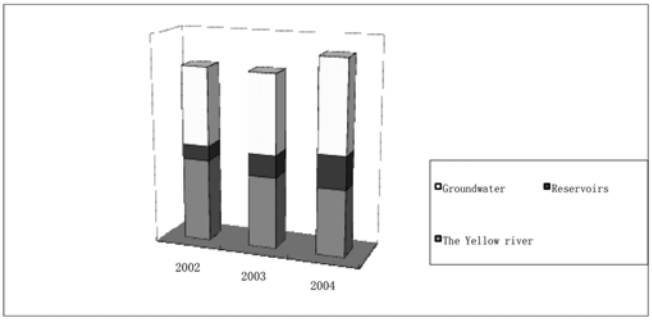

Figure 1: Water supply structure of Jinan city

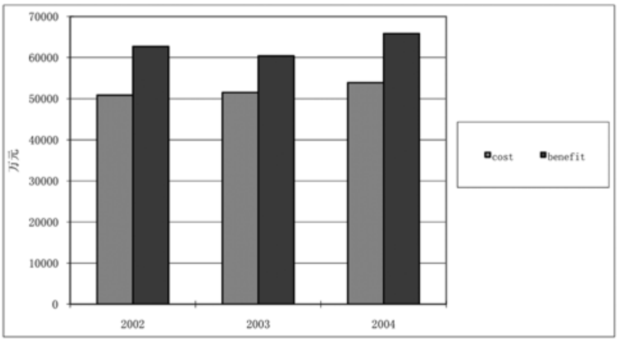

Figure 2: 2002~2004 water supply cost and benefit of Jinan city

5.2 Cost-benefit analysis of the Jinan City groundwater protection action plan

According to the "action plan for groundwater protection in Jinan City" and the long-term goals for spring protection, a long-term target of water supply of Jinan City is shown in table 5.

Table 5: A long-term target of water supply of Jinan City

Groundwater (10^{4}m^{3})	The Yellow river water(10^{4}m^{3})	Spring water (10^{4}m^{3})	Reservoir water (10^{4}m^{3})	Others (10^{4}m^{3})
15330	29200	3650	3650	14600

In order to protect the springs, underground water exploitation should be controlled. The volume of groundwater extracted was160,000 m^{3}/d in the spring zone and about 360,000 m^{3}/d outside of the zone and the total groundwater supply was 520,000 m^{3}/d.

Spring water resources should be used effectively. Spring water is first used for landscape and then collected for domestic water use. A project for this plan will be built. The landscape water reserve for domestic water project planned to supply 100,000 m^3/d of spring water for domestic use and invest 155 million Yuan. The depreciable life span will be set as 50 years according to 'The Regulation of Water Project Fixed Assets Classified Depreciable Life'. During the operation, the depreciation cost for one year is 3.1 million Yuan. The annual project's operating cost, taking 2.5% of the total investment, is 3.875 million Yuan. Comparing with 2002, which is part of the additional costs.

The plan suggests making full use of surface water. 10^5 m^3/day of water from Jinxiuchuan and Wohushan reservoirs would supply the city. Queshan, Yuqing and Donghu reservoirs supply 1.2 million m^3/day of water from the Yellow River and South-to-North water diversion project (SNWDP). The cost of water from SNWDP should be calculated independently from the 2002 prices. For this water source, the entrance price is 0.8 Yuan/m^3, the water resource fee is 0.35 Yuan/m^3, the water treatment costs are 0.34 Yuan/m^3 and the management costs are 0.25 Yuan/m^3. Therefore, at the 2002 level, the cost of SNWDP Water is 1.74 Yuan/m^3.

Finally, taking 2002 as a base year, the cost-benefit analysis shows that the total cost of the groundwater protection and long-term water supply target scheme was 870.93 million Yuan and the total benefits were 1.101077 billion Yuan.

6 Conclusion

According to the long-term "Action plan for groundwater protection in Jinan City" and using 2002 water price. the total cost of the long term protection plan would be870.93 million Yuan with the benefits totaling 1.101077 billion Yuan. In conclusion, the plan appears feasible.

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Storm Water for Groundwater Recharge in Beijing: Opportunities and Limits
北京利用雨水进行地下水回灌：机遇与局限

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Abstract

The capital of the P.R. China, Beijing, is one of the cities facing a serious water shortage and pollution problems. Hasty urbanization has dramatically reduced the area of pervious and vegetated land surfaces. As a result, the risk of flooding increased due to the limited drainage capacity of the city’s rivers and lake systems. Furthermore, natural groundwater recharge has been reduced and over-pumping has decreased the groundwater levels to such an extent that water supplied from groundwater has become extremely expensive.

In order to contribute to the solution of these problems, from 2000 to 2004 a joint Chinese-German research project, “Sustainable Water Management in Urban Areas, Flood Control and Groundwater Recharge”, was realized with the University of Essen, represented by Professor Geiger, and the Beijing Hydraulic Research Institute, represented by Professor Ding, as the leading institutions. The WASY, a German company, had the task of analyzing and planning groundwater recharge facilities as well as placing the findings into the regional context of the greater Beijing area. Major results are presented in this paper.

Since 2004, another Chinese-German research project has gotten underway, “Sustainable water concept for the Olympic Park 2008” with the Tsinghua University (INET, Professor Zhao) and WASY as the leading partners. Again, possibilities for groundwater recharge were studied and results will be discussed.The results of research and practical experiences in Beijing as well as in Germany will be summarized and future needs for research and management are presented.

摘要

中国的首都北京是严重缺水和面临水污染的城市之一。飞速的城市化使植被覆盖的地表和能够渗透的地区急剧减少。结果，由于城市河湖系统排水能力的限制使洪水的风险增加。而且，天然地下水回灌的减少和过度开采在一定程度上使地下水位下降，地下水供水变得非常昂贵。

为了解决这些问题，2000 年到 2004 年实行的一项中德联合的研究项目“城区可持续的水管理，洪水控制和地下水回灌”以德国埃森大学（盖革教授）和北京市水利科学研究院（丁教授）为主要机构。WASY 的任务是分析和规划地下水回灌的可能性以及对整个北京地区研究结果进行分区。本文将介绍主要的研究结果。

从 2004 年开始，另一项与清华大学开展的中德研究项目“2008 奥运公园可持续的水观念”，WASY 是主要的合作伙伴。地下水回灌的可能性在这个项目中再次得到研究，结果也将在文中讨论。本文总结了北京和德国的研究结果和实践经验，介绍了将来研究和管理的需要。

1 Background: the Problems

The Northern Provinces of China and the Beijing municipal area are confronted with two main problems of water resources management in their relevant catchment areas: the increasing shortage of available water resources due to increasing water demand and, perhaps decreasing water resources, and the qualitative status due to rural and urban development.

These problems pose serious barriers for sustainable development and social welfare in the northern region in general and in the capital, Beijing. Beijing today with more than 15 million inhabitants is one of the largest urban centres in the world. Per inhabitant, however, there is only 300 m^3 of water available per year as compared to 2200 m^3 in China or even 9000 m^3 world-wide. Two thirds of Beijing's water supply is taken from groundwater sources. Groundwater resources are highly overused and groundwater levels have continued to decrease, as Figure 1 illustrates.

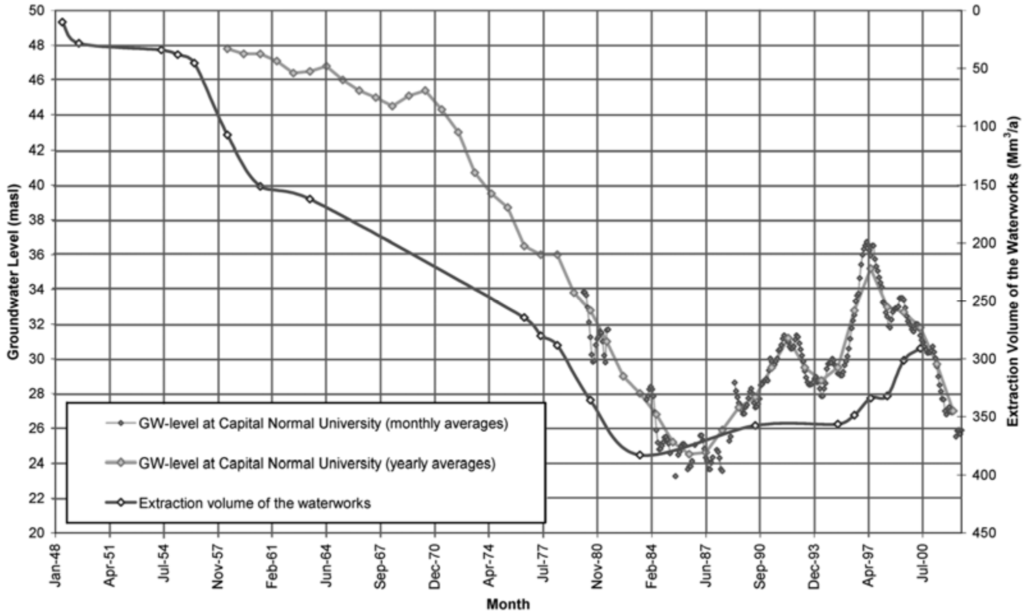

Figure 1: Groundwater depletion and groundwater extraction in Beijing

Consequences of this depletion are:

- Vulnerability of urban water supply
- Increasing pressure on surface waters and lack of surface water

- Land subsidence due to over pumping
- Negative impacts on ecology and the environment
- Overuse of groundwater resources results in short term benefits but leads to endless longer
- term consequences, unless the lacking resources are recovered

One of the possible solutions to these problems is groundwater recharge, both, using storm water and artificial groundwater recharge (surface water, reclaimed waste water). In the following sections, aspects related to storm water management and groundwater recharge are discussed.

2 The Chinese-German Projects

Over the past10 or more years, Chinese-German research projects related to Beijing's water problems have been realized, some of which are still running, see Figure 2 for an overview. All of those projects tackledaspects of storm water management and / or groundwater recharge. Two of these projects will be presented here.

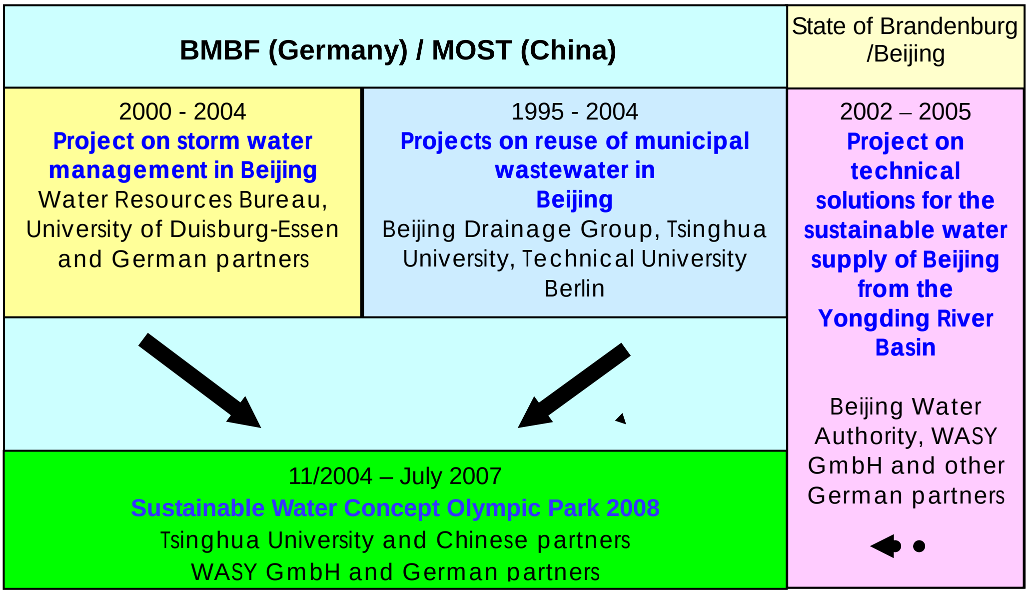

Figure 2: Chinese-German water projects in Beijing

2.1 Research project:Flood Management and Groundwater Recharge

This project, supported by BMBF and MOST[1], was initiated and co-ordinated by Prof. W. Geiger, University of Essen, and Mr. Pan Anjun, Beijing Water Authority.

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[1] Editor's note:BMBF: German ministry of Education and Research; MOST: Chinese Ministry of Science and Technology

The purpose of this project was to demonstrate that the objectives of groundwater recharge and flood control in Beijing can be met both in existing and newly developed urban areas by applying newer techniques for water saving, storm water detention, treatment and infiltration. For this reason, six different demonstration bases were selected. The demonstration bases had to reflect existing densely built-up situations, the density of existing built-up areas and completely new development conditions, residential, commercial and other urban uses with different pollution potential. This paper will focus on two sites from the point of view of groundwater recharge; Beijing Institute of Geological Engineering (Site I), an existing densely build-up area (3 ha) in the centre of Being City and Tianxiu Garden (Site II), a completely newly developed area (11 ha) in the north-western part of town.

2.1.1 Site description and development

In both demonstration bases it was decided to develop a decentralized rainwater harvesting system, which regenerates as much water as possible into the groundwater by means of infiltration.

The geological conditions of both project areas show a comparable impermeable topsoil layer. This layer had to be penetrated in order to be able to recharge large amounts of water. At Site I (Beijing Institute of Geological Engineering) this layer had a thickness of more than 9 m and at Site II (Tianxiu Garden) a thickness of about 6 m. These depths are too deep to use areal surface infiltration. Besides the depth, the high losses due to evaporation (ca. 2000 mm/a) make this kind of artificial recharge in general not a suitable solution for Beijing conditions. It was therefore decided that a sub-surface infiltration would be the best solution for both project areas. For monitoring and maintenance purposes it was also decided that all sub-surface recharge facilities will be implemented as recharge wells which penetrate the impermeable topsoil layers.

2.1.2 Demonstration site I

At Site I the recharge wells were designed as short and wide as possible for two reasons: (1) to provide easy access for maintenance and (2) to have a large distance between the bottom of the well and the groundwater table, which increases the filtering capacity of the sandy subsoil. To minimize the technical effort, wide concrete rings for the purpose of maintenance were placed in the upper part of the structure. The remaining part of the borehole is surrounded by a perforated steel pipe and filled with coarse gravel, the permeability of which being higher than the permeability of the permeable soil beneath the well. Based on analytical calculations and in close consultation with the other project team members it was decided to choose an infiltration rate of 4 l/s for each well. It was calculated that the necessary diameter of each well should be 1.2 m. An example of a well is shown in figure 3.

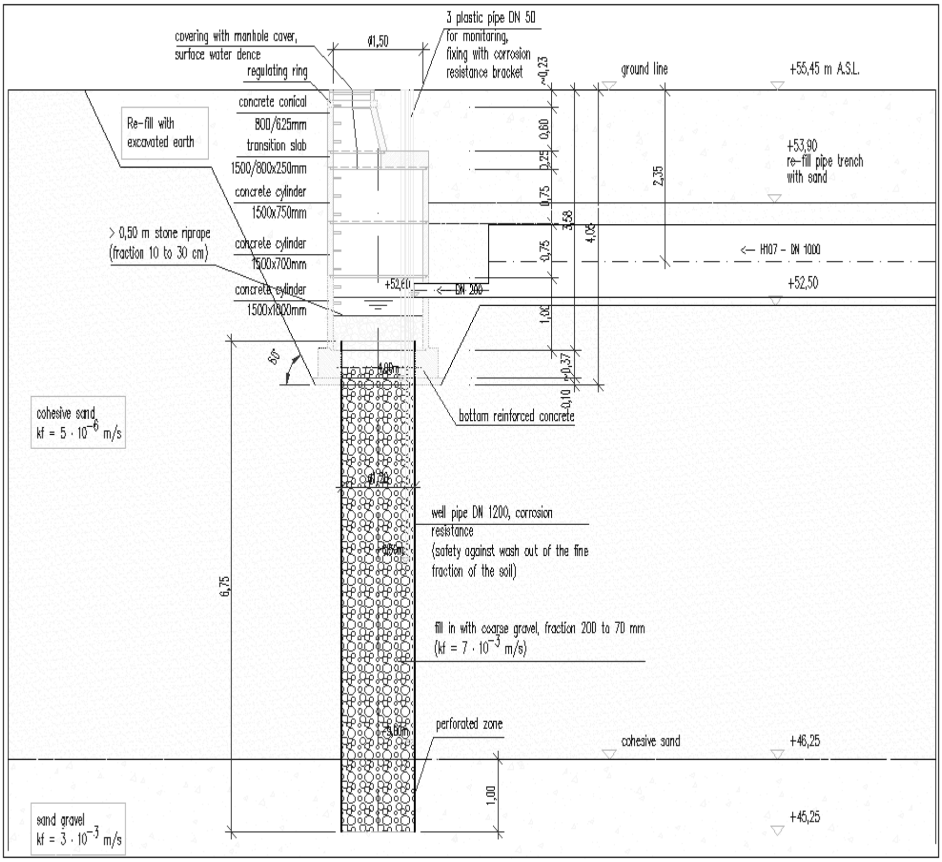

Figure 3: Example of the design of the recharge wells for demonstration site I

2.1.3 Demonstration site II

In the next figure (Figure 4), the layout of the storm water collecting system for this site is shown. The blue crosses show the two planned recharge wells facilities, with 4 wells at the end of the 4 legs of the cross. At the crossing, a dividing shaft has been positioned.

Due to the less permeable aquifer, the diameters of the recharge wells planned for Tianxiu Garden are bigger than the ones for Beijing Institute of Geological Engineering (where each well has a diameter of 2 m). Like at Site I (Beijing Institute of Geological Engineering), the shafts have been made of concrete rings. Because the topsoil is not as thick as at Site I, these rings penetrate directly into the permeable medium sand layer. There is no steel pipe beneath the concrete rings. The distance (centre to centre) between two neighbouring wells in one facility was determined to be at least 17.5 m to avoid too much of an influence between both wells. The shaft bottom is filled with a coarse gravel layer approximately 1.0 m thick, which is covered by a stone riprap as a protection against erosion.

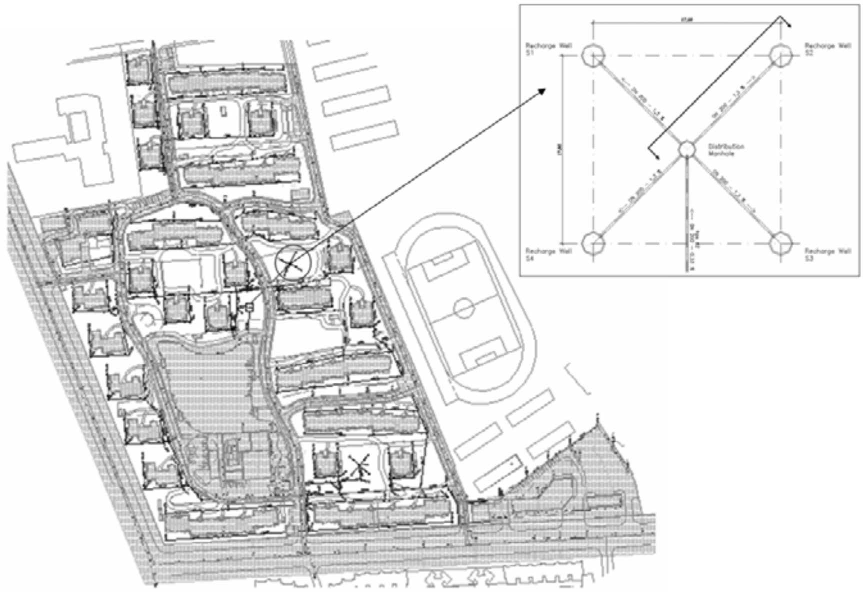

Figure 4: Layout of storm water collecting system of demonstration site II

At the beginning of the planning for the final technical design, a complete centralized system with only one recharge facility was chosen. This is the southern facility. To calculate the infiltration rates for this facility a 3D FEFLOW[1] groundwater model has been created based on all available data which could be collected during the project. Compared to Site I, the amount of hydro-geological data was rather satisfying. Another reason to use a more scientific approach to determine the infiltration rates was the fact that the groundwater levels in this area are close to the surface and were therefore limiting the infiltration capacities. This influence could be analyzed effectively using the 3D unsaturated groundwater model.

The mesh of the FEFLOW groundwater model was created in a way which perfectly reflected the size of each individual well. For the northern facility a similar model was created, assuming that the capacities of both facilities are not affected by each other. In both models the empty wells have been described by a rather large k_f-value. The concrete rings were consequently modelled with very low permeability's. The mesh of the model representing the southern facility is displayed in the next figure (Figure 5). Using both models it was analyzed under which groundwater conditions an infiltration rate of 8 l/s for each recharge facility could be guaranteed. This was the assumed value on which the storm water collecting system had been designed by other members of the German project team. It was concluded that only once in 5 years the groundwater conditions will be too high to guarantee this infiltration rate. As this is also the design criteria for the flood system as a whole, the results were satisfactory.

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[1] Editor's note:FEFLOW is a registered trademark of WASY GmbH.

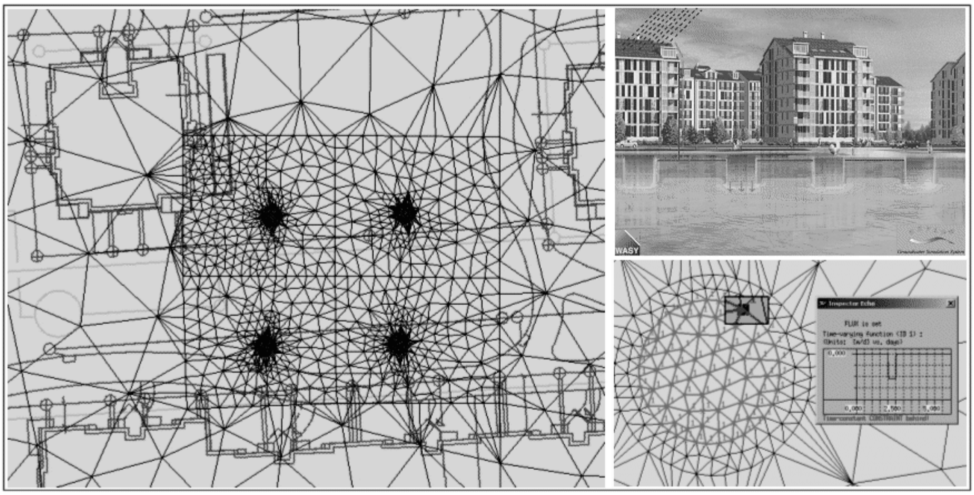


Figure 5: Detailed view of the mesh of the 3D groundwater model

2.1.4 Monitoring of infiltration (quantity)

For both sites, a detailed monitoring concept was developed, and each separated in a qualitative and a quantitative part. Because the construction of Tianxiu Garden (site II) was delayed and had not been completely finished until the end of the project, the monitoring system was only successfully implemented for Site I.

In the next figure (Figure 6), the basic principle for the monitoring of the yard and roof runoff is shown. At all cleaning, dividing and recharge units the water level is continuously observed by so-called dippers. Additionally, directly in front of the recharge wells the outflow of the system is measured by a flow control developed by one of the German team members (UFT Umwelt und Fluid-Technik). From this discharge, knowing the change of water level in the well, the actual recharge in time can be calculated. As all measures of the different units are known, also the discharges between all remaining units can be calculated.

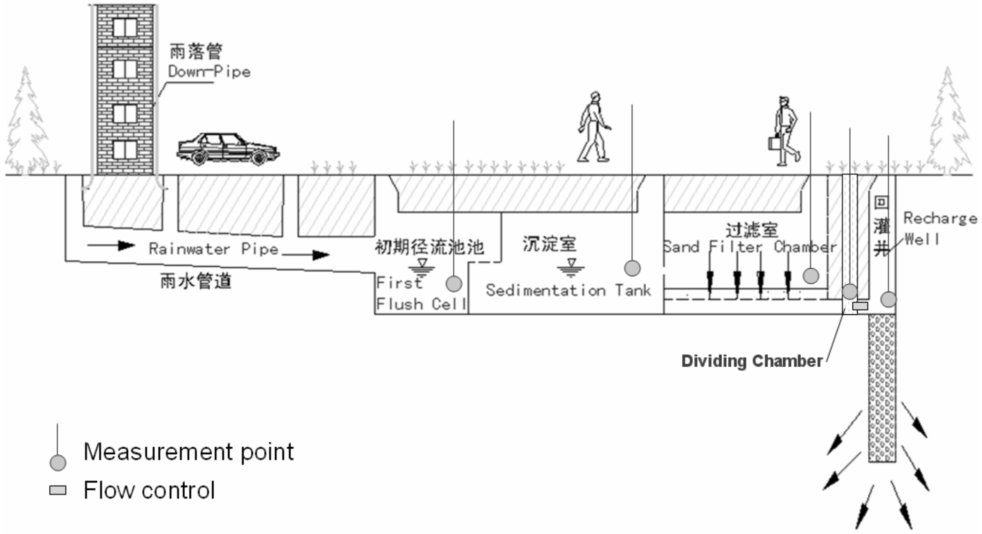
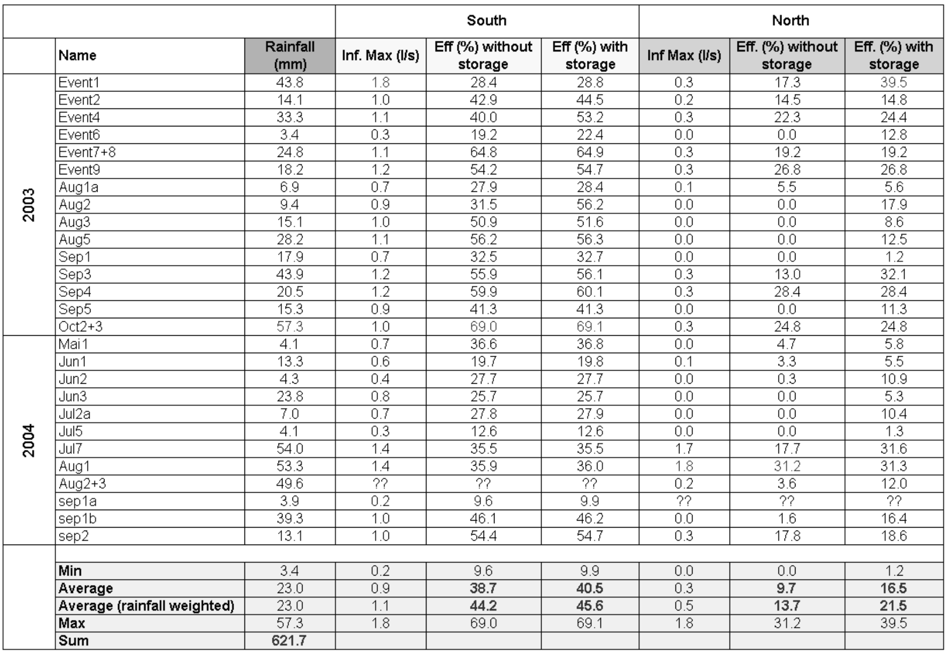


Figure 6: Basic principle of quantitative monitoring

This principle has been integrated in a macro-based Excel file, with which the discharges to all units during an observed period can be calculated automatically. Besides, the software compares the results with the observed rainfall volume in order to evaluate the efficiency of the system. The complete system has been successfully verified by local measurements. Due to differences between design and construction measures and other more or less practical problems, the monitoring was launched under rather difficult circumstances. Nevertheless, 27 rainfall events with a total of 622 mm could be analyzed in 2003 and 2004. The results are shown in the next table. They are separated according to the type of rainwater collection; roof runoff (South) and yard-roof runoff (North).

The biggest storm that was analyzed occurred in October 2003 with 57 mm. The heaviest storm occurred in July 2004 (125 mm). Unfortunately, the measurement technique failed during this event and it could not be analyzed. The maximum infiltration rate for a single well amounts to 1.8 l/s, which is only half of the rate being designed. However the maximum infiltration rates could not be analyzed as the wells were not completely filled during any of the observed events. The roof runoff (South) shows an average efficiency (Eff) of about 45%, which is satisfying regarding the high initial and evaporation losses. The combined runoff (North) shows only an efficiency of 14 to 22 %, depending on the fact if the storage in the cleaning units is taken into account or not. This is definitely too low.

Table 1: Monitoring results



			South			North		
	Name	**Rainfall (mm)**	**Inf. Max (l/s)**	**Eff (%) without storage**	**Eff (%) with storage**	**Inf Max (l/s)**	**Eff. (%) without storage**	**Eff. (%) with storage**
2003	Event1	43.8	1.8	28.4	28.8	0.3	17.3	39.5
	Event2	14.1	1.0	42.9	44.5	0.2	14.5	14.8
	Event4	33.3	1.1	40.0	53.2	0.3	22.3	24.4
	Event6	3.4	0.3	19.2	22.4	0.0	0.0	12.8
	Event7+8	24.8	1.1	64.8	64.9	0.3	19.2	19.2
	Event9	18.2	1.2	54.2	54.7	0.3	26.8	26.8
	Aug1a	6.9	0.7	27.9	28.4	0.1	5.5	5.6
	Aug2	9.4	0.9	31.5	56.2	0.0	0.0	17.9
	Aug3	15.1	1.0	50.9	51.6	0.0	0.0	8.6
	Aug5	28.2	1.1	56.2	56.3	0.0	0.0	12.5
	Sep1	17.9	0.7	32.5	32.7	0.0	0.0	1.2
	Sep3	43.9	1.2	55.9	56.1	0.3	13.0	32.1
	Sep4	20.5	1.2	59.9	60.1	0.3	28.4	28.4
	Sep5	15.3	0.9	41.3	41.3	0.0	0.0	11.3
	Oct2+3	57.3	1.0	69.0	69.1	0.3	24.8	24.8
2004	Mai1	4.1	0.7	36.6	36.8	0.0	4.7	5.8
	Jun1	13.3	0.6	19.7	19.8	0.1	3.3	5.5
	Jun2	4.3	0.4	27.7	27.7	0.0	0.3	10.9
	Jun3	23.8	0.8	25.7	25.7	0.0	0.0	5.3
	Jul2a	7.0	0.7	27.8	27.9	0.0	0.0	10.4
	Jul5	4.1	0.3	12.6	12.6	0.0	0.0	1.3
	Jul7	54.0	1.4	35.5	35.5	1.7	17.7	31.6
	Aug1	53.3	1.4	35.9	36.0	1.8	31.2	31.3
	Aug2+3	49.6	??	??	??	0.2	3.6	12.0
	sep1a	3.9	0.2	9.6	9.9	??	??	??
	sep1b	39.3	1.0	46.1	46.2	0.0	1.6	16.4
	sep2	13.1	1.0	54.4	54.7	0.3	17.8	18.6
	Min	3.4	0.2	9.6	9.9	0.0	0.0	1.2
	Average	23.0	0.9	**38.7**	**40.5**	0.3	**9.7**	**16.5**
	Average (rainfall weighted)	23.0	1.1	**44.2**	**45.6**	0.5	**13.7**	**21.5**
	Max	57.3	1.8	69.0	69.1	1.8	31.2	39.5
	Sum	**621.7**						

From the first analyses it had to be concluded that the main reason for this is that the down pipes of the roofs in the combined system are not connected to the sewers directly but end freely above the surface. Furthermore, it seems that not all connected yards divert the water towards the drainage system.

2.2 Research project: sustainable water concept for the Olympic Park, Beijing 2008

The Chinese-German Project "Sustainable water concept and its application for the Olympic Games 2008", supported by BMBF and MOST, intends to apply the latest scientific results, methods and technologies for a sustainable water management of the Olympic Park. Figure 7 gives an overview of the co-operating partners. The project was coordinated by Professor Zhang Xuan from Tsinghua Universityand Professor S. Kaden from WASY GmbH, Berlin.

Within the sub-project of WASY possibilities of groundwater recharge with storm water have been analyzed. Some results are presented in the following.

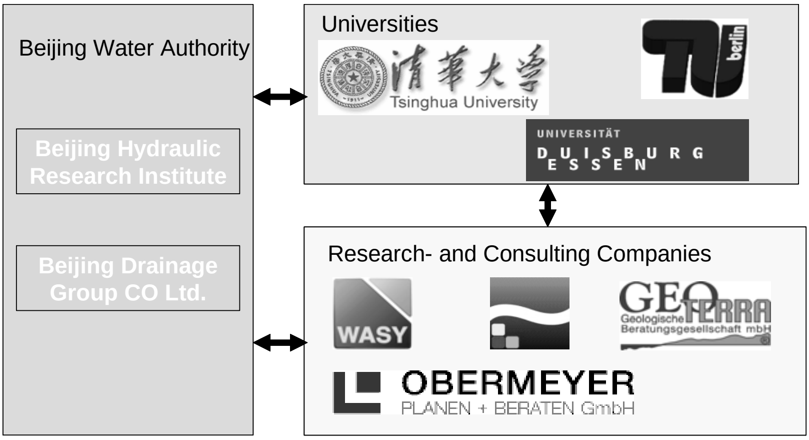


Figure 7: Project partners of the Olympic Water Project

One planning alternative for a sustainable water concept of the Olympic Park was to recharge groundwater via injection wells. If the ground allows sufficient infiltration an appropriate concept for artificial recharge should be developed.

The first step was to set up a hydrogeological model. For that purpose the software HydroGeo Analyst (Waterloo Hydrogeolgic Inc.) was used. Based on the hydrogeological model a 3D groundwater model with the software FEFLOW was developed for the estimation of the infiltration capacity and calculation of different scenarios.

2.2.1 Creating a geometric model

According to available information a regional model area was selected with about 39 km² as shown in Figure 8. The western border is oriented along the Xiaovue River. The northern border corresponds with the Qing River. In the south the model boundary is defined by the channel. The ground surface is between 31 to 48 m a.s.l. inside of the model area and declines from southwest to northeast. The actual investigation area is the central part of the Olympic Park with about 3.2 km².

The first step of the model construction is the spatial subdivision. Therefore a super mesh was generated, which contains important topographically and other structures and consists of 54 polygons. Based on this the finite element mesh was developed with 73,566 triangular elements and 43,463 nodes relating to 6 model layers and 7 slices (see Figure 8).

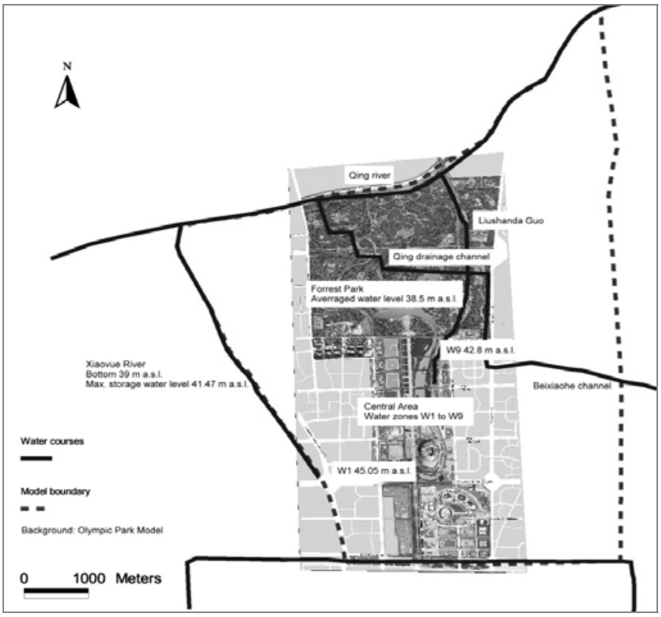


Figure 8: Overview of the model area and relevant receiving water courses for the groundwater modelling

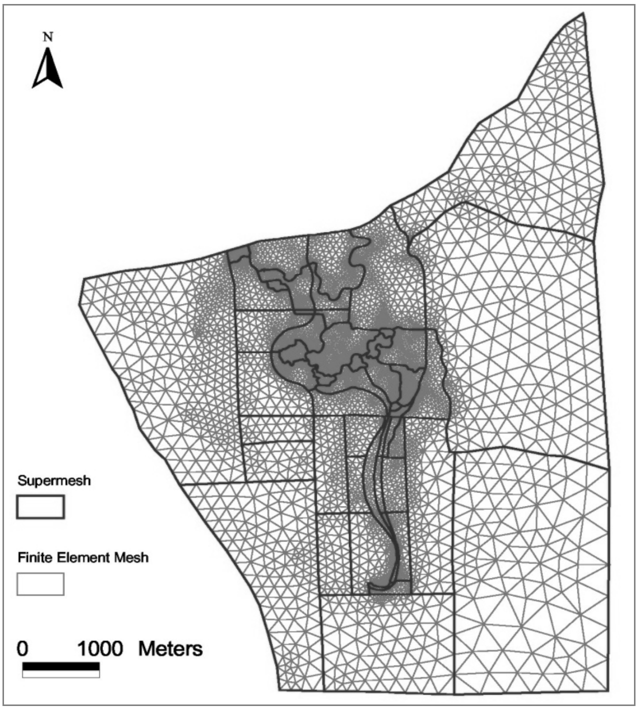
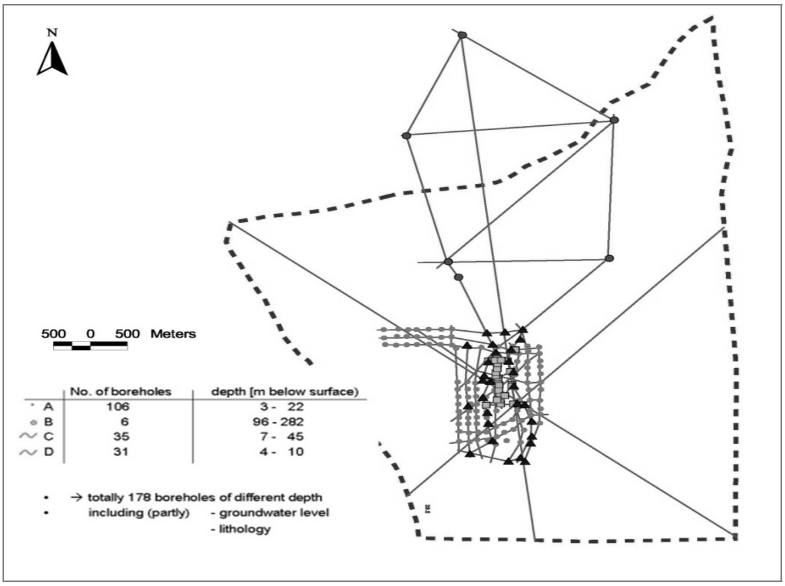


Figure 9: Super mesh and finite element mesh of the groundwater model

2.2.2 Designing a hydro geological model

The study area is situated in the lower region of the alluvial fan of the Youngding River, descending from south to north topographically. In the central area there are two to four aquifers in a 40 m range, typically three aquifers.

For the central area of the Olympic Park a lot of borehole data and geological cross sections have been provided. Outside of this area little information existed. Therefore, it was necessary to interpolate and extrapolate respectively for the preparation of the hydrogeological model. Figure 10 shows the available boreholes in the whole model area and give some information about the depth and the number of boreholes and created cross sections. Only a few boreholes (approximately 10 boreholes) were so deep that they reached the confined and unconfined third aquifer.



	No. of boreholes	depth [m below surface)
· A	106	3 - 22
● B	6	96 - 282
~ C	35	7 - 45
~ D	31	4 - 10

- → totally 178 boreholes of different depth
- including (partly) - groundwater level
  - lithology

Figure 10: Available boreholes in the model area

The following layers based on the available drilling logs could be distinguished:

- Aquitard 1 contains artificial filling materials and top soil mostly composed of silt and silty clay.
- Aquifer 1 corresponds to a powdery fine sand layer and a sandy silt layer.
- Aquitard 2 corresponds to silty clay layer.
- Aquifer 2 consists of powdery fine sand too and rarely of gravel.
- Aquitard 3 is a silt layer.

2.2.3 Parameterization of the groundwater model

Information about the permeability was available from pumping tests, infiltration tests and lab tests. For layers without any information about the permeability, values were estimated based on the description in the drilling logs. Figure 11 shows a cross section from North to South through the entire model area.

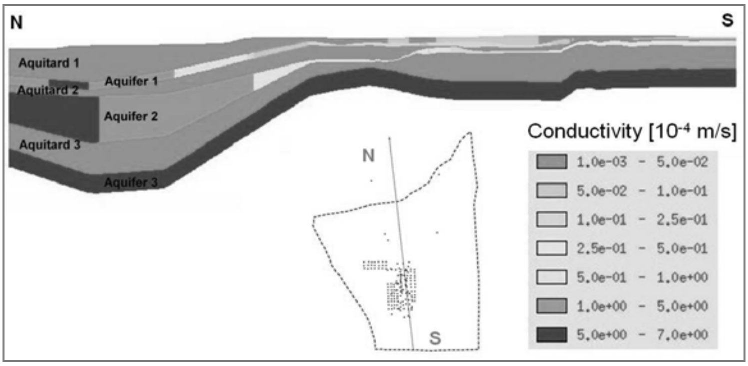


Figure 11: Vertical discretization and parameterization of the groundwater model

3 Results

For a first estimation of possible short-term infiltration rates in the study area 10 infiltration wells were positioned along both sites of the planned water course. It was assumed that water can infiltrate in a well until the depth to groundwater is not less than 1.5 m. In Figure 12 the location of the infiltration wells as well as the difference of groundwater tables between the variants with and without infiltration wells after 5 days in the first aquifer is shown. After 5 days the local increase in the groundwater table at the site of the well was about 4 to 5 m. The increasing range of the groundwater table was between 30 to 100m.

In consideration of the assumption made, a water quantity of approximately 7,500 m³ would infiltrate within 24 hours corresponding to a precipitation of 7.5 mm per km². Figure 13 shows the infiltration capacity.

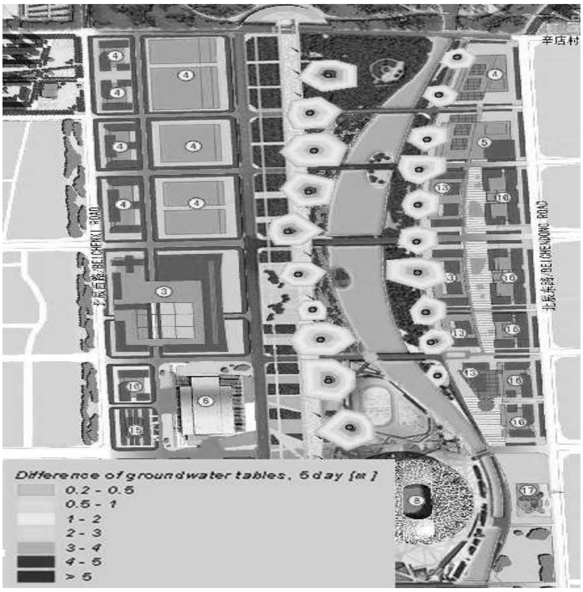


Figure 12: Local increasing of groundwater table of about 3 m after 5 days

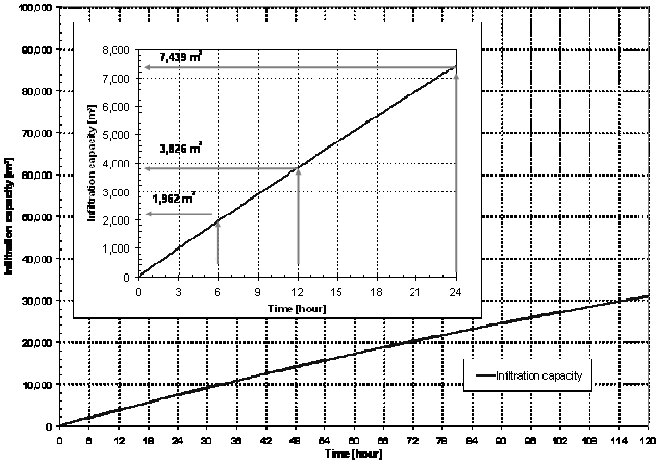


Figure 13: Potential infiltration capacity of the 20 wells

From this data it becomes clear that the hydrogeological conditions in the study area are not appropriate for efficient artificial recharge of storm water. There are essentially two reasons:

- On the top is an silty aquitard located with a thickness of about 4 m
- The following aquifer being relevant for the artificial recharge only has a thickness of about 2 m and consists of powdery fine sand and sandy silt.

Large storage capacities would be necessary to infiltrate remarkable amounts of storm water**.**

4 Conclusions: Opportunities and Limits

At the end of the Chinese-German research project on Flood Management and Groundwater Research there was an attempt to balance calculated water demand and water resources in the Beijing area by considering different strategies. The major steps and results of this analysis were achieved through the co-operation between WASY (Mr. B. Monninkhoff) and Dr. Wilhelm (now GeoTerra GmbH).

Step 1 Estimation of the potential infiltration volume / groundwater recharge

	Western part of Beijing	Eastern part of Beijing	Total
Rainfall (mm/a)	593	594	593
Total area (km^2)	405	248	653
Paved area (km^2)	296	181	477
Percentage of decoupled paved area (%)	60	20	45
Decoupled area (km^2)	177	36	214
Infiltration efficiency (%)	50	50	50
Infiltration volume (Mm^3/a)	53	11	63

Step 2 Estimating water demand

Two major scenarios have been distinguished: Scenario I “Water saving and moderate grey water recycling” and scenario II “Intense water recycling”.

	Present state	Scenario I	Scenario II
Total demand without savings (Mm^3/a)	1791	1791	1791
Reduction domestic demand (%)	0	50	77
Reduction domestic demand (Mm^3/a)	0	290	450
Remaining demand 1 (Mm^3/a)	1791	1499	1342
Reduction industrial / agricultural demand (%)	0	30	50
Reduction industrial / agricultural demand (Mm^3/a)	0	311	519
Total demand with savings (Mm^3/a)	1791	1188	823

Step 3 Estimating groundwater resources

(Mm^3/a)	Present State	Scenario I	Scenario II
Natural recharge 5th Ring	17	15	15
Artificial recharge from rainfall	0	63	63
Additional grey-water infiltration	0	29	0
GW inflow into urban area	133	133	133
Wastewater infiltration	135	60	28
Irrigation infiltration	16	11	8
Total groundwater availability	301	311	247

Step 4 Balancing water demand and water resources

(Mm^3/a)	Present State	Scenario I	Scenario II
Total demand	1791	1188	823
Total available water	1201	1211	1147
Balance	**- 590**	**23**	**324**

The conclusion from these findings is as follows: groundwater recharge from storm water could be a solution to the problem of water scarcity – but it is not the ultimate one. It has to be combined with other steps such as controlling water demand and water saving.

Implementing a groundwater recharge from storm water strategy, the following problems arise, which relate to the character of groundwater as a hidden resource:

- effects of groundwater recharge from storm water are not visible
- due to the uneven rainfall distribution in Beijing, groundwater recharge from storm water is only effective during the summer season
- groundwater recharge from storm water requires manifold decentralized (frequently expensive) measures, taking into account the heterogeneity of the ground.

As a result, there is a certain reluctance to apply such a technology. Obviously there is a broader acceptance of artificial groundwater recharging options such as with surface water and recycled waste water. One “sleeping” technology is bank filtration, which has proved effective, for example in Berlin, but has only rarely been applied in Beijing.

Groundwater protection and sustainable groundwater management are important parts of future strategies to ensure water supplies and protect natural environments under conditions of rapid global change. It is essential to make better use of the natural treatment and storage capacity of the sub-soil.

Institutional Framework and Management Practice for Large Cities Water Supply with Special Regard to Groundwater Resources

以地下水为水源的大城市供水制度框架和管理实践

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Abstract

Groundwater resources are most essential for water supply in the Berlin-Brandenburg region. The large city of Berlin, the German capital, is surrounded by the large, but compared to Belin, sparsely populated State of Brandenburg which is a more rural environment. The water supply of Berlin to a large extent depends on Brandenburg's groundwater resources, as well as from surface water from the region which is used in Berlin for bank filtration and artificial groundwater recharge.

Consequently, the groundwater (and surface water) resources of Berlin and Brandenburg have to be protected and managed jointly, within a complicated institutional environment (Brandenburg and Berlin are widely independent German States).This situation and the yearly water balance are similar to Beijing although the scale is different.

The paper gives an overview on how water resources in Berlin-Brandenburg are protected and managed (with special regard to groundwater) and how the co-operation between Brandenburg and Berlin is organized at the institutional level. The importance of planning and management on the river basin scale will be discussed, taking into the account the requirements of the European Water Framework Directive (binding for all members of European Union).

摘要

地下水源是柏林——勃兰登堡地区最主要的供水来源。德国首都柏林周边的勃兰登堡地区面积很大，但与柏林相比人口较稀疏，是一个更像农村的环境。柏林的供水在很大程度上依靠勃兰登堡的地下水源，勃兰登堡的地表水也被用作柏林的河岸渗滤和人工地下水回灌。因此，柏林和勃兰登堡的地下水（和地表水）水源必须在一个复杂的环境中联合起来保护和管理（勃兰登堡和柏林在很大范围内独立于德国政府）。这种情况和每年的水分平衡跟北京很相似，只是范围不同。

本文概述了柏林和勃兰登堡的水资源是如何管理的（特别是地下水），以及柏林与勃兰登堡之间怎样在制度的层面上开展合作。考虑到“欧洲水框架指令”（为欧盟的所有成员国所遵守）的要求，本文还讨论了流域范围的规划和管理的重要性。

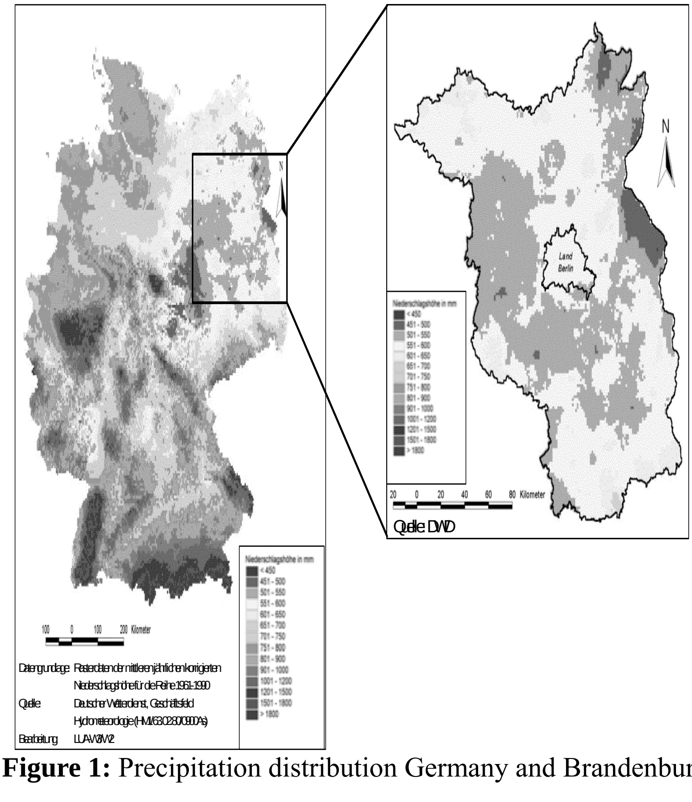
1 The Federal State Brandenburg: Overview

Brandenburg is one of 16 German federal states. It is located in the eastern part of Germany and when the territory of the former German Democratic Republic experienced its political transformation in 1990 it was one of the five new states added to the Federal Republic of Germany.

With a land area of nearly 30,000 km² it is the largest of these new federal states. Its population, at roughly 2.6 million, is relatively small. Berlin – which is both a federal state and the capital of Germany – is located in the middle of Brandenburg and has nearly 3.4 million people on a substantially smaller amount of land.

The low number of inhabitants is due to the low population density of 87 inhabitants per km². By comparison: the population density for all of Germany comes to roughly 230 inhabitants per km². Hence, Brandenburg is one of the most sparsely settled areas in all of Germany.

To understand the state it is helpful to consider the statistics related to land use: some 6 % is devoted to urbanized land and traffic infrastructure. The state's predominantly agricultural character is reflected by the fact that this sector takes up roughly 56 % of total land area. In comparison to Germany as a whole the proportion of our state covered by forest is above average, 36 %. The fact that Brandenburg is the state with the greatest amount of surface water is reflected by its unusually high share of 2.4 %.Of course, one important basic fact for water management is the amount of annual precipitation.



Datengrundlage: Rasterdaten der mittleren jährlichen korrigierten Niederschlagshöhe für die Reihe 1961-1990
Quelle: Deutscher Wetterdienst, Geschäftsfeld Hydrometeorologie (HM1/63.02.80/0900As)
Bearbeitung: LUA W3/W2

Quelle: DWD

Figure 1: Precipitation distribution Germany and Brandenburg

As Figure 1 illustrates, in Germany we have a very uneven distribution of precipitation: the western part of the country gets substantially more than the eastern areas. In this context, what really stands out are the mountain ranges, for example the Black Forest region in the southwest, or the Alps far to the south where at times more than 2,000 mm/a of precipitation is measured.

Brandenburg is located in the relatively dryer east. It is important to point out the lowland situated along the Oder River and referred to as the Oderbruch. The Oderbruch has one of the lowest precipitation levels in Germany. The average precipitation for Brandenburg, seen across many years, is 617 mm/a. By comparison: for Germany as a whole this figure stands at 790 mm/a.

The following Figure 2 shows the extent to which the water resources are used by Berlin and Brandenburg. In this graph you can clearly recognize the political transformation which took place in the early nineties.

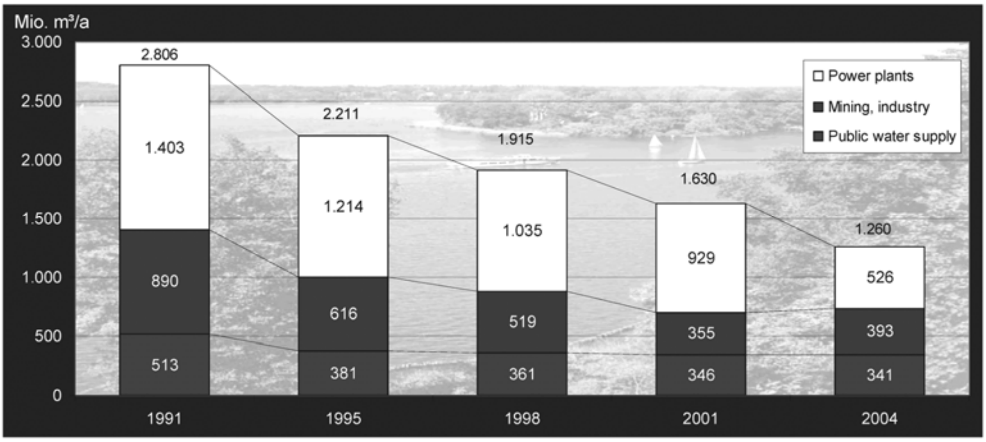


Figure 2: Water use Berlin + Brandenburg

While in 1991 water abstraction still stood at roughly 2.8 billion cubic meters, this value fell to some 1.2 billion cubic meters by the year 2004. Important uses for water are:

- Cooling water for power plants
- Industry
- Lowering groundwater levels for mining purposes
- Meeting the need for public drinking water

The reasons for the enormous reduction in water abstraction are due to the large reduction in water consumption, specifically caused by:

- Rising water prices and, hence, a greater cost awareness among consumers
- Decline in population
- Collapse of industrial production in eastern Germany due to decreased competitiveness
- Pull-out of Russian troops

In the coming years, for us, one special problem will also be the decline in population. This is expected throughout Germany, and Germany's eastern states will be especially hit by it.

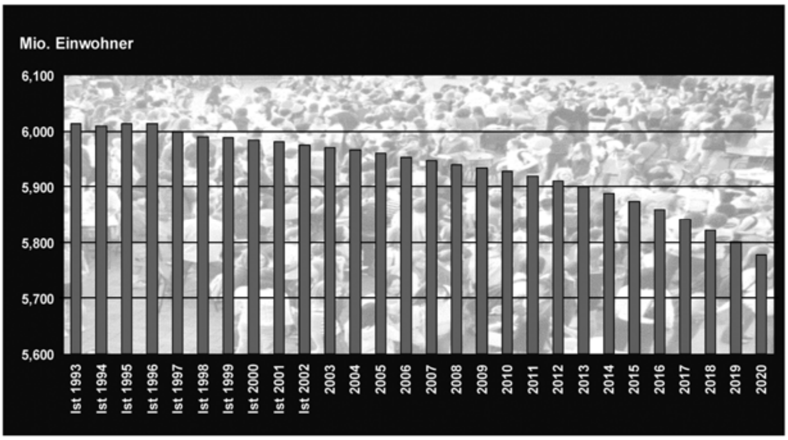


Figure 3: Population development Berlin + Brandenburg

While at present we still have 5.96 million inhabitants in Berlin and Brandenburg, this value will fall by 2020 to less than 5.8 million. In the coming years, our important task will be to establish what consequences the fall in population will have for supplying drinking water and managing wastewater.

2 Institutional Framework

Berlin and Brandenburg are both federal states of the Federal Republic of Germany. Each of these states has its own government and administration as well as a parliament. In many areas related to the enactment of laws the federal states have a large degree of independence. Until now, laws related to water and waterways have been nearly exclusively the responsibility of the individual states.

Berlin, Germany’s capital is in the middle of Brandenburg's territory. The most important receiving water body in this area is the Havel River and its tributary, the Spree. Five states share in the catchment area of the Spree-/Havel system. Important questions of surface water management which impact the catchment area beyond the borders of individual states must be coordinated between the state governments.

Figure 4: Map overview Berlin + Brandenburg

This coordination work has not taken place within a rigid institutional framework. Any problems which have arisen were resolved one-by-one by the cooperative efforts of public employees working for the individual states.

In the summer of 2006 an extensive modification of Germany's Basic Law was approved by the Bundestag, Germany's house of parliament. Among the important agreements reached was the transfer of authority to enact laws related to water to the federal level. At present, it is still not possible to estimate what the impact of this will be. I think that the water management problems with impacts across state borders will continue to be solved directly by the states most directly involved.

3 Water supply in Berlin and Brandenburg

In Brandenburg the greater share of drinking water, some 81 %, comes from groundwater. The share of bank filtrate amounts to 13.5 % and groundwater recharge contributes some 5 % to the supply of drinking water comes from groundwater, groundwater protection has a very high priority. The legal regulations applicable throughout Germany state that contaminants must not be released into the groundwater. An even more restrictive protection of groundwater is provided in areas designated as drinking water protection zones. In these areas manufacturing plants which can be release contaminants, such as refineries, metal processing plants and chemical processing factories, are prohibited. Furthermore, in the drinking water protection zones restrictions also extend to agriculture. The use of fertilizers and pesticides is largely regulated.

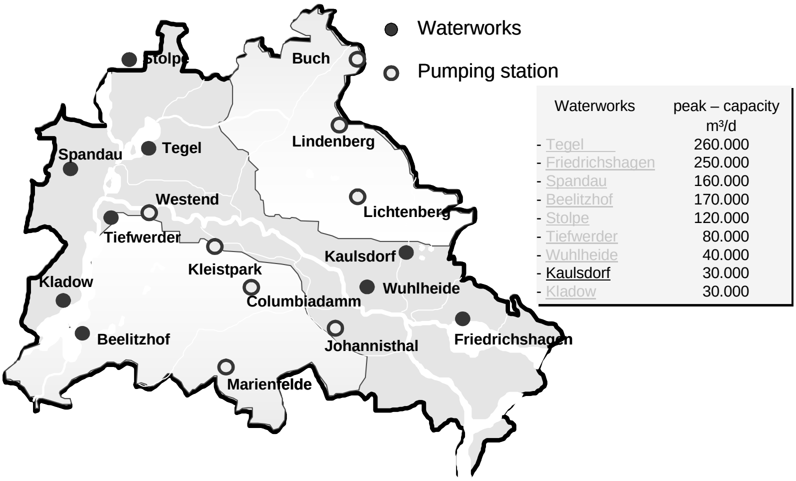
In Brandenburg we have 620 drinking water protection zones, which comprise a surface area of nearly 2,000 km². This represents 6.7 % of the state's surface area.

The protection of groundwater is regulated in the ordinances related to water protection zones. These ordinances are enacted by Brandenburg's Minister of Environment. One problem for us is that nearly all protective ordinances were enacted back in the days of the GDR. Hence, they do not meet the standards of the Federal Republic of Germany and must gradually be modified to be compliant with new protective zone ordinances.
The good groundwater protection means that the incoming water to Brandenburg's water treatment plants only requires simple treatment. Usually only geogenically increased iron and manganese concentrations must be lowered. As a result, high quality drinking water is delivered to the consumer.

Let us turn to the situation in Berlin. Here you can see the potential groundwater capacity for Berlin. Drinking water in Berlin is received from groundwater wells. However, these wells are not only fed by groundwater. They also receive a substantial amount of bank filtrate. The groundwater continues to be recharged from bodies of surface water as well. The share of bank filtrate and groundwater recharge in the drinking water amounts to 67 %.

Due to this large share of bank filtrate Berlin is especially dependent on the in-flow of sufficient quantities of water which is as clean as possible. This is why water protection in the catchment area of the Havel and its tributary, the Spree, is especially important. We will soon see the special set of problems in the catchment area of the Spree which must be tackled by intelligent water management.

The water treatment plants from which Berlin draws its drinking water are situated, with one exception, within the city's borders. The largest water treatment plants are Tegel (with a peak capacity of 260,000 m³/d) and Friedrichshagen (250,000 m³/d).



Waterworks	peak – capacity m³/d
- Tegel	260.000
- Friedrichshagen	250.000
- Spandau	160.000
- Beelitzhof	170.000
- Stolpe	120.000
- Tiefwerder	80.000
- Wuhlheide	40.000
- Kaulsdorf	30.000
- Kladow	30.000

Figure 5: Water works and pumping stations in Berlin

In Berlin water recovery is protected by drinking water protection zones (Figure 6). Some protection zones, as in the case of the Friedrichshagen treatment plant, extend beyond the state's border into Brandenburg. Likewise, several protective zones of Brandenburg water treatment plants extend into Berlin.

The legal regulations which specify the restrictions in protective zones are determined by ordinance. In the case of cross-border protective zones each state, Brandenburg and Berlin in this case, must each adopt an ordinance for its own territory. Officials from both states confer on how the borders of the protective zones should be drawn. In the process of defining the cross-border protective zones no problems have arisen between Berlin and Brandenburg.

For the Brandenburg section of the protective zone the Brandenburg Minister of Environment must enact a statute.

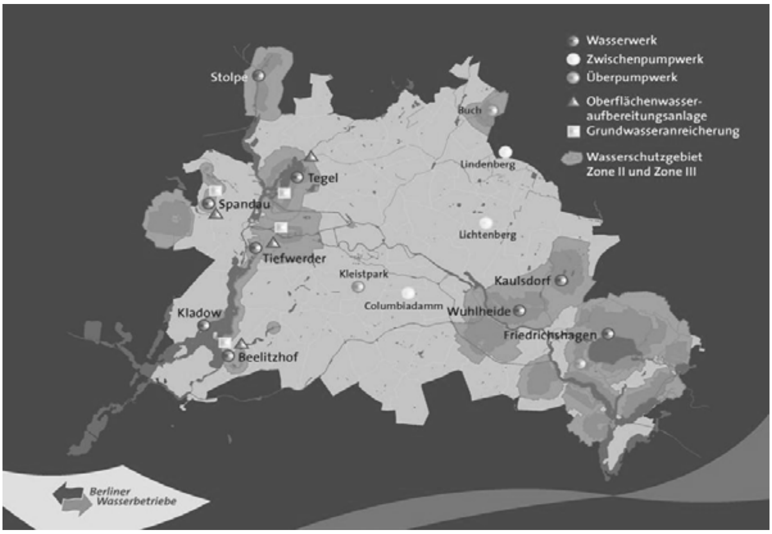


Figure 6: Groundwater protection zones in Berlin

I already mentioned that in past years the consumption of available water has dropped dramatically. This is also reflected in drinking water consumption in Berlin and Brandenburg. While in 1991, in both states, consumption remained at roughly 140 liters per inhabitant per day, drinking water consumption fell to 117 liters in Berlin and 100 liters in Brandenburg.

4 The Water Framework Directive

Finally, I would like to discuss a European directive which has substantial effects on the cooperation within the river catchment basins. The EU Water Framework Directive (WFD) obligates the federal states, as well as the EU member countries, to cooperate intensively.

After several years of negotiations within the European institutions, the WFD came into force on 22 December 2000.

The EU enacted directives related to water protection as far back as the seventies of the previous century. But instead of following a uniform line, each of them regulated acute water management problems. The WFD was the attempt to bundle the EU's piecemeal water laws and its many directives and combine them with modern aspects of water protection. However, not all water protection directives were replaced by the WFD. For example, the Urban Waste Water Treatment Directive, the Bathing Water Directive and the Drinking Water Directive continue to exist as independent directives.

In the coming years, the WFD should lead to uniform laws related to water protection across the EU, which has a membership of 25 sovereign states. Of course, this is also meant to contribute towards European integration.

Let me discuss a few of the objectives of the WFD in greater detail: one important aspect is their implementation within river catchment basins. It is thus ruled by the recognition that numerous water management measures towards the improvement of water quality only become effective if their implementation is coordinated within the catchment area. So, one example would be the elimination of barriers to fish migration, most of these being structures across rivers such as weirs. Fish which migrate long distances such as salmon cannot re-establish themselves in river headwaters until barriers are re-designed to permit their passage.

The general goal for bodies of surface water is to achieve a good ecological status which is characterized by the most natural possible occurrence of certain groups of organisms in the bodies of water, and a good chemical status, which is when contaminants do not exceed their limit values.

In the case of groundwater, the objectives should also be achieved by staying within the limit values set for contaminant concentrations. In addition, groundwater must be abstracted in such a manner that the abstraction does not exceed the build-up of new groundwater recharge in a groundwater catchment area and that groundwater dependent land ecological systems, e.g. wetlands, are not damaged.

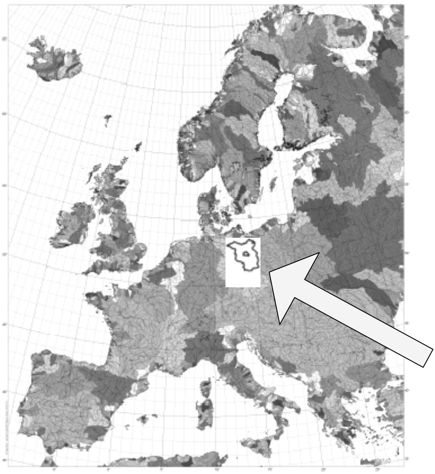
The WFD also has a very ambitious time plan. In 2015 its objectives will be met in all bodies of water in the EU.

One of the most important ideas of the WFD is that the bodies of water should be managed on the basis of the catchment areas. The catchment area includes the whole surface area whose surface drainage flows through streams, rivers, or possibly through lakes, into a single river mouth, whether estuary or delta, into the sea.

Figure 7 shows the river catchment areas in Europe. In the EU, which has expanded to a membership of 25 countries since 2004, there are 123 river catchment areas.

Of these, a respectable 34 are cross-border. Of these, two or more member countries must coordinate the implementation of the WFD.

By 2004 an inventory was carried out. In its framework the purpose was to determine in particular what contaminants are impacting the bodies of water. Then an estimate followed to determine if the objectives of the WFD have been met, or whether these bodies of water fell short of the objectives.



Brandenburg and Berlin are situated in the centre of Europe

Figure 8: River catchments in Europe

Since 2006 the bodies of water have been monitored, which involves determining the measurement values of their water quality.

The inventory and the water quality monitoring high light the differences which may exist between the actual water conditions and the target good water quality required by the WFD. Based on this deficit analysis, the necessary remedial steps can be decided. In programmes that seek to determine good ecological and chemical condition of the bodies of water in river catchment areas, all the measures must be listed.. Feasible measures could be, for example, the renaturalization of bodies of water or the tightening of limit values for waste water released into the environment.

The central instrument of the WFD is the management plan for the catchment areas. It contains all the information gathered for the individual catchment areas on the basis of the WFD. Even the most important contents of the programmes of measures must be contained in the management plan. The management plans must be developed for the complete surface area of the whole river catchment unit, for example, the Elbe. The management plan and programme of measures must be completed by the end of 2009.

By 2012 the necessary measures must be implemented so that by 2015 the objectives of the WFD are met: a good ecological and chemical status for the bodies of surface water as well as good groundwater status in terms of chemical concentrations and quantities.

Figure 9 shows the river basins which are at least partly located in Germany: there are ten partly located in Germany, including the Rhine and the Danube.

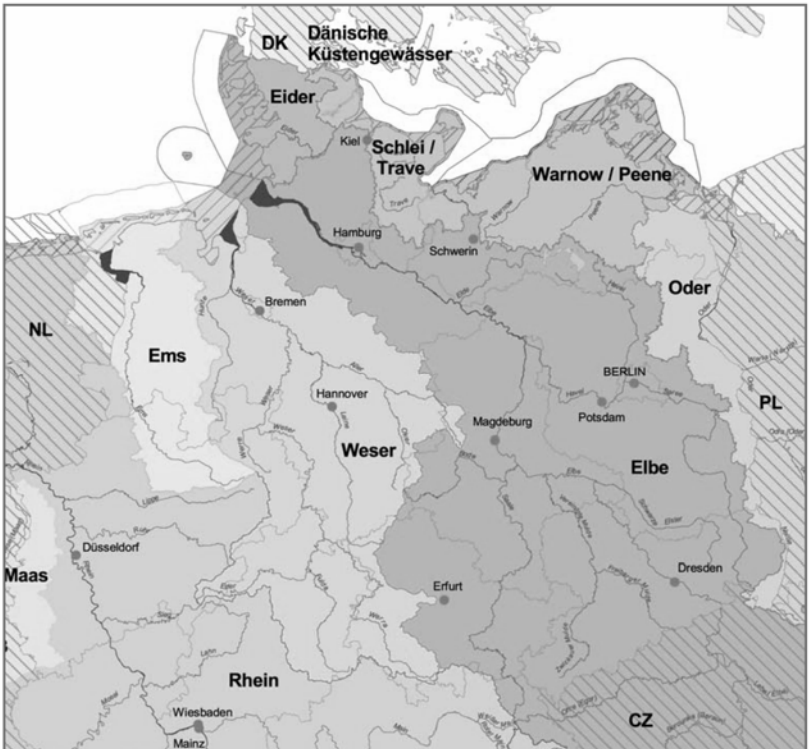


Figure 9: River catchments in Germany (northern part)

Berlin is completely within the Elbe basin. The territory of Brandenburg is largely within the Elbe basin and, to a lesser extent, in the Oder basin.

Since both basins extend beyond Germany's borders, we must work together with the water protection officials of several countries.

We coordinate through existing organizations. In the nineties, for example, the river area commissions for the Elbe and Oder were founded. They were designed to facilitate the coordination of the participating countries in several areas of water management, e.g. flood control or coordination in case of accidents and disasters.

For the Elbe, there is the International Commission for the Protection of the Elbe (ICPE), and for the Oder, the International Commission for the Protection of the Oder (ICPO).The joint implementation of the WFD has substantially intensified this coordination. The ICPE is relevant for the cooperation between Berlin and Brandenburg.

The Elbe catchment covers an area of nearly 150,000 km². To subdivide this large area into manageable areas, ten sections, referred to as working areas, were created. These include one or several sub-catchment areas and facilitate coordination on a regional level. In Germany there are five working areas. The largest share of the working area around the Havel, a tributary of the Elbe, is in Brandenburg. In this working area Berlin and Brandenburg coordinate the water management measures needed to implement the WFD.Along the river Elbe basin a total of four EU member states are involved: Germany and the Czech Republic and, to a minor extent, Austria and Poland as well.

Until now, Germany laws related to water were primarily handled by individual states. Hence, it is significant that 10 German states are involved in the Elbe basin. To implement the WFD these ten states have formed the Elbe River Area Community which cooperates closely with the ICPE.

Hence, the cooperation of 14 administrations must be coordinated. A complicated organizational structure had to be developed to enable the partners to cooperate. In the future it will also be necessary to simplify the complicated structure and by doing so ensure an even more effective cooperation.

5 Conclusion

Groundwater resources are the basis of the supply of drinking water in Brandenburg and, to a lesser extent, in Berlin as well.
In addition, Berlin’s water supply is highly dependent on bodies of surface water which flow from Brandenburg into the greater metropolitan area, since bank filtration and artificial groundwater recharge are essential sources of Berlin's drinking water.

The EU Water Framework Directive requires a high degree of co-ordination between European countries and the federal states in the river basin units.

Policy Options for Sustainable Urban Water Cycle Management in Lahore, Pakistan
巴基斯坦拉合尔市的可持续
城市水循环管理政策取向

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Abstract

This paper provides an overview of Pakistan's water-related problems in an urban context and how environmental policies have failed to address water quality degradation. Urban water problems include droughts, floods, water pollution and deterioration of water-related ecosystems. Evolution of water law and policy to protect environment and its links with the urban water quality are explored. A possible improvement of the city's sustainable water resources development plan is introduced to cope with groundwater degradation issues. The main source of water in Lahore, Pakistan is groundwater which is recharged by the River Ravi. The Ravi River is also a recipient of the urban and industrial waste waters from Lahore as well other urban and industrial waste on its way to Pakistan from the Indian part of the catchment. The River Ravi once a river that could sustain life and livelihoods for tens of thousands of people, is now one of the most polluted river in the world. It has been converted into a river of death because of wide- spread urban and agricultural pollution. The river presently receives 47% of the total municipal and industrial pollution load discharged into all the rivers of Pakistan. Environmental policies which link urban, agricultural and industrial water cycle are important to help with the sustainable management of Lahore's water supplies. It is hoped that Lahore's sustainable water development experience may provide reference for other urban centres in developing countries which are facing similar water problems.

摘要

本文概述了巴基斯坦的城市水问题以及环境政策在解决水质下降问题上的失败。城市水问题包括干旱，洪水，水污染以及水生态系统的退化。一项可能改善城市可持续水资源发展的规划被引进用以解决地下水退化的问题。巴基斯坦拉合尔市的主要水源是地下水，由拉维河补给。拉维河也接收拉合尔的城市和工业污水以及流域内从印度至巴基斯坦沿线的其它城市和工业的废水。拉维河曾经是维持数以万计人生命和生计的河流，现在却是世界上污染最严重的河流之一。由于城市和农业污染的扩大，它已经变成一条没有生命的河。这条河目前承担着巴基斯坦所有排入河流的城市和工业污染负荷的47%。 环境政策与城市，农业，工业的水循环相关，它对于帮助拉合尔供水系统的可持续管理十分重要。希望拉合尔可持续的水发展经验能够为集中在发展中国家，面临同样问题的其它城市提供借鉴。

1 Introduction

Pakistan is situated North-West of the South Asian Sub-Continent, lying between 24-37 degrees North Latitude and 61-75 degree East longitude. It is bounded on the East by India, on the North and North-East by China and on the North-West by Afghanistan, on the West by Iran and in the South by the Arabian Sea (Figure 1). Pakistan is a country of over 141 million people, which is expected to grow to over 220 million by the year 2025. The most pressing need over the next quarter century in Pakistan will be to manage the rapidly increasing population and provide them with basic amenities such as water and sanitation. The increasing population will have a major impact on food, power, water and the environment.

Figure 1: Map of Pakistan

Pakistan has achieved record growth rates, buoyant levels of investment and sustainable fiscal balances through economic reforms. Long term growth rates have been reasonable, averaging 2.6 percent since 1960, exceeding most other countries in South Asia. Despite this remarkable record, however, the natural resources are stressed and environmental costs are very high, threatening to undermine growth prospects. The urgency of addressing Pakistan's environmental problems has probably never been greater. Conservative estimates presented in the World Bank Report (2006) suggest that environmental

degradation costs the country at least 6 percent of GDP, or about Rs. 365 billion per year (US $ 6.05 billion per year), and these costs fall disproportionately upon the poor. The future growth and maintenance of existing life functions are threatened by Pakistan's low, unreliable rainfall averaging 250 mm a year. Classified as water stressed, the country uses almost all of its available water supplies in most years. Population growth coupled with the demands of industrialization and urbanization are already creating conditions of water scarcity. Water shortages are further compounded by urban pollution leading to poor water quality. Untreated pollutants from industrial, agricultural and urban sources are released directly into surface and ground water bodies intended for human consumption, with little regard for assimilative capacity of eco-systems. The result is heavily polluted water around towns and cities and a high incidence of disease, especially among the urban poor.
To ensure sustainable development, there are calls for complementary policies that address environmental issues.

Water is the key element of a nation's development needs. In the case of Pakistan water resources are facing pollution challenges. This paper provides an overview of Pakistan's water problems and the commendable track record of devising environmental policies to promote conservation and longer term sustainability. Such environmental policies include the National Conservation Strategy of 1992 through to the adoption of a National Environment Policy (NEP) in 2005. However, effective implementation of these initiatives remains a challenge. In the later part of the paper, policy options for managing urban water cycle in Lahore, Pakistan (a mega city dependent on River Ravi and a major canal system for its recharge) are outlined. The city of Lahore is dependent on groundwater for its social and economic activities and therefore needs policy which combines sustainable development with environmental management of the underlying aquifer system.

2 Overview of Urban Water Supply and Sanitation Systems in Pakistan

Despite the enormous size of the Indus Basin system, water availability on a per capita basis is declining at an alarming rate, from about 5,000 cubic meters per capita in 1951 to about 1,100 in 2006, which is just above the internationally recognized scarcity rate, and is projected to be less than 700 by 2025 [World Bank Report, 2006]. Although household use is only a small percentage of the total use, increasing competition for resources and continuing degradation of water quality are severely impacting efforts to improve levels of household service provision.

The majority of the population relies on groundwater as their principal source of drinking water. This is true both for rural areas and for major cities, apart from Karachi city (which gets its water from the River Indus), and Islamabad city (which has a number of different sources). Pakistan can be divided into five groundwater zones, for purposes of drinking water supply: (i) sweet groundwater areas; (ii) areas where canal or river water is a real alternative; (iii) mountainous and hilly areas where spring water is available; (iv) the eastern desert belt where groundwater is available at increasing depth; and, (v) coastal areas where groundwater is saline. About 80% of Punjab Province has fresh groundwater, with saline water in the south and desert areas. In addition, there is some evidence of high fluoride or arsenic content in Punjab Province, and a number of locations have been contaminated by industrial wastewater discharges. Less than 30% of groundwater in Sindh Province is fresh, with much of the province underlain by highly brackish water, and some instances of elevated fluoride levels. In North-Western Frontier Province (NWFP), increasing abstraction has resulted in wells now reaching into saline layers, and much of Balochistan Province also has saline groundwater [World Bank Report, 2006].

Over 60% of the populations get their drinking water from hand or motor pumps, with the figure in rural areas being over 70%. This figure is lower in Sindh Province, where groundwater quality is generally saline and an estimated 24%of the rural population gets water from surface water or dug wells. In almost all urban centres, groundwater quantity and quality has deteriorated to the extent that the availability of good quality raw water has become a serious issue. Over-extraction has resulted in declining groundwater levels, and groundwater quality has deteriorated as a result of the discharge of untreated sewage and industrial effluents. Groundwater over-extraction and pollution have typically been seen as problems for rural and agricultural activities but its broader impact on water supply will make the challenges of surface water transfers to growing urban areas even more difficult [World Bank Report, 2006].

There is no regular monitoring of drinking water quality, in terms of either the source of supply or the water as received by the user. Although groundwater is still the primary source of drinking water supplies, it is estimated that 40 million residents depend on irrigation water for their domestic needs, especially in areas where groundwater is brackish. The associated health risks are grave, as bacteriological contamination of irrigation water often exceeds World Health Organization (WHO) limits for irrigation. The poor quality of drinking water has major socio-economic consequences for Pakistan. A study conducted by UNICEF found that 20-40 % of the hospital beds are occupied by patients suffering from water-related diseases, such as typhoid, cholera, dysentery and hepatitis, which are responsible for one third of all deaths. The total health costs associated with the deaths and sickness caused by waterborne disease are estimated to amount to more than 1.8 percent of GDP [World Bank Report, 2006].

3 Principal Sources of Urban Water Pollution in Pakistan

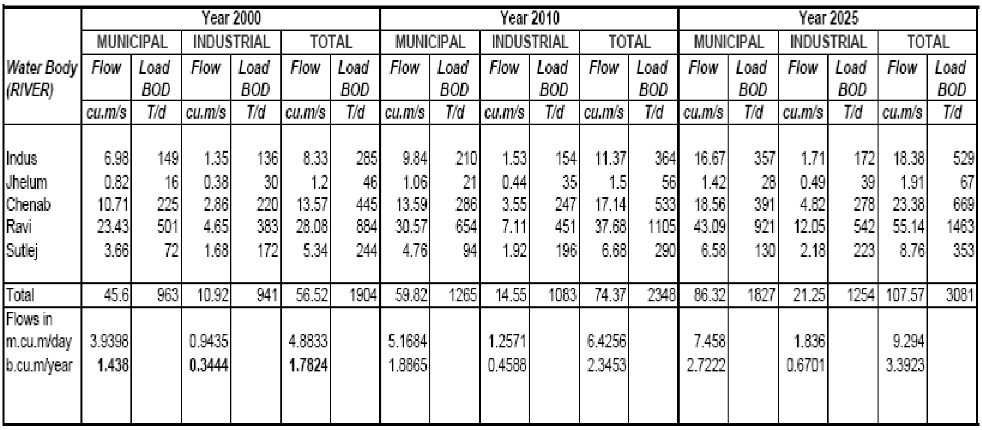
Municipal Effluent: Most surface water pollution is associated with urban centres. Typically, nullahs and storm water drains collect and carry untreated sewage which then flows into streams, rivers and irrigation canals, resulting in widespread bacteriological and other contamination. It has been estimated that around 2,000 million gallons of sewage is discharged into bodies of surface water every day. Although there are some seweage collection systems, which typically discharge into the nearest water body, collection levels are estimated to be no greater than 50 % nationally (less than 20% in many rural areas), with only about 10% of collected sewage treated effectively. Although treatment facilities exist in about a dozen major cities, in some cases these have been built without the completion of associated seweage networks, and the plants are often either under-loaded or abandoned. In effect, only a few percent of the total wastewater generated receives adequate treatment before discharge to the waterways [World Bank Report, 2006].

Industrial Effluents: It has been reported that in Lahore city, only 3 out of some 100 industries using hazardous chemicals treat their wastewater adequately. In Karachi city, two of the biggest industrial estates in Pakistan have no effluent treatment plant, and effluent containing hazardous materials, including heavy metals, is discharged directly into the river and harbour. In Faisalabad, one of the biggest industrial cities, there is little segregation of domestic and industrial wastes, and although there is a simple effluent treatment plant, its operational efficiency is not known as there is no regular monitoring [World Bank Report, 2006].

Agricultural Runoff: The quantity or quality of agricultural runoff has not been measured or tested at the national level but with an estimated 5.6 million tonnes of fertilizer and some 70,000 tonnes of pesticides used annually, pollution from agricultural sources can be expected. The contribution of agricultural drainage to the overall contamination of the water resources has not been determined. It is believed to be a small part of the total load but can be important in local hot-spots [World Bank Report, 2006].

The Urban Wastewater Treatment Master Plan for Pakistan 2003-23 gives a present total sewage treatment capacity of 339 Ml/d which represents less than 1% of total domestic sewage generated in urban areas, and some of this capacity is unused due to lack of sewerage infrastructure. This means that virtually all municipal and industrial wastewater is returned to the rivers, nullahs and streams untreated, which results in deterioration of water quality and causes water borne diseases. Table 1 shows the municipal and industrial flows disposed to inland surface waters in 2000 and its projection in 2010 & 2025. The future projections are based on 24.95% increase for the year 2010 and 23.153% increase over 2010 for the year 2025. Figure 2 shows the Chemical Oxygen Demand (COD) levels in surface waters of Pakistan.

Table 1: Municipal and Industrial Flows Disposed to Inland Surface Water
Source: Ministry of Water & Power, 2002



	Year 2000						Year 2010						Year 2025					
	MUNICIPAL		INDUSTRIAL		TOTAL		MUNICIPAL		INDUSTRIAL		TOTAL		MUNICIPAL		INDUSTRIAL		TOTAL	
Water Body (RIVER)	*Flow*	*Load BOD*	*Flow*	*Load BOD*	*Flow*	*Load BOD*	*Flow*	*Load BOD*	*Flow*	*Load BOD*	*Flow*	*Load BOD*	*Flow*	*Load BOD*	*Flow*	*Load BOD*	*Flow*	*Load BOD*
	cu.m/s	*T/d*	*cu.m/s*	*T/d*	*cu.m/s*	*T/d*	*cu.m/s*	*T/d*	*cu.m/s*	*T/d*	*cu.m/s*	*T/d*	*cu.m/s*	*T/d*	*cu.m/s*	*T/d*	*cu.m/s*	*T/d*
Indus	6.98	149	1.35	136	8.33	285	9.84	210	1.53	154	11.37	364	16.67	357	1.71	172	18.38	529
Jhelum	0.82	16	0.38	30	1.2	46	1.06	21	0.44	35	1.5	56	1.42	28	0.49	39	1.91	67
Chenab	10.71	225	2.86	220	13.57	445	13.59	286	3.55	247	17.14	533	18.56	391	4.82	278	23.38	669
Ravi	23.43	501	4.65	383	28.08	884	30.57	654	7.11	451	37.68	1105	43.09	921	12.05	542	55.14	1463
Sutlej	3.66	72	1.68	172	5.34	244	4.76	94	1.92	196	6.68	290	6.58	130	2.18	223	8.76	353
Total	45.6	963	10.92	941	56.52	1904	59.82	1265	14.55	1083	74.37	2348	86.32	1827	21.25	1254	107.57	3081
Flows in																		
m.cu.m/day	3.9398		0.9435		4.8833		5.1684		1.2571		6.4256		7.458		1.836		9.294	
b.cu.m/year	1.438		0.3444		1.7824		1.8865		0.4588		2.3453		2.7222		0.6701		3.3923	

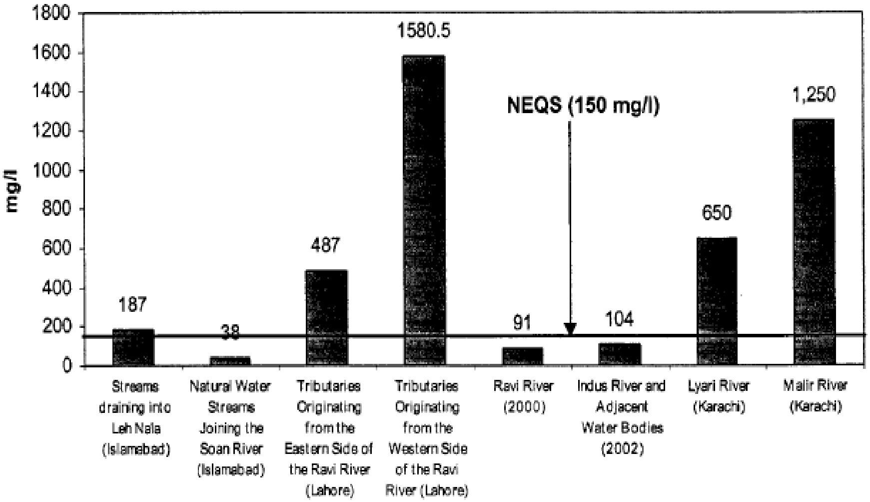


Figure 2: COD Levels in Surface Water Source: World Bank Report, 2006

There is presently very little opportunity for investor-operators in the water utilities sub-sector, especially in the larger towns and cities. The Water & Sanitation Agencies (WASAs) and municipal bodies are generally financially weak and do not generate capital for urgent rehabilitation, improvement and expansion of the existing infrastructure and facilities. This is increasing public pressure for better services.

Some of the causes of the poor performance of public sector organizations responsible for water sanitation include:

- political influence in management and staffing resulting in overstaffing with the wrong type of employees,
- rampant unionism,
- widespread theft of water due to the connivance of water vendors, local politicians and staff,
- poor economic returns, especially from governmental water users

As it has been observed in the case of several South East Asian countries where concessions have improved services and financing rehabilitation and expansion, the increase in public pressure for better service and the weakness of some existing institutions did not contribute to a more attractive investment climate in the water utilities sub-sector. However, in Pakistan, much of the urban water infrastructure is in a poor state of repair and major investment will be required for its rehabilitation. Investment requirements to accommodate growing populations will also be significant. In addition, there is apparently significant public opposition to privatisation within the water sector, which will need to be taken into consideration as the assessment of the potential for private sector involvement is carried out.

The expectations of the stakeholders in privatisation are that the privatisation would put an end to political interference, overstaffing, mismanagement, theft of water by low-income localities and corruption. The other benefits of privatisation will be better service for the bill-paying citizens and lower water rates for low-income localities that now depend on expensive and poor quality drinking water supplied by water vendors.

The stakeholders fears regarding privatisation of water supply & sanitation are that there will be i) massive redundancy of staff and resistance from unions; ii) substantial increases in tariff; iii) no significant increase in service level during the initial years, since the available amount of water would not increase and no major investments were foreseen; iv) no improvement in wastewater collection and treatment, since financial return on sewerage is low; v) resistance from the stakeholders operating the private water market and vi) social unrest in case non-paying consumers would be denied further service [GOP, 2001].

The Privatisation Commission of Pakistan presently does not pursue any privatisation plans in the drinking water and sanitation sectors.

4 Overview of Environmental Policies and Laws in Pakistan

In response to changing national needs and international obligations, Pakistan has progressively developed a number of policies & laws for the protection of the environment at the Federal and the Provincial levels. Some of the environmental laws in Pakistan have their origin in the colonial times, such as:

- Canal and Drainage Act 1873
- The Explosives Act 1884
- The Ports Act 1908
- The Forest Act 1927

The key environmental laws enacted post-independence include [Hagler, 2000]:

- The Fisheries Ordinance 1961
- The Punjab Wildlife (Protection, Conservation and Management) Act 1964
- The Fire Wood and Charcoal (Restriction) Act 1964
- Motor Vehicles Ordinance 1965
- The W. P. Regulation and Control of Loudspeaker and Sound Amplifier Ordinance 1965
- The Agricultural Pesticide Ordinance 1971
- The Antiquities Act 1975
- Environmental Protection Ordinance 1983
- Pakistan Environmental Protection Act (PEPA) 1997

Under the Pakistan Environmental Protection Act 1997 [GOP, 1997] a number of rules, standards and institutional have been implemented [Ahmad, 2002] :

- Establishment of the Pakistan Environmental Protection Agency
- National Environmental Quality Standards (self-monitoring and reporting by Industries) Rules, 2000
- Environmental Samples Rules, 2001
- Provincial Sustainable Development Fund Board (Procedure) Rules, 2001 Pollution Charge for Industry (Calculation and Collection) Rules, 2001

- National Environmental Quality Standards (Environmental Laboratories Certification) Regulations, 2000
- Provincial Sustainable Development Fund (Utilization) Rules, 2002
- Composition of Offences and Payment of Administrative Penalty Rules, 2002 Hazardous Substances Rules, 2002.
- Appointment of senior civil judges as Environmental Magistrates to deal with cases related to the handling of hazardous substances and vehicular pollution.
- Establishment of Environmental Tribunal

The implementing agencies do not have the capability and capacity to fully implement the legal provision. This is due to factors such as:

- Political instability and lack of multi-sector commitment
- Corruption and weak governance
- Absence of a strong policy framework
- Limited institutional, technical and legal capacity
- Poverty and external debt resulting in conflicting growth policies for example, subsidies on fossil fuels and establishment of new industry without proper environmental safeguards

In some cases, NGOs and courts in Pakistan have played a key role in implementing principles of sustainable development but there is still an urgent need for wider public participation from different sections of society, especially poor and disadvantaged groups.

The other measures for protection of the environment are:

- National Conservation Strategy (NCS), 1992
- National Environmental Action Plan (NEAP), 2001
- National Environmental Policy (NEP), 2005

The top priority of the National Water Policy (NWP), recently approved by the Federal Government, is the provision of safe drinking water for all, along with hygienic sanitation for urban and rural populations. The NWP establishes important basic principles including protection of sources, monitoring and maintenance of drinking water quality, and progressive upgrading of facilities for the provision of water and sanitation, on a sustainable basis.

Though the National Water Policy (NWP) provides a framework within which to establish a single set of rules and regulations for Pakistan's future water management there is still a need to harmonise this plan with the Pakistan Environmental Protection Act (PEPA) 1997.

The national environmental laws and policies have not been effectively implemented due to range of reasons:

- Lack of political will
- Influence of industrial lobby groups in the government sectors
- Inability to describe implementation pathways
- Disconnect between the legislative and implementation bodies
- Inadequate monitoring, reporting and implementation infrastructure

- Lack of capacity building programs for the regulation and implementation bodies

These issues are further elaborated by using the example of Lahore city's water resources.

5 Description of Study Area

5.1 Introduction

Lahore is located on flat alluvial plain on the left bank of river Ravi. Lahore District lies between 31°-15' and 31°-42' north latitude, 74°-01' and 74°-39' east latitude. It is bounded on the north and west by Sheikhupura District, on the east by India (international border) and on the south by Kasur district (Figure 3). The general altitude of the area is 208 to 213 meters above sea level.

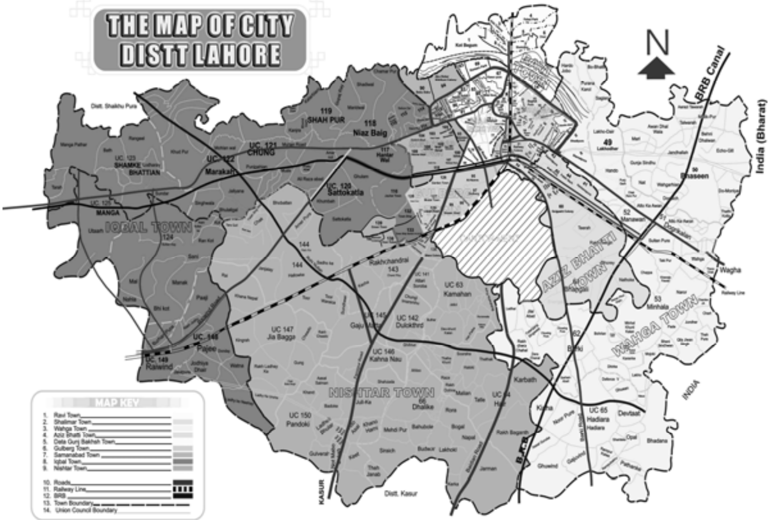


Figure 3: Map of the Lahore District with Urban Sanitation Zones

Lahore is the provincial metropolis and the largest urban district of Punjab. It is also the second largest urban center in Pakistan after Karachi. Lahore encompasses a range of commercial, social, cultural, industrial and educational activities. According to the 1998 population, there were 5.75 million inhabitants, which have now become 10.0 million, in the City District of Lahore. The main source of recharge to the Lahore aquifer systems is the River Ravi, which has been winding its way through the western Pakistani city of Lahore for thousands of years. The flows in the River Ravi are highly variable during different times of year. They also vary along the length of the river due to link canals discharging into the river and water withdrawals at channel head works. In the driest months of 1985, which was an exceptional year for the whole of Pakistan, the minimum monthly average daily flow remained only 254 cusecs for seven consecutive days, which is the lowest flow recorded in the last 50 years at Shahadara gauging station, see Figure 4 [Khan, 2006]. The River Ravi is the most polluted river in Pakistan.. Most wastewater discharges in the river reach between

Lahore and Balloki, a length of 62 km. The river presently receives

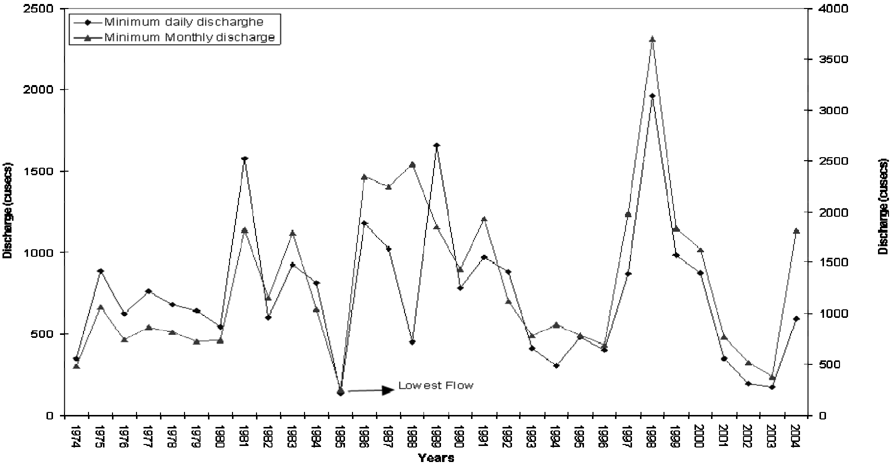


Figure 4: Lowest Flow in River Ravi

47% of the total municipal and industrial pollution load discharged into all the rivers of Pakistan. The BOD in the river after receiving Lahore municipal discharges is estimated to be 77 mg/l on the basis of mean annual flow. Between Lahore and Balloki, under low flow conditions, the river is completely devoid of Dissolved Oxygen (DO) and simply acts as a sullage drain. At Balloki the river water quality improves through augmentation of flow from the Qadirabad-Balloki Link canal. Here the Biological Oxygen Demand (BOD) values are low (2.3 - 3.9 mg/l), DO ranges from 6.2 to 8.2 mg/l, Total Dissolved Solids (TDS) are between 98 and 225 mg/l and sodium absorption ratio (SAR) varies from 0.1 to 0.55. At Balloki the river water meets the quality requirements for irrigation water. The high levels of faecal coliform are, however, of concern for other water uses. Data collected for the last 20 years indicate a decreasing trend in DO level and an increasing trend in BOD and TDS levels [Sami & Kheiri, 2000]. The quality of water in a river varies with flow. As mentioned earlier, there are considerable variations in the River Ravi flows. The clear picture of the water quality of the river can therefore be obtained only from a regular monitoring programme. Unfortunately, the River Ravi is not being regularly monitored for its quality in a highly polluted stretch near Lahore.

The Hudiara drain is also a major source of pollution for Ravi. It enters Pakistan loaded with pollution from India, is diluted with agriculture runoff and mixed with some industrial pollutants in Pakistan. The drain carries mainly industrial and agricultural waste from both India and Pakistan. The average values recorded at the time Hudiara enters Pakistan and at the confluence of Hudiara with Ravi are shown Table 2. It is seen that the main pollutants, BOD and COD, are diluted in Pakistan. It may also be mentioned that the average effluent flow in Hudiara is much higher from India and hence the total quantity of pollution in Hudiara drain from India is much more compared to that from Pakistan.

Table 2: Pollutants Comparison Source: Sami (2001)

Pollutants entering Hudiara Drain from India							
DO (mg/l)	**Discharge (cusec)**	**pH**	**BOD_5 (mg/l)**	**COD (mg/l)**	**TDS (mg/l)**	**TSS (mg/l)**	**Settleable solids (mg/l)**
0.55	187.7	7.94	113	276.4	695.2	348	4.25
Pollutants entering River Ravi from Hudiara Drain							
DO (mg/l)	**Discharge (cusec)**	**pH**	**BOD_5 (mg/l)**	**COD (mg/l)**	**TDS (mg/l)**	**TSS (mg/l)**	**Settleable solids (mg/l)**
0.51	180.3	7.88	104.10	255.7	859.3	220	2.01

Water samples were collected by Pakistan Council of Research in Water Resources (PCRWR) from 16 locations covering the major part of the Lahore city area and sources i.e. Tubewells (16) (Table 3 and 4). Out of the 16 locations none of any source was supplying safe drinking water. In each case one or more parameter(s) was falling under non-acceptable guideline values. The data was computed and processed which showed that 43% of samples were polluted with Coliform Bacterium. None of the sample showed E-coli contamination. The overall picture of other parameters depictedthat 100% of water samples possessed higher concentrations of As compared to WHO guide line values. The higher concentration of Fe was found in 50% of water samples [PCRWR, 2004].

Table 3: Physical & Aesthetic Parameters in Drinking Water of Lahore Pakistan
Source: PCRWR (2004)

Source: T/well	**pH**	**EC (mS/cm)**	**Turbidity (NTU)**	**Taste**	**Odour**
Minimum	7.40	376	0.02	Unobjectionable	Odourless
Average	7.77	1020	0.40		
Maximum	8.20	2321	3.70		

Table 4: Water Quality Parameters in Drinking Water of Lahore Pakistan
Source: PCRWR (2004)

Sour. T/W	**Alk m. mol/l**	**HCO_3 mg/l**	**Ca Mg/l**	**Mg mg/l**	**Hard mg/l**	**Cl mg/l**	**Na mg/l**	**K mg/l**	**SO_4 mg/l**	**NO_3 mg/l**	**PO_4 mg/l**	**TDS mg/l**
Min.	3.00	150	20	13	140	11	11	1.40	19	0.40	0.17	226
Avg.	5.90	295	34	26	193	29	87	3.99	83	0.56	0.24	539
Max.	8.80	440	64	36	300	99	142	6.00	186	0.85	0.34	763

6 Lahore’s Geography

6.1 Temperature

Lahore experiences extremes of climate. The summer season starts in April and continues till September. The hottest months are May, June and July. The mean maximum and minimum temperatures during these months vary between 40.4℃ and 27.4℃. The winter season lasts from November to March. The coldest months are December, January and February with a minimum temperature reaching up to freezing point. The mean maximum and minimum temperatures for this period are 22℃ and 5.9℃ respectively.

6.2 Humidity

Relative humidity throughout the day is higher in winter than in summer months. May and June are very hot and dry during which dust storms occur occasionally. Towards the end of June or beginning of July, the monsoon season starts, which is characterized by heavy down pour and humid sultry weather. It practically becomes oppressive in July, August and September.

6.3 Rainfall

Rainfall varies from year to year also from month to month. Maximum rainfall however, occurs in July and August when the monsoon depression travels westward. Maximum rainfall is observed during the month of July which records 32.1% of the average rainfall and shares 22.1% of yearly number of rainy days. The average annual rainfall in Lahore is about 629 mm with 34 rainy days i.e. 9.3% of total days in a year. The heaviest rainfall recorded during 24 hours over the last 50 years was in September, 1954 with 228 mm. The recent heaviest downpour in 24 hours was recorded on 22nd August 1996, with 189 mm followed by 185 mm on the following day and 65 mm on the third day when most of the city area was inundated with rain flood.

6.4 Topography

The topography of Lahore is generally flat and slopes towards south and south west at an average gradient of 1:3000. River Ravi flows in the west of Lahore city forming boundary with Sheikhupura district. The original physiographic features like channels remnants, levees have been destroyed or changed by the construction of urban infrastructure. Flood plains have been confined by the construction of embankments (bunds), spurs etc. The following five main natural drainage channels also run through the city and finally discharge in to River Ravi:

- Upper Chotta Ravi
- Lower Chotta Ravi
- Sukh Nehr drain
- Mian Mir drain
- Sutto Katla - Hudiara drain

6.5 Hydrogeological Set Up

Lahore area is underlain by unconsolidated alluvial deposits of Quaternary age. The alluvial sands constitute the aquifer material. The aquifer is composed of unconsolidated alluvial complex formed by contemporaneous filling of a subsiding trough resulting in a huge sedimentary complex of more than 400 meters (1300 ft) thickness. Sediments have been deposited by the present and ancestral tributaries of river Indus during Pleistocene-Recent periods. In accordance with its mode of deposition by large streams in constantly shifting channels, the alluvial complex is heterogeneous and individual strata have little lateral or vertical continuity. However, in spite of their heterogeneity, the alluvial sediments constitute a large aquifer, which on regional basis behaves as a homogenous and highly transmissive aquifer. The ground water occurs under water table conditions and the individual lenses of silt and clay do not impede the flow of ground water.

7 Lahore Water Supply

Water and Sanitation Agency (WASA), Lahore is responsible for providing water supply, sewerage and drainage facilities to 90% population of Lahore. The remaining population of Lahore is served by other agencies like Lahore Cantonment Board, Model Town Society etc.

Ground water is the main source of water supply in Lahore. WASA has installed 316 tubewells of varying capacity in Lahore, which operate for an average duration of 16-18 hours a day. The depth of these tubewells, vary from 150 m to 180 m. These tubewells inject water directly into the main water supply system. With the help of these tubewells WASA is supplying 720 mgd of water to 531,336 connections. WASA water supply system is designed to provide water at an average rate of 80 gallons per capita per day (gpcd). The water distribution network of WASA consist of 3,200 Km of water supply lines including 79.5 Km Main Grid (12" to 30" dia). Asbestos Cement (AC) pipes have been used for the distribution system. In some areas of LDA Housing Schemes Polyvinyl Chloride (PVC) pipes have been used and comparatively older system in central part of the city has Ductile Iron (DI) and AC pipes.

To ensure drinking water quality in the service area of WASA, chlorination is done to eliminate the chances of contamination. Water quality is regularly monitored by WASA in its own laboratory for chemical and bacteriological examination of water. Any contamination noticed is rectified by flushing, chlorination and maintaining positive pressure in the distribution system. At present 30% of the total water supply connections are metered and the remaining 70% are un-metered.

8 Lahore's Sewage System

The sewerage system of Lahore was built in early nineteenth century with the construction of egg-shaped sewers and sewage pumping station at Main Outfall Road. Lahore Municipal Corporation was responsible for the maintenance of water and sewerage system in the city till1967, when it was handed over to Water Wing of Lahore Improvement Trust (LIT). With the establishment of Lahore Development Authority (LDA) in 1975 LIT Water Wing was converted to WASA.

The existing sewerage system in the WASA service area consists of 405 Km of trunk sewers and 3,205 Km of lateral sewers making a total length of 3,610 Km. The diameter of sewers vary from 300 mm to 1650 mm (12" to 66"). The entire sewage is pumped into different sullage/storm water drains which ultimately discharge sewage into River Ravi.

Due to the flat terrain of the Lahore city a large quantity of storm water also finds way to the sewerage system, therefore the sewerage system of Lahore can be called a semi-combined sewerage system. The flat terrain of the city is also responsible for the large number of intermediate pumping station. Presently WASA is operating eleven main pumping stations and 61 intermediate pumping stations.

In order to facilitate the operation and maintenance of the sewerage system the entire service area of WASA has been divided into seven sewerage districts. Sewage from these districts is carried through a network of lateral, secondary and primary sewers towards the disposal stations.

9 Lahore Drainage System

Lahore is comparatively a flat area with a mild slope towards south-western side. There are five natural drainage channels in Lahore with a total length of 51 Km. Additionally WASA has also constructed 2 drainage channels with a total length of 8.25 Km. These drainage channels serve to discharge the storm and sullage water outside the city and finally into River Ravi.

Operation and maintenance of drainage channels is managed by WASA. The operation and maintenance of drainage channels mainly covers the frequent de-silting of channels so as to maintain their maximum carrying capacity. Both mechanical and manual methods of de-silting are adopted by WASA. The job is performed through the seventeen drainage sub divisions of WASA.

Silting of sewers and drainage channels is one of the major problems faced by WASA in the disposal of domestic and storm sewage. To keep the sewers and drainage channels functioning efficiently cleaning of sewers and drainage channels is carried out periodically. A large part of the Lahore sewerage and drainage network has been silted up resulting in considerable loss of its carrying capacity. Sewage Zones A, B, G and H1 which are located in different areas of Lahore (Table 5) but share the same topography and climatology, need cleaning of sewers and drainage channels. The location of each sewage zone is shown in Figure 5.

Table 5: Cleaning of Sewers & Drainage Channels Required in Sewage Zones of Lahore

Sr. No.	Zone	Area
1	A	Timber Market, Qasurpura, Qilla Laxman Singh, F & V Market, Circular Road, etc.
2	B	Data Nagar, Siddiquepura, Usman Gunj, Sher Shah Road, Loha Market, etc.)
3	G	Krishan Nagar, Gowalmandi, Railway Road, Dil Mohammad Road, Dharampura, Allama Iqbal Road, Garhi Shahau, etc.
4	H1	Mozang, Ichra, Lyttan Road, Old Anarkali, Nabah Road, etc.

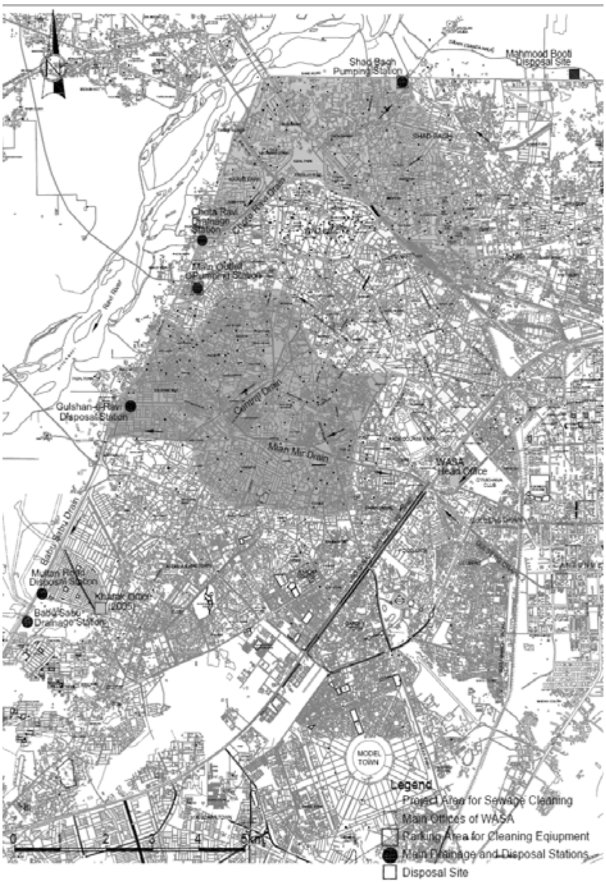


Figure 5: Location of Sewage Zones

10 Lahore's Water Resources

Ground water is the only source of water in the Lahore. Ground water abstraction from the Lahore aquifer has been going on since time immemorial. Water abstraction rate by WASA is estimated to be around 1.45 million cubic meters per day. WASA, Lahore operates 316 No tubewells, which include 197 No of 112 lps capacity, 3 No 84 lps capacity, 83 No of 56 lps capacity, 6 Nos 42 lps and 27 No 28 lps. The depth of these tubewells varies from 150 m to 180 m. These tubewells operate for an average duration of 16-18 hours per day and inject water directly in to the main water supply system.

The subsoil water level is decreasing in the city due to injudicious use of water for drinking and cleanliness purposes. The Wasa authorities are now sinking tube-wells from 600 to 700 feet (185 m to 215 m) depth owing to decline in the underground water level. The underground aquifer of the provincial metropolis is also being threatened by excessive pumping of water, affecting its quality as well as its taste. According to a study conducted by Water and Sanitation Agency (Wasa) some time back, static water level below ground surface has been dropping significantly in different parts of the city during the last many years. Between 1976 and 2000, average decline in water level rose to seven feet per year from 1.89 per year. According to the Wasa report, the water table since 1961 has gone down to 61 feet on an average. Between 2003 and 2004, the water table depleted by 17 feet in the Ravi Road area, 10 feet in Ichhra, nine feet in Industrial Area Kot Lakhpat and Misri Shah, 29 feet in Mustafabad, 7.3 feet in Gulberg, five feet in Green Town and Baghbanpura, 2.3 feet in Data Nagar, two feet in Islampura and Iqbal Town, four feet in Samanabad, 0.6 feet in Mughalpura subdivisions, 7 feet in Shahdara and Shimla Hill, 6.4 feet in Mozang, six feet in Garden Town, and 4.2 feet in Township [Daily International The News (Internet Edition) (2006)]. Mean average decline in ground water level in Lahore is 2.03 feet per year. In 1987 the lowest contour was 192 m above mean sea level around Mozang Area (Sewage Zone H1), which has now gone down to 183 m above mean sea level [WASA website].

11 Wastewater Treatment

At present WASA has no wastewater treatment facility. All the wastewater is discharged untreated in to River Ravi. WASA has plans to construct five wastewater treatment plants in Lahore. Feasibility study, design work and tender documents are complete and 900 acres of land has also been purchased. The proposed treatment technology is facultative lagoons. WASA intends to construct four wastewater treatment plants in the next five years [WASA website].

12 Solid Waste Disposal

Average per capita solid waste generation in Lahore city ranges from 0.5 kg to 0.55 kg per day. On this basis it is estimated that presently 3500 tons/day of solid waste is generated in Lahore (Approximately 1.25 million tons per year) of which 87% is collected from the ex-MCL area and remaining from Defence Housing Authority (DHA) and Model Town Society (MTS). Presently solid waste is collected from the communal bins placed at various locations in the city and transported to landfill sites. Both public and private sector are involved in managing solid waste within the city. The solid waste dumping sites in Lahore are Mahmood Booti, Sagian, Kahna Kacha and Bagrian [WASA website].

13 WASA Water Supply & Drainage Tariff Structure

The current slab rates of both domestic and commercial in meter account are shown in Table 6 and 7.

Table 6: Tariff Structure of Metered Connections (Domestic)

Consumption Slab (in gallons)	Water rate Per 1000 GPM	Sewer/Drainage per 1000 GPM
Up to 5000	PKRs. 9.20	PKRs. 6.44
5001 to 20000	PKRs. 14.90	PKRs. 10.43
20001 to above	PKRs. 19.50	PKRs. 13.65

Currency Equivalent: US$ 1.00 = PKR 60.55 (October 30, 2006)

Source: www.lda.gop.pk/lda_wasa.html

Note: Where a meter is not installed or found missing after installation, the average consumption for domestic connection is fixed as under:

S. No.	Plot Size	Average Per Month
1	20.9 m^2 to 104.51 m^2	10,000 Gallons
2	106.6 m^2 to 209.02 m^2	15,000 Gallons
3	211.11 m^2 to 418.05 m^2	20,000 Gallons
4	420.14 m^2 to 836.10 m^2	25,000 Gallons
5	877.90 m^2 and above	30,000 Gallons

Source: www.lda.gop.pk/lda_wasa.html

Table 7: Tariff Structure of Metered Connections (Commercial/Industrial)

Consumption Slab (in gallons)	Water rate (per 1000 GPM)	Sewer/Drainage (per 1000 GPM)
Up to 5000	PKRs. 19.53	PKRs. 13.67
5001 to 20000	PKRs. 34.89	PKRs. 24.42
20001 to above	PKRs. 50.48	PKRs. 35.34

Currency Equivalent: US$ 1.00 = PKR 60.55 (October 30, 2006)
Source: www.lda.gop.pk/lda_wasa.html

WASA charges for sewerage & aquifer charges for private tubewells are shown in Table 8.

Table 8: Sewerage & Aquifer Charges for Private Tubewells

Capacity of Tubewell	Aquifer Charges	Sewer Charges
1 Cusec	PKRs. 5,000 per month	PKRs. 5,500 per month

Currency Equivalent :US$ 1.00 = PKR 60.55 (October 30, 2006)
Source: www.lda.gop.pk/lda_wasa.html

For all industrial, commercial, non-residential, Government and Semi Government organizations, corporate bodies and manufacturing units not directly connected with WASA water/sewerage system but disposing off sewerage through drainage system are liable to be charged Rs. 1188/- per acre per half year as drainage charges.

14 Need for an Effective Urban Environmental Policy Linked To the Water Cycle

Environmental policies all over the world are undergoing a fundamental change as governments, businesses and non-government organizations are exploring new ways of strengthening environmental protection and restoring environmental quality. The need to re-examine and build upon traditional policy approaches is being fuelled by the recognition that narrowly prescribed command and control-based systems, while essential to the early efforts at environmental protection, have not fully achieved the desired results.

Advancements in technology and gains in ecological efficiency have been offset by increased population and per capita consumption. New concerns, such as climate change, biological diversity and persistent organic pollutants, have emerged, requiring new approaches in policy design and implementation.

Stakeholder driven institutional reform is a key driver for creating a new policy-based approach to environmental protection and enhancement. Budget and staff reductions have led public agencies to re-think the design and enforcement of policies. Market-based instruments, voluntary approaches and co-management are becoming more important. Though some of these measures promise more cost-effective solutions but they will contribute to reaching environmental objectives only if public agencies continue their essential functions of regulation, standard setting, research, monitoring and enforcement which is lacking in Pakistan. Devolving environmental responsibilities with the notion that regional and local governments are more effective in dealing with them will work only if there is sufficient capacity and resources to make the transition and if the leadership is there to fill the gap left by public sector bodies.

15 Evaluation of Policy Options

Since long measures are being taken to curb water pollution. To date, the most successful strategy has been traditional regulation targeted at major point sources, which yields substantial improvements in urban water quality. However, while water pollution problems caused by major point sources can be controlled easier as compared to diffuse pollution which is also called as non-point source pollution. A wide variety of policy options are now available for dealing with diffuse pollution as can be seen from Table 9.

Table 9: Possible Options for Addressing Diffuse Pollution from Agriculture

Education and Information Initiatives
— Information campaigns (government or industry associations)
— Off-site training in environmental management
— On-site training in environmental management (which may be subsidised)
— Information from suppliers, namely chemical companies producing pesticides and fertilisers
— Soil, manure and water monitoring

Voluntary Instruments
— Industry codes of practice
— Environmental management standards
— Voluntary agreements

Economic Instruments
— Input taxes or levies on nitrogen and phosphorous fertilisers, or pesticides (could be introduced on all inputs, or just those above a specific quota)
— Tradable nutrient quotas (could be based on inputs or soil concentrations) or emissions trading (between non-point and point sources or non-point and non-point source)
— Subsidies for external audits and/or the adoption of best practices
— Financial compensation for setting aside land, such as the creation of buffer strips or zones
— Liability Rules which guide compensation decisions when polluters are sued for damages

Regulatory Instruments
— Compulsory adoption of environmental management plans
— Placing a cap on polluting emissions
— Controls on rates of fertiliser application

— Banning environmentally risky farm practices (e.g. not leaving buffer zones to water ways and clearing vegetation near water ways)
— Compulsory disposal methods of farm waste, particularly manure
— Cross compliance provisions (depending on the extent of state government subsidies)

Planning Instruments

— Rezoning land to exclude agriculture
— Land retirement contracts or covenants
— Land management contracts or covenants

Source: Gunningham and Darren Sinclair (2005)

In recognition of the changes that are occurring, a conceptual framework to guide environmental policy development during the next decade and beyond, with the objective of developing a new policy framework for environmental sustainability needs to be based on the principles of effectiveness, credibility, transparency & accountability and efficiency.

Beside the above principles being embedded in the policy, the policy needs to address the core design criteria of i) senior-level commitment from participants**;** ii) clear environmental objectives and measurable results; iii) clearly defined roles and responsibilities; iv) consultation with affected and interested stakeholders**;** v) public reporting; vi) verification of results; vii) incentives & consequences; and vii) continual improvement. The new policy needs to be based on the factors such as cost-effective & efficient, fair, dynamic efficient, political acceptable and easily enforceable.

16 Roles of Various Institutions in Water Quality Protection

The Federal Ministry of Environment (MoE), provincial environmental authorities, and local governments have an important role to play in: (i) protection of water sources, (ii) water supply and sanitation service provision, and (iii) regulation of drinking water quality.

Protection of water sources: This clearly should involve the environmental authorities as having a principal responsibility for providing an overview of water quality, but monitoring of canal and drainage water quality is also a mandate of the irrigation departments. The irrigation authorities conduct regular monitoring of salinity and other parameters relevant to their operations, but do not normally test for heath-related parameters. Some broader studies have been carried out (e.g. those by PCRWR) but there is no overall water quality monitoring program, and MoE should take the lead in clarifying the needs and practical scope of such a program (World Bank, 2006).

Water supply & sanitation service provision: Prior to devolution, responsibility for the provision of water supply and sanitation services rested with provincial governments, and was exercised though Development Authorities (DAs) or Water and Sanitation Authorities (WASAs) in urban areas, and provincial Public Health Engineering Departments (PHEDs) in rural areas. As part of the devolution process, water and sanitation are now assigned to tehsils, except in the case of city districts where they are district responsibilities. While MoE has an important role to play in reporting on progress towards the relevant MDGs, and is presently implementing a national mandate to provide water treatment plants under the Clean Drinking Water initiative, in overall terms water and sanitation is an operational function that must have a strong local dimension (World Bank, 2006).

Regulation of drinking water quality: From the point of view of public health, there is an important need to monitor water supply services, in particular the bacteriological and chemical quality o f the water as it is received by users. This is also clearly tied to efforts to upgrade the coverage and overall quality of water services. There have been some studies of the quality of water delivered (for example the PCRWR work) but there is no structured system in place. In 2002, the Pakistan Standards and Quality Control Authority (PSQCA) issued a drinking water quality document, in line with WHO guidelines, but this is a guidance document and is not enforceable on water service providers. Consequently, there are currently no drinking water quality standards in Pakistan to protect users. Once such standards are established, the ideal system for monitoring water supplies would be through a tiered approach, including routine sampling by the operator, monitoring by the local or provincial health or environmental authorities, with oversight, review and consolidated reporting by MoE. Designing and putting such as system in place (which will require resources and skills at all levels) could be an important task for MoE.

Protection of ambient water quality (both surface and groundwater) is an essential part of the mandate of the environment authorities. In this context, the NEP identifies the need to establish a use-based system for classification of water bodies, as a first step in setting objectives for protection and rehabilitation. This must be followed by clean-up of priority water bodies, to avoid the recurrence of health crises caused by the use of polluted water. Such a program would require the refinement of standards, clarification of responsibilities, better information systems and additional support for the enforcement of discharge standards (World Bank, 2006).

17 Urban Water Reform for Lahore

17.1 Water demand management options

The various urban water demand management options can be i) use of price of water as a policy instrument; ii) education & persuasion; iii) water audits; iv) water accounting; v) subsidies for adopting water saving fittings and appliances; and vi) water sensitive urban design.

17.2 Urban water supply options

The various urban water supply options can be i) price because it is as much an instrument to influence supply as it is to influence demand; ii) incentives to install rainwater tanks to flush toilets and to water gardens; iii) mandatory use of rainwater tanks in new residential and industrial and commercial buildings and developments; iv) incentives to incorporate grey-water recycling systems; v) water sensitive urban design; vi) recycling of wastewater; vii) use of stormwater for aquifer recharge; and viii) use of Aquifer Storage & Recovery (ASR) technique, where technically feasible.

The discharge in River Ravi remains mostly very low from October to May which usually remains so low that it does not have the ability to dilute or transport the sewage water which is being added through drains from Lahore city. Due to extensive extraction of groundwater as well as low flow in River Ravi, water table is lowering very rapidly. So, there are more chances of groundwater being recharged with the polluted river water since the head is increasing. There is an urgent need to augment River Ravi water from adjacent River Chenab via a link canal constructed upstream of Lahore city to improve the water quality of River Ravi.

18 Discussion

Water and Sanitation Agencies (WASAs) and municipal bodies remain responsible for the management of water supply and sanitation services in the urban areas. While many of these are run relatively well, they all suffer from inadequate funds due to the way they are financed. In very few cases do they collect enough money from water tariffs to cover O&M costs, let alone funds for replacement, improvement and extension of services? All are run down with very large backlogs of maintenance. In the absence of raising their own money, WASAs must rely on *ad hoc* inputs of money from central government reserves which are infrequent and inadequate. Hence, most urban water systems are in a poor state of repair without real ability to improve the situation.

In addition, there is no central body to assist and support WASAs in planning, development and management of their systems. Instead, they compete with one another for funds and plan and implement on their own, not always most efficiently. A central body would help in the strategic planning for urban water supply and be able to more easily regulate tariff levels, collection mechanisms, planning, etc.

While there is general agreement that the quality of water in rivers is poor and deteriorating, there is only a limited amount of information to support this. Water quality monitoring is carried out regularly at only a few locations and there is no real water quality monitoring network or information system. There are no Water Quality Standards for surface or groundwater in Pakistan. Drinking water quality standards follow WHO standards and FAO standards are referenced for irrigation water. Whether these are appropriate for Pakistan still remains to be determined.

There is a dire need for the development of Sectoral NEQS, which should provide acceptable pollution limits for major industrial sectors i.e. textile, pulp & paper, sugar, fertilizer, cement and chemicals. The implementation of the general NEQS is practically impossible as some of the standards in some industrial sectors are very stringent while those are very lax in other sectors. The Federal EPA has been considering suggestions regarding sectoral pollution limits but development and enactment of such standards are still awaited.

Lahore needs an urban water reform to optimise the use of water supplies and water industry infrastructure in the context of frequent droughts, urban population growth and increased supply variability due to climate change. There are several aspects to this. First, efficiency of WASA, Lahore providing water services need to be improved. Second, the demand for water should be managed in a way that is compatible with waste minimisation and most efficient use of current and proposed water and wastewater assets. Third, cost effective ways to augment water supplies are essential to meet anticipated demand growth.

There is no easy answer for water reform. Reforms predicated on single, or limited option solutions may be simpler to market, but do not provide all the answers. Rather, all options need to be examined thoroughly. It is preferable to take a diversified portfolio approach to water reform. Basing water reform on a wide spread of options offers the accumulation of small gains from many sources, minimising disruption and spreading the risks of failure. It also maximises the use of known and existing technologies to meet the widest range of community and industry needs. This ensures that progress is not stymied by the search for new technology when effective management and current technologies can do the job now. Finally, systematic diversification, with an emphasis on persistence over time, will work to ensure that simple inexpensive options are not discarded in favour of more risky, and costly options that are superficially attractive.

19 Conclusions

Pakistan is facing major environmental and water scarcity crises due to rapid population growth. In response to rapidly degrading environment, Pakistan has formulated a number of environmental policies. However, these policies do not clearly provide means for protection of water quality in urban areas. A review of Lahore’s water quality indicates multiple types of pollution from the industrial and non-industrial sources. The present water policy and the associated environmental policies have failed to secure long term water quality and quantity for the citizens of Lahore.

In this paper we proposed institutional reforms linked with the objectives of sustainable development. This institutional reform should lead to sustainable water policy through active public participation. A key aspect of this policy should be water auditing, water accounting, water management and ensuring an inter-generational equity. The roles and responsibilities of various institutions involved in protection of water sources, water supply & sanitation service provision, and regulation of drinking water quality should be clearly defined. The current National Environmental Quality Standards (NEQS) provide standards for emissions and effluent from selected sources, but do not establish standards for the ambient quality of air or water. In addition, aspects of these standards are out-of-date, no longer reflecting current understanding or technologies. Also there are currently no formal drinking water quality standards in Pakistan to protect users, a gap which should be filled as a matter of priority. There is an urgent need to augment River Ravi water from adjacent River Chenab via a link canal constructed upstream of Lahore city to improve the water quality of River Ravi.

Pakistan urgently needs harmonization of its growth needs with sound environmental policies and urban water cycle. This will require transparency and accountability of institutions responsible for water supply and wastewater management.

Acknowledgements

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Sustainable Urban Groundwater Management: Integrating People into the Solution

可持续的城市地下水管理：
让人民参与解决方案

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Abstract

Urban population and municipal geographic growth is associated with China’s astoundingly rapid economic development. However China is a country faced with scarce water resources, water pollution, flooding, and soil erosion. The already problematic situation of inadequate sustainable surface and groundwater resources are forecast to increase.

The government system managing urban water resources in China is complex and fragmented. Groundwater under 90 percent of China’s cities is contaminated or not dependably safe. Research has documented that water pollution exposes people in China’s cities to infectious and parasitic disease as well as exposure to a growing volume of industrial chemicals, heavy metals, and algal toxins. Individuals have no way to avoid exposure. The related poor public health lowers productivity and increases health costs. As individual residents are affected, economic progress is also affected.

Water management planners, in China and elsewhere, routinely use tools from science, engineering, and technology to plan and implement strategies. The “Technical Fallacy” continues—this is the notion that thorough and rigorous technological analysis is sufficient to implement a solution. Experience shows the biggest obstacles are social, institutional, community relations and social acceptance of environmental programs.

This paper examines how the state of California has implemented a program of water awareness educating all people—young and old—about water resources, management and the roles of government agencies. The extensive system of government departments, non-profit organizations, and business enterprises in California is outlined. One groundwater project under the auspices of the Sonoma County Water Agency is discussed showing how education, collaboration, and integration resulted in local stakeholders participation in water management planning. Stakeholders participation has overcome the hazards of the Technical Fallacy.

The paper demonstrates that “The Technical Fallacy” can be avoided. Integrating people in sustainable groundwater management programs has long-term financially viable results.

摘要

中国城市的人口和地理范围的增长是同其飞速发展的经济分不开的。然而中国面临着水资源短缺，

水污染，洪水和土壤侵蚀的问题。已经存在的地表和地下水水源持续不足的问题预计还会增加。

中国城市水资源管理的政府体系复杂而分散。中国城市 90%的地下水被污染或不安全。研究已经证明水污染是导致中国城市人口患上传染性疾病和寄生虫病的原因, 同时他们还受到工业化学品，重金属和藻类毒素数量增加的威胁。个人是无法避免这些威胁的。相对较差的公共卫生设施降低了生产力，增加了医疗的费用。当居民个体受到影响时，经济的发展也会受到影响。

在中国和其它地方，水管理规划者通常应用科学、工程和技术的工具来规划和实施战略。“技术错误”延续着这样的观念——全面严格的技术分析足以解决问题。经验显示最大的障碍是社会、制度和社区的关系以及环境项目的社会接受程度。

本文考查了加利福尼亚州怎样实施水意识项目，对所有人——年轻的和年老的——就水资源、管理、政府部门扮演的角色进行教育。概要介绍了加州政府部门、非政府组织和企业的广泛组织系统。讨论了索诺玛县水管局资助下的一个地下水项目，说明教育、合作和综合管理怎样促使当地的利益相关者参与水管理规划。利益相关者的参与克服了“技术错误”的危险。

本文还证明“技术错误”是可以避免的。让更多的人参与可持续水管理项目长期来说在财政上具有可望成功的结果。

1 The Problem

To ensure continued astoundingly rapid economic growth China needs to resolve serious environmental problems.[1] Chinese environmental health experts say that air pollution is the worst problem, but water pollution is close behind (Hricko 1994). China is a country faced with scarce water resources as well as flooding, water pollution, and soil erosion. And the problem is not just environmental. A crisis is on the horizon. Insufficient water is already limiting industrial and agricultural output in some areas. As Sheng Huaren, vice-chairman of the NPC noted last year in Shanxi province, “Environmental problems have become a restraint on…economic and social development” (http://english.peopledaily.com.cn/200607/17). Solutions need to be found, and found quickly.

1.1 Demands and scarcity

In a survey of China’s environmental state of affairs, Dr Elizabeth Economy of the Council on Foreign Relations reports that 60 million Chinese people have limited access to water; and 10 times as many drink contaminated water (February 2004).

China’s geography and its population distribution are a major component of the water scarcity problem. An estimated 44 percent of the populous nation lives in the northern and northeastern provinces, and some 58 percent of its cultivated land is also in this area. However only 14 percent of the country’s total water resources are found in the region

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[1] For a comprehensive understanding of China’s growing environmental crisis and its implications for the country’s development see Elizabeth C. Economy’s 2004 book *The River Runs Black.*

(Anonymous, New Agriculturalist On-line, October 2004). Thus it is not surprising that the major water deficits are in this northern, northeastern region. Massive reclamation projects have been undertaken in China, but two-thirds of the cities in China are now short of water.

The nation’s economic development is associated with urban growth—both in number of cities and expanding urban populations. As urban industry and population regions expand the local demand for water increases. Yet, two-thirds of China's cities have been short of water for years, if not decades (Asia Times On Line, August 6, 2003). In 2001, some 75% of all urban areas lacked adequate systems for the supply and distribution of potable water (People’s Daily Online 2001). The capacities of public water supplies in the rapidly growing urban-industrial agglomerations (e.g., Guangdong) need to be increased dramatically. In conjunction with industrial growth and urban expansion China’s authorities face problems related to continually increasing demands for water, especially urban ground water.

The continued existence of some cities is threatened by a lack of water. River and lake waters now, all too often, are unavailable for urban use. Taiyuan, the capital of Shanxi, is one example of problem. The 2.8 million residents have all but depleted their water sources. The Fen River, which supplied much of the city’s industry with water, dried up as the result of use by upstream factories. The city has dug wells on the dry riverbed, but most of those wells have gone dry. Taiyuan is beginning to sink. The water pressure in Taiyuan is so bad, that water no longer reaches above the second floor of most buildings.
Taiyuan’s solution to the problem, like that of Beijing and other northern cities, has been to tap into the Yellow River. Construction started in 1999 for a series of tunnels to divert water 280 miles from the Yellow River, to Taiyuan (see World Bank 1996; United States Embassy 1997). The research of one Chinese water resources scientist, Shen Dajun, concluded that climate warming will reduce rainfall at the water consuming part of the water transfer route, thereby making more efficient irrigation and water reuse by industry all the more important (US Embassy 1997). The problem is not going to go away.

1.2 Sinking cities

Cities have drilled ever deeper for water. As groundwater is withdrawn the aquifer compacts and the ground level sinks, affecting building stability and flooding. The water table in Beijing has been dropping. Shanghai alone has sunk 1.7m in the past 40 years. The Shanghai Geological Research Institute reported that excessive groundwater pumping contributed to 70% of Shanghai’s surface subsidence with the remaining 30% created by the physical weight of skyscrapers (People’s Daily 2003). The China Geological Studies Bureau has been monitoring the rate at which the ground is sinking, as well as the water levels. In December 2003 People’s Daily reported that the China Geological Studies Bureau study showed surface subsidence had picked up speed over the last two decades hence contributing to more use of groundwater resulting in 46 cities sinking.

1.3 Pollution and treatment

China must contend with not only surface and groundwater pollution, but faulty system maintenance, lack of wastewater treatment, and urban ground subsidence.

Effective infrastructure for municipal wastewater treatment—municipal and rural—is rare in China. Since the early 1980s the major cities in China implemented modern water supply and sanitation facilities, however smaller cities and towns in rural areas, in particular, still have only very basic wastewater treatment facilities. Most of the 20 billion tones of urban sewage that China's expanding cities produce annually are dumped straight into rivers and lakes (Becker 2003). As factories have multiplied along the river banks, a shortage of water treatment plants means that about 80% of industrial wastewater is untreated when it is discharged back into rivers. China has by far the highest total emission of organic water pollutants in the world--equivalent to those of the USA, Japan and India combined (Anonymous, New Agriculturalist on-line, and October 2004). Water quality ranges from poor to poisonous, but farmers and many urban dwellers have no alternative for drinking or watering their crops.

The implications for China's health risks related to water pollution are significant (see Hricko 1994; Wu et.al. 1999). Human health is at risk from pollution, hence likely to affect sustainable development. Research has not yet been conducted in China, but there is fear that the country's high rates of hepatitis A, diarrhea, and liver, stomach and esophageal cancer may be linked to this pollution.

The need to provide the rapidly growing Chinese urban population with clean drinking water grows. Yet over time the development of a functioning waste disposal and wastewater treatment infrastructure becomes more complicated, and costly.

Chinese officials are well aware of the issues and, as noted, have formulated policies and regulations on urban wastewater treatment and reuse. The government has established financing, pricing and management. However polluted water continues to be a reality.

1.4 External interest

By 2001 the World Bank had established a partnership with the Chinese government in water resource conservation. The Bank supported China by financing fifteen projects with significant urban wastewater components. These projects covered about half of China's provinces, and involved an investment of more than two billion U.S. dollars. The total investment of the World Bank in urban wastewater treatment facilities in China is expected to top ten billion US dollars in five to ten years (People's Daily Online 2001).

In 2001 the 21st Century International Conference and Exhibition on Developing Strategy for Urban Waste Water Treatment and Reuse was held in Beijing. In October 2006 the international conference under the UNDP was held in Beijing and focused on means to combat the flow of sewage and other forms of pollution from land to sea. (See United Nations Environment Programme 2006).

1.5 Problem is policy not technology

Meeting with Chinese water resource scientists in Beijing in October 1997, American

Embassy Environment, and Science and Technology section officers concluded that the PRC's chronic water scarcity problem "…is policy not technology" related (US Embassy 1997). Better water pricing policy could drastically improve the situation, but rural poverty makes raising prices difficult. Furthermore, water re-use by industry in China (about 30%) is much less than that (around 70%) in developed countries.
Water management leaders in China, and elsewhere, need to expand the focus of sustainable water management, including groundwater management, beyond financing, pricing, and technology.

1.6 The technical fallacy

Through education and research scientists and engineers continually expand technical means to attack environmental issues—including those related to groundwater. Indeed management projects rarely fail from lack of scientific or engineering skill. As a result scientists and engineers logically assume that *thorough and rigorous technological analysis is sufficient to implement a solution* to problems. This line of thinking is known as "The Technical Fallacy."

Incorporating the technical fallacy as accepted policy, agencies and organizations throughout the world often implement wholly technically researched projects. Though useful, this approach only partially addresses the situation. Experience has shown the biggest obstacles to solving environmental problems are social, economic, and institutional. Saving water is not a matter of technology. Chinese farmers and industries need water but they find conservation and/or re-use a complex matter of non-technical problems. Individual and community needs and perspectives must be addressed if the water programs are to be accepted. Public opposition can, and does, occur. For example, even if water is scarce and a technically advanced well has been installed, people may well refuse to use the well if it was placed on sacred ground.

Overcoming the Technical Fallacy involves incorporating water stakeholders in all phases of water management.

1.7 Stakeholders

Stakeholders are those individuals or groups that have a substantial interest in what is being done and in the outcome, i.e., landowners, business people, government officials, and/or local residents.

Incorporating stakeholders in water management is a three step process: (1) education, (2) collaboration, and (3) implementation.

1.8 California, an example

California groundwater management integrates people into the planning and implementation of policies. Various government departments and agencies, professional non-profit organizations, and businesses network and collaborate on water issues. As will be discussed below, education about water resources, use, and treatment has been a prime component in water planning and management in California. Stakeholders collaborate with one another and with government policy makers. By instituting widespread water-related education as the first step in the education-collaboration-implementation process, California has achieved a positive step toward overcoming the Technical Fallacy

In the United States, crop irrigation uses the most ground water.. About 75% of American cities and many factories use ground water in some way. Altogether more than 50% of the people in the U.S. use ground water for drinking and other household uses (CA Dept Water Resources 2006). Groundwater basins supply nearly 40% of the water Californians use (State Water Resources Control Board 2001:9).

Though China and California are in significantly different phases of development, overall they share similar varying hydrological regions and geological zones.

This paper will give a general introduction to the diverse water related California government departments, as well as the numerous water-focused non-profit and business based organizations and institutions in the state. There is significant interaction and collaboration amongst these groups. As will be discussed, a recent project in groundwater management undertaken by one of these groups, the Sonoma County Water Agency, is one example of success in overcoming the Technical Fallacy. Their emphasis has been on education and stakeholder involvement.

2 Groundwater in California

Most of California's groundwater occurs in material deposited by alluvium streams, i.e., those with coarse deposits, such as sand and gravel, and finer-grained deposits such as clay and silt. In an alluvial environment, the coarse materials usually provide the best source of aquifers; whereas, the finer-grained clay and silt deposits are relatively poor sources of water--aquitards. California's groundwater basins usually include one or a series of alluvial aquifers with intermingled aquitards. In addition the groundwater development occurs in fractured crystalline rocks, fractured volcanics, and limestones.

2.1 Government water management in the state of California

To understand the groundwater management in California, in fact to understand any water management in California, one must first have a general awareness of the complex system of state government agencies that are involved with water supply and control issues.

2.2 California Department of Water Resources (CWR)

Since the founding of California in 1850, disputes and political and legal contests have existed over water rights. In 1956 the California governor signed a legislative bill to combine the then Division of Water Resources of the Department of Public Works with the State Engineer's Office, the Water Project Authority, and the State Water Resources Board into a new department: the *Department of Water Resources*.

The department constructed and now operates and maintains the nation's largest state-built water and power development and conveyance system—the State Water Project that includes the California Aqueduct. This unique facility provides water supplies for 23 million Californians and 755,000 acres of irrigated farmland.

The department also provides dam safety and flood control services, assists local water districts in water management and conservation activities, promotes recreational opportunities, and plans for future statewide water needs.

The Department has been subject to numerous legislative, judicial, and administrative orders that dictate how the Department should protect the public trust. Like any other water user, DWR must apply for water rights permits from the State Water Resources Control Board (see below). Unlike most other users, the Department also must answer to the Governor's Office and State Legislature.

2.3 California strategic water plan

Under the auspices of the California Department of Water Resources (CWR)and a 65-person Public Advisory Committee the *California Water Plan* is drafted, updated, and published at five year intervals—the most recent (Bulletin 1 60-05) being published in 2005. This documentation is a strategy to meet the state’s future water needs and provides a framework for water managers, legislators, and the public to consider options and make decisions regarding California’s water future.

The Plan, prepared with stakeholders input, presents basic data and information on California’s water resources and uses. This includes water supply evaluations and assessments of agricultural, urban, and environmental water uses. In addition it identifies and evaluates the existing and proposed statewide demand management and water supply augmentation programs.

2.4 California water resources control board

The *California Water Resources Control Board* and the Department of Water Resources are separate but collaborative units working on water assets and needs.

The *California Water Resources Control Board* system, created by the Legislature in 1969, comprises the State Water Resources Control Board in Sacramento, the state capital, and nine regional water boards, each semi-autonomous comprised of part-time Board members appointed by the governor. In 1991, the Boards were brought together with five other State environmental protection agencies under the newly crafted California Environmental Protection Agency (Cal/EPA). They now serve collectively as the state bodies responsible for ensuring the quality of California’s waters. The State Board is also solely responsible for allocation of surface water rights. California has no permit process for regulating groundwater use. In most areas of the state, landowners whose property overlies groundwater may pump it for beneficial use without approval from the State Water Board or a court.

The State Board is organized into four divisions encompassing three broad program areas and an administration function that supports not only the State Board, but also the nine Regional Boards. Five full-time, appointed Board members and over 550 employees work at the State Board.

2.5 Local water management

In addition to state water agencies, county and local government divisions play a part in managing water resources. An example of this is the Water Resources Management division within the Santa Cruz City Water Department. Of the nine divisions within the Santa Cruz City Water Department, the Water Resources Management is the most closely related to groundwater. They are responsible for the drinking water source and natural resource protection work. As their website (www.ci.santa-cruz.ca.us/wt/index. html#RM) says, “Along with other responsibilities, Resource Management staff provide environmental review support for the Department; conduct biological and hydrologic surveys, including drinking water source stream gauging and anadromous fishery habitat typing/population assessments; work on the Department's Habitat Conservation Plan; manage the Department's watershed lands, develop drinking water source assessments; and perform outreach and education with drinking water source watershed stakeholders.”

2.6 Coalition of public water agencies: Association of Water Agencies (ACWA)

The Association of California Water Agencies is the largest coalition of public water agencies in the United States. Founded in 1910 by five irrigation districts to protect their watersheds and promote construction of water facilities, by the 1970s the ACWA expanded to include urban agencies. Between 1910 and 1970 cities, as well as agricultural regions, had grown. Thus more public water agencies, urban and rural, had come into being.

The ACWA now has 447 member agencies that together are responsible for 90% of the water delivered in California. ACWA members provide water for municipal, industrial / commercial and agricultural needs. Member agencies include: irrigation districts, county water districts, municipal water districts, California water districts, other water-related special districts, and city water departments. Governed by a 33 member Board of Directors, the ACWA’s primary mission is to assist its members in promoting the development, management and beneficial use of water in an environmentally balanced manner. (See http://www.acwa.com//aboutacwa/acwafacts.pdf)

3 Non-profit Agencies and Institutes

Working alongside, and interacting with the state government water agencies are non-profit groups, including the California Ground Water Association, the Groundwater Resources Association, California Water Institute, and the Water Education Foundation.

3.1 California Groundwater Association (CGA)

The California Groundwater Association is a non-profit organization that has promoted protection of groundwater since 1948. Membership represents over 15,000 groundwater professionals. Water well drilling and pump contractors, suppliers and manufacturers, geologists, engineers, hydrologists, government employees and others working in the groundwater field are members. The mission of the association is to care for California's groundwater resources, provide quality service to members and to the public, and to act in the best interest of the groundwater industry. The CGA works with legislators to protect California's groundwater while opposing adverse and poorly designed bills.

The California Groundwater Association is dedicated to providing skill and knowledge to its members, and to the general public. Members receive newsletters and can attend chapter seminars, professional education programs, and the annual convention and trade show. The CGA offers scholarships to students in a field of study related to the groundwater industry as well as general fields of study. A prime interest of the association is to disseminate accurate information to the public regarding quantity, quality and availability of California's groundwater resources.

3.2 Groundwater Resources Association in California (GRA)

Both the California Groundwater Association and the Groundwater Resources Association work to protect groundwater resources both interact with legislators on groundwater issues and both support education of their members on groundwater topics. However in general terms the CGA is more applied while the GRA is more academic.

The Groundwater Resources Association (GRA) is a group of scientists, engineers and other professionals dedicated to resource management that protects and improves groundwater through education and technical leadership. Regular members with voting rights hold academic degrees in science, engineering, or environmental science, a California drilling or pump contractor's license and two years experience, and/or six years experience under supervision of a certified groundwater professional. Associate members, without voting rights, are students and individuals interested in groundwater resources.

The organization is "dedicated to resource management that protects and improves groundwater through education and technical leadership" (http://www.grac.org/). To achieve this they promote the professional development of scientists and engineers, help formulate statewide policy, disseminate information, and are pro-active with the legislature. (For more detailed information see: www. http://www.grac.org/about.asp)
Using the services of the full-time GRA, they advocate that all individuals have an avenue to influence future groundwater policy of the State of California.

3.3 California Water Institute (CWI)

One non-profit university-based water group is the California Water Institute (CWI), at

California State University, Fresno. The CWI was founded to be a forum for unbiased, open, collaborative discussion, research ,education and policy analysis on water-related issues. It was founded by a voter approved bond funding and now has on campus laboratories to conduct research related to issues of water supply and quality. The focus has come to be how to manage the ever-increasing demand for water.

CWI has laboratories to conduct technical research to assist California in answering critical questions and issues related to water supply and quality. Fresno State students get an opportunity to be at the forefront of this research and technology.

3.4 Water education foundation

Founded more than 30 years ago, the Water Education Foundation "Works to create a better understanding of water issues and help resolve water resource problems through educational programs." (www.water-ed.org). The volunteer Board is composed of 30 members from a cross section of business, agricultural, municipal, environmental and public interest communities. They and the staff of 10 individuals have succeeded in creating a resource used by teachers, students, and the general public for information about water issues. In addition to being a resource for books, magazines, movies, DVDs, and audios, they offer a variety of programs including information on geography and science of water, and related political and policy decisions. They have a variety of school programs designed for primary, secondary, and college level presentation. In addition, the Foundation serves as the coordinator for the Project WET California (Water Education for Teachers of grades K-12).

Each March in Sacramento, the state capitol, the Foundation sponsors an Executive Briefing that features speakers from stakeholder groups, the Legislature and governmental agencies. At these sessions representatives from the urban, business, farming, environmental and public interest sectors discuss and debate their viewpoints on current water issues at this day-and-a-half briefing.

4 Local Business Water Consciousness

Not only are executives from California business enterprises volunteering as board members in such organizations as the Water Education Foundation, they are working in collaboration with government agencies to promote technologies and good practices. An example of this was the November 8, 2006 Sonoma County Water Supply and Conservation Summit. This morning meeting was organized by the Santa Rosa Chamber of Commerce, the City of Santa Rosa, and the Sonoma County Business Environmental Alliance. It was sponsored by the California Landscape Contractors Association, Codding Enterprises, and the Sonoma County Water Agency. The focus of the summit was to let the business community know about the urgency of water conservation and what government agencies would be expecting from local business. They explained that water conservation does not mean just costs, but could also mean savings to the bottom line. This is especially true when many local businesses use 50% more water for irrigation than is needed.

5 California Water Awareness Campaign

California government agencies, non-profit organizations, and businesses have independently and cooperatively instituted programs for educating students and adults about water resources and issues.

In 1987 in response to a prolonged period of drought, the California Department of Water Resources, the Association of California Water Agencies, and the Water Education Foundation collaboratively initiated a program to increase public awareness about the need for all Californians to use water wisely, and to heighten public awareness of water and the role water agencies and allied entities play in conservation, management, water supply, water quality and distribution. Today approximately 300 water agencies, farm bureaus, cities, counties, water agencies, companies and other organizations throughout California unite under the program's umbrella to conduct activities and programs they individually plan and implement. The mission is to inform and educate all residents of all ethnic groups – from kindergartners to seniors.

5.1 Adult education

The Water Awareness Campaign focuses on the month of May each year with the observance of Water Awareness Month. In May and throughout the summer, many water agencies conduct awareness projects such as water facility tours. They place ads on television and radio, billboards, and buses, as well as in public recreation places such as movie theaters. In addition water agencies enclose printed information about water awareness in statements to their customers. Some communities conduct gardening workshops to advise consumers about the role they can play in water conservation and the maintenance of quality water supplies. All of these activities focus on reinforcing the public's appreciation for the value of smart water use. The advertisements offer common-sense tips, such as using a broom and not a hose to clean driveways and adjusting sprinkler timers to prevent over-watering landscapes.

5.2 Student contests and scholarships

The California Farm Water Coalition conducts a poster contest and offers prizes to grammar school students who enter poster contests as part of The Water Awareness Campaign (California Farm Water Coalition: http://www.cfwc.com/ archives/water_wire/ww0102.html). The aim of the contest is to have students understand the role water plays in agriculture.

Since 2002 the Water Awareness Campaign has made two $2500 scholarships available for graduating high school or junior college students who are interested in pursuing a career in the water industry. The recipients may attend the college of their choice. (For more information see http://www.cfwc.com/ archives/water_wire/ww0102.html.)

5.3 California water resources board's toolbox

In May 2006, associated with the Water Awareness Campaign, the California Water Resources Board released a comprehensive set of storm water educational resources in a wide-reaching effort to address polluted runoff that affects communities throughout the state and nation. Their "California Storm Water Toolbox" was developed as part of the State Water Board funded Erase the Waste storm waste water public education program, a $5 million community-focused campaign. (California Environmental Protection Agency. www.swrcb.ca.gov/press/docs/2006/06_009.pdf). The action-oriented tools of the Storm Water Toolbox are free to all interested parties as part of the state's commitment to improving water quality. They are to be promoted and distributed in partnership with dozens of organizations including the California Department of Education, Integrated Waste Management Board, and Regional Environmental Education Community network.

The Water Tools are being shared with, and promoted out-of-state in other states and countries. Already government and school officials and organizations in China, Mexico, and South Korea have received Storm Water Toolboxes. The tools are designed to address varying water pollution priorities in different regions and for different recipients: community and civic groups, educators, and municipalities.

6 Sonoma County Water Agency: An Example

Having reviewed California's complex system of government departments and non-profit and business oriented organizations related to water resources, let us look at a recent groundwater conservation project that has successfully integrated stakeholders.

The Sonoma County Water Agency is administered as a part of the authority of California's County of Sonoma. The General Manager of the Agency reports directly to the County Board of Supervisors. There is no single, overall management authority to carry out daily direction and overall coordination. This function is in the hands of the Board of Supervisors, with assistance from the County Administrator, when so directed by the Board. The Agency, unlike any other in county government, is exempt from being required to respond to recommendations and questions raised by a Grand Jury. The Agency is an inter-county organization and this makes its spending immune to the California constitution provision that limits the amount of debt that a county can run up to a certain percent of its income.

In 2001 an agency planner went before the Board to present plans for Sonoma Valley water conservation. Local people had become concerned because they were aware of water scarcity and were concerned about any new policies affecting their land rights. The Board agreed that a multiple year exploratory study should be conducted. The U.S. Geological Survey (USGS) agreed to undertake the study because they had not updated their work in that region for some time. The study found areas of thermal water with toxic arsenic and boron and showed that saline had migrated toward the City of Santa Rosa. There also was concern that while some wells had not become dry, the water levels had declined.

In 2004 the Sonoma County Water Agency planner appeared before the Board with the USGS study results and was granted permission to develop a groundwater plan for the Valley. Influenced by the fact that the Agency had been able to engage the USGS to conduct their study the state Department of Water Resources (DWR) agreed to engage in partnership with the Agency, and help share funding with Sonoma County.

At that point the Agency conducted a series of interviews with 150 Sonoma Valley local agricultural and dairy people, small farmers, business people, elected officials, and land owners. The goal was to learn their interests and concerns in developing a groundwater plan. It became obvious that for the stakeholders concerns about availability of water had become one of the prime issues and they supported designing a plan.

A Basic Advisory Panel was formed with 20-plus members representing the diverse interests in the Valley (i.e. Sonoma County Water Agency, County of Sonoma, Valley of the Moon Water District, City of Sonoma, and the Sonoma Valley County Sanitation District). The first meeting was held in September 2006 with plans to meet monthly for the following 16 months with the goal of guiding development of a groundwater management plan for the Sonoma Valley. Members of the media and public are invited to attend all meetings. At the initial meeting the basics of groundwater—movement, recharge, quality, and protection—were presented along with the results of the USGS study.

Thus a stakeholder group is working in consensus to design an underground water plan for Sonoma Valley. The California Department of Water Resources (CWR) is funding this collaboration and has hired a technical consultant (from the non-profit Center for Collaborative Policy) to write the plan.

The Sonoma County Management Conservation Project is an excellent example of the benefits of integrating stakeholders in groundwater management. This will not be a plan that is formatted solely by government employees with the expectation that stakeholders will automatically implement it without contention. Rather local stakeholders are working in collaboration with multiple government bodies to create a plan they desire. In all likelihood the Board will pass the plan without contention knowing that stakeholders, with the support of government offices, have been the designers.

7 Conclusion

As discussed, China is a country faced with scarce water resources as well as water pollution, not to mention flooding and soil erosion. With groundwater withdrawal aquifers dropping and causing cities to sink, it is important to note that the problem is not just environmental. Along with urbanization and expanding urban populations China's water demands increase. Water issues are an important component affecting not only resources for production, but life styles and health as well. If China's astoundingly rapid economic growth is to continue the problems of scarce water resources, pollution, as well as flooding and erosion must be resolved.

While China differs from California in numerous ways: cultures, social organization, economic resources, residents of both are concerned with adequately managing water resources. Both have complex systems of multiple layers of government departments and agencies involved with water resources. In addition both have numerous environmental groups (For information on the growing number of environmental NGOs in China see Economy 2005).

Officials and planners in both China and California have use of well educated, talented scientists and engineers to help attack environmental issues including water. Both have successfully implemented and managed projects through the use of scientific and/or engineering skills. Thus, it is all too easy for program officials and planners to fall into "The Technical Fallacy." That is, to logically assume that *thorough and rigorous technological analysis is sufficient to implement a solution* to problems. However all too often projects based solely on technology fail. If stakeholders have not been included in the planning and implementation, most likely only part of the problem has been addressed. As noted earlier, the biggest obstacles to solving environmental problems are social, economic, and institutional. For water management projects to be successful individual stakeholders, be they property owners, business people, government officials, and/or local residents, must be included in policy design and implementation. Including people is a three step process: education, collaboration, and integration.

As discussed, California has implemented a major program directed at heightening public awareness of water. This program is designed for the education of all the residents—young children all the way to older adults. Residents learn the role water agencies and allied entities play in conservation, management, water supply, water quality and distribution, and they learn how to use water wisely. As a result they are more interested in taking an active part in water management. As was discussed, stakeholders in Sonoma Valley have been made aware of local issues in depth and have become active participants in collaborating and planning groundwater management. Consequently the Board is likely to approve the final plan knowing that not only government employees, but stakeholders as well, have participated in creating it.

As in other parts of the world California will always have water resource, use, conservation, and sanitation issues. However by incorporating public education and incorporating stakeholders in planning California has a high rate of collaboration within and between government agencies, non-profit associations, commercial enterprises, and local individuals. Hence California projects can avoid the pitfalls of the Technical Fallacy. Can China meet the challenges of overcoming the Technical Fallacy?

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Technology Study on Sand Infiltration System of the Yongding River Basin
官厅水库流域不同河道源水渗滤净化技术研究

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Abstract

Based on the research and pilot projects on point pollution treatment, water quality improvement and pre-treatment of drinking water in the Yongding River basin, this paper aimed to provide sand infiltration systems and slightly-polluted source water pre-treatment techniques. Many running parameters were tested and analyzed in the study and a set of rational and economical technical solutions were developed. The study would supply important technical support for the implementation of an ecological and environmentally comprehensive water treatment for the Yongding River basin.

摘要

通过对永定河流域点源污染治理、河道水质净化及饮用水水源预处理等不同河道源水净化技术的示范研究，摸索探讨河道源水净化技术与工艺，分析了各示范技术运行参数与运行效果。提出了一套适于永定河河道源水净化技术，为全面实施官厅水库流域水生态环境综合治理工程提供重要技术支撑。

1 Introduction

As the first large reservoir built since the foundation of the P.R.China, and one of the two surface water sources of Beijing, the Guanting Reservoir contributes greatly to the economic and social development of the capital and peripheral regions. With rapid economic and social development of the upstream section of the river there has been an increase in direct discharge of wastewater into the river, causing increasingly serious water pollution. As a result, the Guanting Reservoir was forced to cease supplying drinking water to Beijing in 1997. The capital is facing a serious water deficiency. The “Stabilization Miyun, Improvement Guanting” water resource protection principle was proposed in the “Capital Water Resources Sustainable Utilization Planning of 21st Century”. With the support of the Beijing Science Committee and the ministry of Water Resources, the Beijing water authority organized the “Guanting Reservoir Technology Research Scheme for Improvement of Water Quality” and the “Key research and demonstration Technologies for Improvement of Water Quality in the Guanting Reservoir” projects from 2000-2005. Considering the technical difficulties shown in the general plan and using both domestic and international experiences for reference, the two projects developed a comprehensive demonstration of treatment research on the reservoir flowing into the Yong Ding river, reservoir water body, reservoir sediment serious pollution zone and channel four key links according to Guanting Reservoir watershed practical situations, and offer a technological support for solving key technology problems regarding basin pollution control and recovering reservoir drinking water functions. This paper is a summary of source water quality improvement technologies with the aim of providing results that may serve as a reference for regions facing similar circumstances.

2 Methods

By establishing a test demonstration area, this research used improved land treatment systems for sewage and effluent reuse through irrigation techniques, channel source water infiltration purification technology and drinking water pre-conditioning techniques and developed indoor and outdoor channel source water quality improvement technology.

(1) The improved sewage land treatment and exploitation system adopted a combined agriculture irrigation and sewage land treatment technique from the China Institute of Water Resources and Hydropower Research and the Australia Scientific Research Organization for Cooperation that solves issues of winter operation in Northern areas, contradictions between sewage treatment and agricultural planting over space and time and the problem of achieving the maximum efficiency .

The test area was located in northwest Yanqing County which has an area of 800m 2. The test facility mainly included a greenhouse for winter experiments, a sewage reservoir, a wastewater pipeline, an underground drainage system, an underground and ground irrigation system and a water measure system. The schematic system is shown in Figure 1.

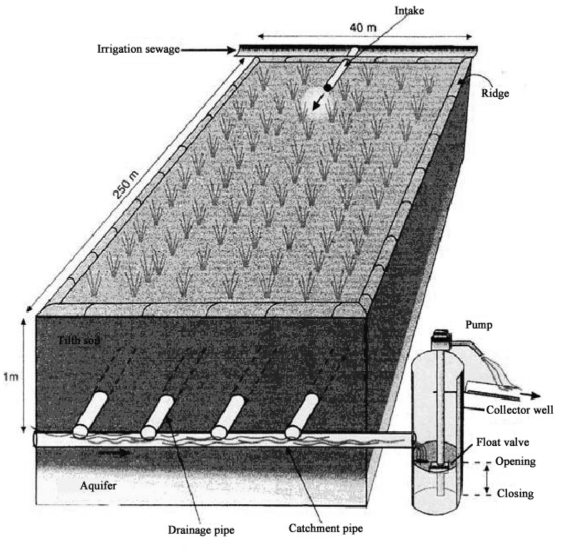

Figure 1: Improved sewage land treatment and exploitation system

(2) Composite-infiltration purification system test area in Heituwa is an s-shaped surface-flow wetland system, which is 4700m^2, has a 0.02 m^3/s water treatment capacity, a 0.368m/d hydraulic load and 30h residence time. Test area layout plan is Figure 2.

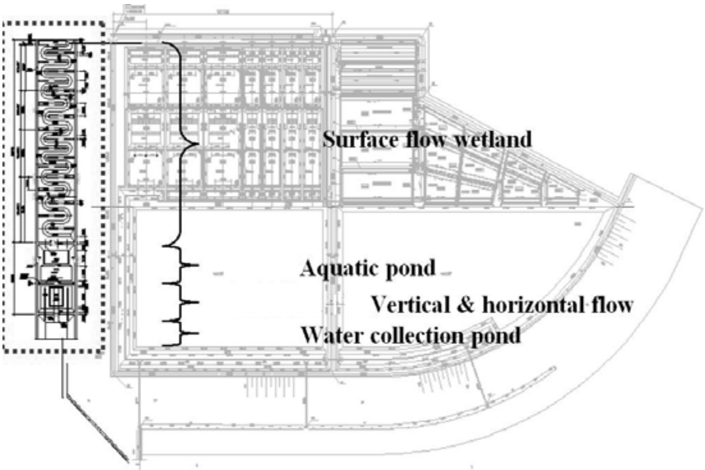

Figure 2: Composite-infiltration purification system test area in Heituwa

(3) Recirculation infiltration demonstration engineering is composed of infiltration pond, observation well and catchment's pipe.

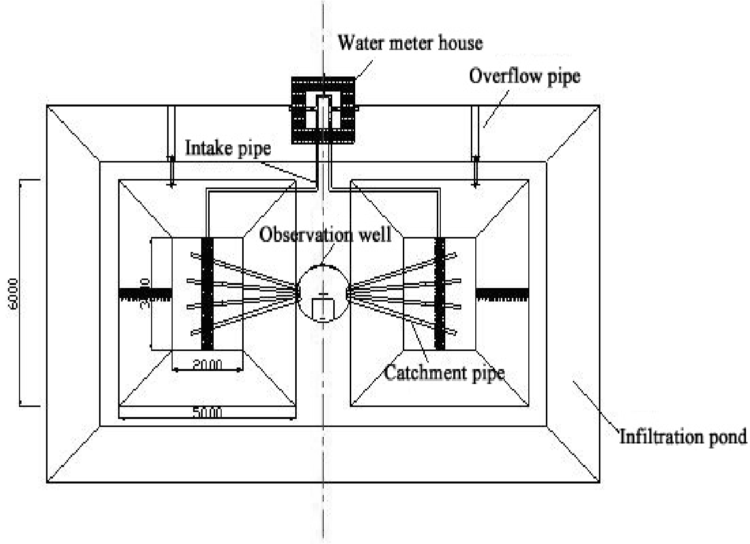

Figure 3: Recirculation infiltration demonstration engineering layout

Around the infiltration pond, the water storage region is constructed by an earth dam which is 0.75m high and has an angle of 45 degrees. Non-woven fabric is used to prevent seepage and leakage from the earth dam around the recirculation pond. An observation well is located between the two infiltration ponds. The catchment's pipes, which function as a means of infiltration water collection, are respectively installed in 0.5m, 1.0m, 1.5m and 2.0m from the pond's bottom and the installation angle is 17 degrees.

(4) The process is feasible for micro-pollution water source production drinking water. Microfiltration purification test area is 1-3m^3/h designing treatment water quantity. And the microfiltration process is full automatic controlling, its all contacting water parts are made of stainless steel or engineering plastics, which microfiltration membranes filter is 8m^2 tubular micro-filtration membrane, backwashing water pressure is 60m, and transmembrane pressure is between 50kPa and 150kPa.
Technological process is as follows:

coagulant/oxidant ↓ oxidant ↓

reservoir water ⇨ lift pump ⇨ prefiltration ⇨ microfiltration ⇨ advanced oxidation ⇨
activated carbon ⇨ stored bucket ⇨

backwashing pump

(5) The research contents of micro-pollution water source treatment applicability are expanded bed reactor on particle activated carbon and membrane reactor on powder charcoal. By building a representative pilot reactor, reactor operating condition of practical application value is obtained. Technological process is shown in figure 4.

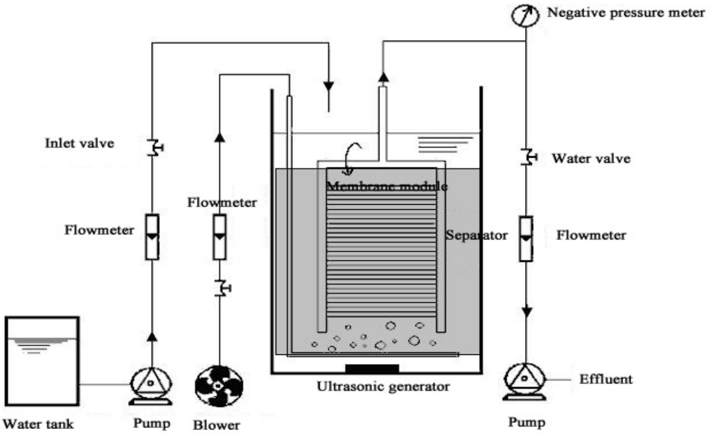

Figure 4: Biological activated carbon - membrane reactor schematic

3 Results

3.1 Improved sewage land treatment and exploitation system

(1) The system effectively removes nutrients from domestic sewage and as well as other pollutants. After the treatment by this system, the indicators of water pollutants excluding

total nitrogen can reach the requirement of class II water quality according to the ‘Chinese Environmental quality standard for surface water’. The system’s hydraulic loading is between 13mm and 15mm per day to effectively reduce land occupation.

(2) The system combined with agriculture irrigation had a better crop yield, and the quality of agricultural products were not influenced by domestic sewage irrigation and therefore the system’s economic feasibility was further improved.

(3) The system’s construction and operation cost was lowered. The engineering cost was 10840 yuan per hectare and its treatment ability per day was between 130m^3 and 150 m^3 per hectare, using conventional agriculture irrigation technology. If it’s granted at nil premiums, the cost of water treatment construction for per cube meter is 80 yuan. In the process of system operation, the operation cost can be offset by the income of crop planted in the lands of this system. However, this method of handling sewage requires more land area than other methodsalthough the system’s hydraulic loading was improved.

3.2 Channel source water infiltration purification technology

It is an efficient treatment technology that includes an infiltration purification system on the channel’s bank or a recirculation infiltration purification system on flood lands. Related technology operation parameters and economic benefit index are obtained through demonstration.

3.2.1 Composite infiltration purification system on bank

(1) Practical application shows that the hydraulic restriction element of sand medium vertical-flow wetland is surface harden layer. And if it is plugged, conveyance capacity decreases more than 80% and hydraulic loading dropped from 3.7m/d to 0.6m/d. Regarding optimization design, reducing medium sized-particles and a dry -wet alternate operation controlling plug were considered in order to reach of the maximum water quality purification and conveyance capacity.

(2) Comparatively speaking, hydraulic loading of the infiltrative dam ranges from 1m/d to 2m/d because of slow plugging, full contact with the water while its purification is better than that of vertical-flow wetlands that contain sand mediums. So the infiltrative dam is suitable for longer flow sections along the river bank, but its plugging problem remains a difficult problem to solve.

(3) When the vertical-flow wetland of undisturbed backfill is not compacted, hydraulic loading reaches 3.0m/d-2.4m/d, and the plugging effect is very little. It is a kind of developing prospect structure mode and needs further research.

(4) When the hydraulic loading of the s-shaped surface-flow wetland is 0.07m/d, the wetland can remove 45% of TN, 25% of TP and 60% of SS, and the water sensory effect and reduction of NH3-N are better except for the removal of organic compounds and micro-pollutants in the water. The wetland is a good measure of the situation prior to advanced micro-pollutant water treatment and because the water’s carbon resource is preserved , the wetland further regulates the carbon-nitrogen ratio.

(5) When the hydraulic loading of sand medium vertical-flow wetland is 0.6m/d, the removal rates for TN, TP, COD $_{Mn}$, SS are 35.8%, 28.1%, 29.3% and 47.6% respectively. And the same removal rates are 37.4%, 22.0%, 11.7% and 53.7% when the hydraulic loading of undisturbed backfill vertical-flow wetland is 2.4m/d. But for the infiltrative dam, the removal rates are 58.8%, 53.7%, 41.3% and 57.3% with 1.0m/d of hydraulic loading.

(6) This system requires little investment, has a lower operating cost and runs well in winter.

3.2.2 Recirculation infiltration system

(1) Treating water with micro pollutants through a recirculation infiltration system, a hanging membrane is suggested in summer but not in winter.

(2) During the winter, in northern areas, the system can also run well below the ice.

(3) Due to the removing effect of COD $_{Mn}$, the south pool is better than the north pool because of layer fine sand on the surface.

(4) When removing nitrogen through the infiltration system, the content of organic carbon is main factor for nitrogen removal.

(5) When treating river water with micro pollutants by infiltration, the leaching of infiltration needs to be considered.

(6) If the system runs during the summer it can adopt a 7-day flooding and 3-day drainage working mode.

3.3 Process of preconditioning technique for drinking water source

3.3.1 Microfiltration purification process

(1) Coagulation-microfiltration process has better effects removing effect of micro pollution water oxygen consumption. While the PAC dose is 30-60mg/l, the oxygen consumption of microfiltration water is removed 40%-50% and is less than 3mg/l in Sanjiadian Reservoir. But not coagulant, the oxygen consumption is only removed 10%.

(2) Coagulation/ pre-oxidation-microfiltration process was better at removing the effects of the oxygen consumption in micro-polluted water. When oxidation hydrogen is 6mg/l and a little copper sulfate is added, the oxygen consumption of the microfiltration water is decreased by 40-50% and has a usual rate of 3mg/l in the Sanjiadian Reservoir. The removal rate of chlorophyll and NH_3-N can reach 97% and 40%, with the condition of 1mg/l NH_3-N. If pre-oxidation isn't used, the oxygen consumption, chlorophyll and NH_3-N are only removed by about 10%, 90% and 20% respectively.

(3) A contrasting study of two microfiltration operation processes showed that cross-flow technical operations can maintain a higher flux for High Algae-laden Water in the Sanjiadian Reservoir with an average flux of 250 $l/m^3 \cdot h$, a back flushing circle of 4h and

pressure of 160 kpa-190 kpa.

(4) Biological pollution is the main contributor to the membrane pollution and this is mainly due to coagulation. By contrasting the different chemical cleaning modes, hydrogen peroxide-acid is shown to be the best and the membrane flux is recovered to its initial state.

(5) The use of the coagulation/ pre-oxidation-microfiltration process instead of the traditional coagulation- precipitation-sand filtration process is a technologically and economically feasible method for improving water quality in the Sanjiadian Reservoir. If using advanced oxidation and activated carbon technology it can replace the present production process of tap water.

(6) Because the occupied area of 'coagulation/ pre-oxidation-microfiltration' water treatment is only one third of the occupied area of traditional water treatment, the construction investment of this new water treatment will be lower than that of traditional one.

(7) The advanced oxidant-activated carbon process is better at removing the effect of oxygen consumption. After activated carbon adsorption, the oxygen consumption decreases about 60%, with a minimum of 49% and a maximum of 69%. Furthermore, the number of oxygen consumption is 1mg/l and the maximum is 1.5 mg/l.

3.3.2 Purification process of biological activated carbon expanded bed

(1) The purification process for biologically activated carbon expanded bed is better at removing effect to COD_{Mn} and NH_3-N of micro polluted source water in the Sanjiadian Reservoir. They also keep the surface water at environment quality standard Ⅱ.

(2) The removal rate of COD_{Mn} is still 15-20% at normal temperature, and UV410 and UV254 is 25%-30%, but they respectively decrease 10% and 15%-20% in the cooler winter period.

(3) The structure of the process is relatively simple and easy to operate. The serial expanded bed replaces the reflow method to save energy during practical production.

(4) Over the long term operation, hydraulic loading doesn't have any obvious effects on this process. After breaking, the reactor operates successfully. If the NH_3-N content is insufficient once the process is restarted, hydraulic loading of the organic compounds can be quickly reduced to accelerate the starting velocity.

(5) This process is used as a biological pretreatment unit for waterworks.

3.3.3 Membrane-Biological Activated Carbon Purification Process

(1) Membrane-biological activated carbon process is better able to purify micro-polluted water in the Sanjiadian Reservoir, where 40-50% of $COD_{Mn\ \mathrm{is\ removed}}$, and even in the winter, a 40% removal rate is maintained.

(2) The removal rate of NH_3-N is between 20% and 80% by using the process. The effluent from this process maintains the surface water's environment quality standard.

(3) The removal rate of TOC is between 30% and 70%. The TOC index of the effluent is maintained at 3-6ppm.

(4) Supersonic promotes the up-take and growth of microbial organic compounds but also activates carbon absorbability. The leading role of dominant microfloras of microbial in the reactor is unchanged under the low intensity ultrasonic.

(5) Ultrasonic, with a frequency of 35 KHz and an intensity of 100-400mW/cm^2, can strongly improve the purification of 'membrane-biological activated carbon' reactor, which mainly contributes to the effect on microbial community activity. It takes the specific form of an improvement of dehydrogenase activity, which can be increased by 30% maximum.
(6) The pilot plant research on the reactor, the removal was determined on a pilot-scale. The set-up period had a better purification effect on micro polluted water sources, and the running time lasted approximately one month.

(7) The pilot scale study of the reactor determined a 60 day cleaning cycle when the air to water rate was 10:1.

(8) The process was more economical benefit and occupied less land. Although the investment and operating costs are higher, it still remains a competitive water treatment process on the whole.

4 Discussion

The study on channel source water infiltration purification technology has the important function of improving pollution water and the channel habitat given the current conditions of water resources and water ecology.

Channel source water treatment technology needs unified planning over the short and long term, and which integrally considers the upper, middle and lower reaches of the river. Ecological, biological and policy approaches and techniques for ecological restoration in the basin will begin to form.
This water treatment process is extremely stable and achieved at a lower cost, and not only guarantees ecological restoration in the future, but also provides a basis for expansion of its application.

Use of Groundwater Resources in Urban Parts of Mongolia
蒙古国城市地下水资源的利用

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Abstract

In Mongolia, the surface water resources are comprised of more than 5,500 rivers, 9,600 springs, 350 mineral waters and 4,200 lakes (NSO, 2005). Despite the apparent wealth of surface water resources, just 20% of total water consumption in Mongolia comes from these surface waters, with the remaining 80% recovered from groundwater sources (Jadambaa, 2005). Surface waters, which are frozen, or partially frozen, for many months each year has lead to the utilization of groundwater as the primary source of water supply for major urban and industrial centers and the extensive animal husbandry sector.

摘要

蒙古国的地表水资源由 5500 多条河流，9600 处泉水，350 处矿泉水和 4200 个湖泊组成（NSO,2005）。尽管地表水资源表面上很丰富，地表水的使用只占整个蒙古国用水量的 20%，其余的 80%来自地下水源（Jadambaa，2005）。地表水在一年之中多个月结冰或部分结冰导致地下水成为大城市、工业中心和广大牧区的主要供水水源。

1 Introducation

Mongolia is a landlocked country located in north central Asia between Russia and China. It is situated on an elevated plateau (average elevation of 1,580m) surrounded by mountain ranges. Mongolia’s territory is divided into two major geographic regions: the Khangai (including the Altai and Khangai-Khenty mountain ranges) in the central and western regions; and the Gobi (including the Steppe and Gobi desert areas) in the southern and eastern regions.

Mongolia experiences a harsh continental climate with four distinct seasons characterized by particularly dry and cold conditions in winter and hot temperatures in summer. Annual rainfall across the country is below the world average and is as low as 50mm in the Gobi desert and up to about 450mm in the northern regions. The country is divided into 22 provinces (aimags) and municipalities and its capital is Ulaanbaatar. The current population of Mongolia is approximately 2.8 million and it contains the lowest national population density in the world (NSO, 2005)

In Mongolia the surface water resources are comprised of more than 5,500 rivers, 9,600 springs, 350 mineral waters and 4,200 lakes (NSO, 2005). Despite the apparent wealth of surface water resources, just 20% of total water consumption in Mongolia comes from these surface waters, with the remaining 80% recovered from groundwater sources (Jadambaa, 2005). Surface waters, which are frozen, or partially frozen, for many months each year has lead to the utilization of groundwater as the primary water supply for major urban and industrial centers and the extensive animal husbandry sector.

2 Urban Centres

Groundwater in cities is generally consumed by central water supply systems (used for potable water and heating), factories and power plants, and wells for private consumption (not connected to central water supplies). Groundwater sources typically provide all the required water demands for major urban centers (as the availability of surface water sources is highly seasonal and often inaccessible).

The major urban centers in Mongolia include Ulaanbaatar, Erdenet, Darkhan, the other 19 aimag centers and more than 340 sum sub centers.

2.1 Ulaanbaatar

Ulaanbaatar is the capital of Mongolia, with a population of approximately 965,000 inhabitants (NSO, 2005). It is the major centre for governance, commerce and industry in Mongolia. Groundwater sources in Ulaanbaatar are chiefly used for electricity and heating (at two major power stations), domestic purposes, meat processing, wool cleaning and by tanneries.

Currently, an estimated 143 production wells supply Ulaanbaatar’s central water supply, 200 wells supply the factories and power plants and 320 wells supply the ‘ger’ (traditional tent-like housing) suburbs (table 1).The 663 wells serving Ulaanbaatar extract approximately 340,000 m^3 of groundwater per day (table 1)

Table 1: Groundwater consumption statistics for Ulaanbaatar

Water User	**Number of wells**	**Yield, 1000m^3/day**	**City Location**
Upper Water Source	41	25.2	Central Area
Central Water Source	76	119	Central Area
Industrial Water Complex	18	34.8	Central Area
Meat Complex Water Source	8	13.8	Central Area
Power Plant #3	13	43.6	Central Area
Power Plant #4	12	25.2	Lower Area
Other Factories	175	52.5	Central Area
Ger Suburbs	320	25.6	Ger Suburbs
Total	663	339.7	

The single largest consumer of water in Ulaanbaatar is the Central Water Source, which supplies water for domestic and commercial purposes in the built-up central section of the city. This sector represents 35% of the cities' total water demand. Factories and power plants constitute the other major water consumers in Ulaanbaatar. Water for these sectors is chiefly extracted from alluvial aquifers bordering the Tuul River, that flows through the city.

The greatest numbers of wells (48%) are located in the 'ger' suburbs (for domestic use); however these are generally low yield wells (yielding only 8% of the city's total consumption). These suburbs house the majority of dwellers in Ulaanbaatar, and the proportion of these households is increasing as many families migrate from rural to urban areas in the hope of greater employment, education and healthcare opportunities. There are great challenges in meeting the demands of these incoming urban residents and particularly maintaining the integrity of groundwater sources in these areas as suburban development and waste disposal proceeds largely unplanned.

Effective access to, and provision of, water supplies for all Mongolians needs to be addressed to increase the national average availability to 20 litres of water per person per day. Currently, water consumption in the 'ger' suburbs is limited to 5-8 litres per person per day, which is 2.5-4 times less than the internationally accepted minimum of 20 litres per person per day (UNDP, 2004).

2.2 Erdenet

Erdenet city is located approximately 230km northwest of Ulaanbaatar. Groundwater in Erdenet is chiefly used for electricity and heating generation, domestic purposes, a food processing factory, a carpet factory and copper and molybdenum mining. Erdenet city currently contains 16 production wells and 24 proposed exploration wells and consumes 65,000-80,000 m^3/day for domestic and commercial purposes, mining and industrial processes.

The chief Erdenet borefield is located approximately 60km from the city, near the Selenge River. Water is supplied to the city and surrounding mine by a large diameter of water supply pipelines. The distance over which the water is conveyed illustrates the heavy reliance of this community on the alluvial groundwater resource of the Selenge River.

Pump tests conducted during hydro-geological exploration of 16 wells in Erdenet provided information on aquifer depth, thickness, drawdown levels, yield and filtering coefficients. These results are summarized in table 2.

Table 2: Range of pumping test results from 16 wells in Erdenet

Depth, m	Water table, m	Thickness, m	Drawdown, m	Yield, L/sec	Filter coefficient, m/day
41.0-44.5	0.27- 2.17	31.8 - 42.1	0.67 - 27	99 - 144.7	114.8 - 398.6

The pumping test results demonstrate that the groundwater table in the alluvial aquifers is very close to the surface and the aquifer thickness is moderate. Yield measurements were generally high; however draw downs varied greatly and were potentially significant.

2.3 Darkhan

Darkhan is located approximately 170km north of Ulaanbaatar. Darkhan utilizes approximately 140,000 m^3/day of groundwater resources for the purposes of electricity and heating generation, domestic use and to supply iron, cement and ceramics factories. Darkhan has 18 production wells with a total yield of 726 L/sec.

2.4 Aimag Centres

Aimag centers in Mongoliainclude Choibalsan, Undurhaan, Baruun urt in the eastern economic area; Sukhbaatar, Zuunmod, Mandalgovy, Sainshand, Dalanzadgad, Darhan, Choir in the central economic area; Murun, Bulgan, Bayanhongor, Tsetserleg, Orhon, Arvaiheer in the Hangai economic area; and Ulgii, Ulaangom, Altay, Hovd, Uliastay in the western area all of which consume a combined total of approximately 691.2- 4502.0 m^3/day (Table 3). Like the three major urban centers, the aquifers used as water sources for Choibalsan, Undurhaan, Sukhbaatar, Murun, Bayanhongor, Tsetserleg, Orhon, Arvaiheer Ulgii, Hovd, Uliastay centres are also alluvial deposits. Baruun urt, Mandalgovy, Sainshand, Dalanzadgad, Bulgan, Ulaangom, Altay are used groundwater in Neogene, Cretaceous, Permian, Devonian sedimentary rocks, and in oldest, metamorphized carbonate aquifers. The most productive and most used aquifers for urban centers:

- Alluvial deposits (Ulaanbaatar, Darhan, Erdenet and other 11 aimag centers),
- Alluvial-proluvial deposits (Ulaangom),
- Neogene aquifer (Baruun Urt),
- Cretaceous aquifer (Mandalgovy, Sainshand),
- Permian sedimentary rocks (Bulgan),
- Devonian sedimentary rocks (Dalanzadgad)
- Metamorphic aquifer (Altay)

In addition to the aimag centers, there are more 340 sub centers that use 58,700 m^3/day of groundwater resources. A study on domestic water supplies, conducted in 2004 by the Institute of Geoecology, showed that for all sub centers about 65% of well yields were used during winter, while 15% were used in summer, with the remainder being used in shoulder periods. High winter yields of groundwater resulted from the inaccessibility to frozen surface waters during this period.

Table 3: Groundwater resources, groundwater use and yields of wells in some aimag centers

Name of center	**Number wells**	**Reliable resources, m3/day**	**Groundwater Use, m3/day**	**Yield (min.-max), l/s**	**Main aquifer**
Tsetserleg	24	10082.8	2000	1.0-31.2	Alluvial deposit (d.)
Bulgan	18	4907.6	1717.6	1.0-12.5	Permian sandstone
Murun	28	6600	2300	1.0-33.4	Alluvial d.
Suhbaatar	15	7480.5	2850	0.9-40	Alluvial d.
Zuunmod	13	3695	1641.6	0.7-18	Alluvial d. and schist
Choibalsan	14	9504.0	4502.0	2.0-30.6	Alluvial d.
Undurhaan	23	10410.0	3000.0	1.0-17.2	Alluvial d.
Baruun Urt	10	5045.0	2300.0	1.9-13	Neogene sand, sandstone
Ulgii	19	13730.0	3500.0	1.7-27.4	Alluvial d.
Hovd	30	7692	3900.0	1.0-23.2	Alluvial d.
Altay	26		691.2	0.8-9.5	Metamorphic rock
Dalanzadgad	10	4000.0	3600.0	0.98-15.4	Devonian sandstone
Sainshand	18	4968.0	3200.0	0.4-27.0	Cretaceous sandstone
Mandalgovy	15	3500.0	2500.0	0.8-10.1	Cretaceous sandstone

Enhancement of Urban Groundwater Recharge and Water Recycling
加强城市地下水回灌和水循环

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Abstract

Managed aquifer recharging, where applicable, can integrate urban water resources, facilitate reuse allow substitution and increase the volume and security of water supplies. Urban aquifers can play a major role in enabling water reuse by providing storage and treatment with minimal use of land, infrastructure and energy. Research shows that the availability of aquifers, and especially those containing groundwater of initially unusable quality, present opportunities for new emerging, cost-effective water management practices that aim to improve the security of city water supplies, especially for rapidly growing cities and/or those where climate is changing. Another requirement for these methods is the availability of land for capture and treatment of urban stormwater and for treatment of reclaimed water prior to recharge. Examples from Perth and Adelaide are used to show the progress of urban groundwater recharge and demonstrate links to flood mitigation and downstream water quality protection where stormwater or reclaimed water are being harvested and reused via aquifers.

摘要

管理可用的含水层可以整合城市水资源，促进水资源的再利用和循环置换并且增加水量和供水安全性。城市含水层在水的再利用方面承担着主要任务，它可以最小限度的使用土地、基础设施和能源来储水和完成污水处理的功效。研究显示，可用含水层特别是那些包含原来不可用的地下水的含水层对新出现的、节约成本的水资源管理的实践提供了机会，这对改善城市的供水安全，特别是对快速发展或气候正在变化的城市来说尤其重要。这些方法的另一个必要条件是有可用的土地来获取和处理城市雨水，并对再生水进行回灌前的处理。本研究用珀斯和阿德莱德的例子说明了城市地下水回灌的过程，并论证了这与减少洪灾以及保护下游水质之间的关系，在下游，雨水和再生水通过含水层得到了收集和再利用。

1 Introduction

The population on earth is growing and becoming increasingly urbanised, and as a result water use is intensifying in some catchments and groundwater systems. Concurrently, evidence for climate change is overwhelming and over large parts of the earth rain storms are decreasing in frequency but increasing in intensity. In many areas evaporation rates are also increasing, affecting demand for irrigation water, increasing the losses from surface water storages, and compounding the competition for scarce water resources between cities and irrigated agriculture. Consequently, many cities in arid and semi-arid areas will need to find new sources of water and increase storage capacities to maintain reliable water supplies for growing urban areas.

Untapped 'new sources' of water supply for various uses in urban areas consist of:

- Conserved water, through reduced distribution losses and more efficient use
- Rainwater harvested from rooves
- Stormwater runoff harvested from urban stormwater drains
- Sewage that may be treated and recycled, whether separated from stormwater or combined, and
- Desalinated brackish groundwater or sea water

Normally water conservation is the cheapest means of maintaining or increasing supplies. This has the benefit of also reducing energy costs and greenhouse gases associated with water supply, as demonstrated for Sydney by Gregory (2000). Rainwater and stormwater harvesting both have additional benefits of potentially reducing the incidence of flooding from storms with small recurrence intervals. They also harvest water close to the point of use, reducing the energy needed to transport water through urban areas (Barton and Argue, in press). These measures may also improve the quality of urban stormwater discharging to receiving waters down-gradient of the city and have aesthetic benefits that are of tangible value to local government (Rinck-Pfeiffer et al, 2005). Sewage however is a more reliable source of water, as it flows every day and grows with the size of the city (Asano and Levine, 1998; Asano *et al*, 2006). Unlike investments in urban stormwater management, capital invested in sewage treatment and water reclamation plants provides daily returns, regardless of rainfall. There may also be large environmental benefits in treating this water well and recycling it to substitute it for water used for landscape irrigation and some industrial water supplies. With the improving efficiency of new water treatment processes, opportunities to recycle water to blend with the initial drinking water sources may be more economical than operating a separate pipe network to distribute water that has been treated to a lower standard. For coastal cities seawater desalination represents a simple option, but at a premium energy and greenhouse gas cost. Where suitable groundwater supplies are available, even brackish groundwater may be a preferred source to sea water due to lower treatment costs of less saline water and closer proximity to the location of demand, although benign waste brine disposal can be an issue.

In addition to sources of water, storage is needed. Near urban areas, new water storage sites are generally rare or expensive. It is becoming increasingly difficult to find new dam sites because of populations that would be displaced, loss of prime valley floor productive land, loss of habitat, and impositions on agriculture and industry in the catchment area to protect water quality. Water sourced from the city would naturally flow down gradient and would require energy to treat and to pump back to the city. Storage within the city depends on tanks, and although there is much innovation in designing storages for new buildings and car parks, costs per unit of volume is moderately high.

Energy consumption, a main factor in climate change is also a major factor in identifying solutions for water shortages. Longer pipelines, higher lifts and more extensive treatments all consume more energy in their construction and operation. For this reason aquifers below cities are becoming highly valued. In the past, wells finding brackish groundwater were back-filled, but now they represent an opportunity to store and recover fresh rainwater, stormwater or reclaimed water with minimal pumping and pre-treatment. Unconfined aquifers that may be vulnerable to pollution can be used for storing water for irrigation whereas confined systems offer more protection and better treated water may be stored there for drinking water supplies. The aquifers themselves contribute to the treatment process for some contaminants (such as pathogens), but water of poor quality needs to be treated before recharge to deal with contaminants that are not attenuated in aquifers (e.g. some endocrine disruptors in anaerobic aquifers) or substances that would clog recharge wells (e.g. suspended solids and nutrients). In some cities that already rely on groundwater, falling levels provide a capacity for storage, and replenishment may be used to reverse saline intrusion or land subsidence (e.g. Gale, 2005). In the future, renewable energy sources will be harnessed to facilitate treatment and pumping, and indirect reuse for drinking water will be commonplace where there is adequate storage time in aquifers and risk-based management of urban waters including aquifers.

Some examples are given below of demonstration groundwater replenishment projects in Australia and elsewhere where experience is being gained to assist with water supply security for cities in semi-arid areas with growing populations and experiencing the effects of climatic change. The four examples chosen are stormwater infiltration, Stormwater ASR, reclaimed water infiltration and reclaimed water ASR at sites in Perth and Adelaide, Australia.

2 Stormwater Infiltration, Perth

Perth has a population of 1.5 million that is growing at 3% pa. It is located on a sandy coastal plain in the southwest of Western Australia. It has a Mediterranean climate with 85% of Perth's rainfall falling over winter but the 25-year moving average annual rainfall has fallen from 850 mm by 25% since 1975 and runoff in water supply catchments has halved. Annual evaporation is 1700mm. Perth's main water supply has traditionally come from hilly surface catchments immediately east of the city and from high quality groundwater in natural unconfined aquifers north and south of the city. Housing is generally single storey with garden areas watered from 150,000 domestic wells in a shallow aquifer system.

Runoff from rooves and driveways has traditionally been discharged into sumps which infiltrate water through sandy soils to the shallow aquifer and help to sustain irrigation and some groundwater-dependent wetlands. Due to climate change, more water per household is now extracted from aquifers, less is recharged, and the number of private wells has increased. Table 1 assumes proportions of a domestic house block that are covered by roof, paving and garden. The depth of average annual recharge or net discharge within these areas for blocks with and without bores is shown for historical and current mean rainfall. Consequently, in large areas shallow groundwater levels are in decline and wetlands are drying up. Domestic wells are subsidised by government and are neither metered nor is there a charge for groundwater consumption. Irrigation rates from bores are expected to be at a higher rate than irrigation rates with mains water which is paid for by consumers on a volumetric basis.

Table 1: Simplified recharge calculations for 'typical' households with and without a well in the Perth metropolitan area to demonstrate the effect of climate change on groundwater equilibrium

		Well		No well	
	Area %	Net recharge (mm) (850mm rainfall)	Net recharge (mm) (640mm rainfall)	Net recharge (mm) (850mm rainfall)	Net recharge (mm) (640mm rainfall)
Roof*	33	760	570	760	570
Paved*	17	0	0	0	0
Garden**	50	-700	-800	100	50
Block total	100	-100	-210	300	210
Offsite runoff #	100	130	100	130	100
Offsite runoff recharge +	100	90	70	90	70
Total household recharge	100	340	260	390	280
Total household extraction	100	-350	-400	0	0
Net household recharge	100	- 10	-140	390	280
Fraction of house-holds with & w/o wells for aquifer equilibrium ++		0.97	0.67	0.03	0.33
Estimated mains water use #	100	200	200	500	550
Estimated gross water use	100	600	650	500	500
Estimated sewer discharge	100	150	150	150	150
Net water use from mains and aquifer##	100	750	850	250	300
Recharge from roof runoff and stormwater sumps	100	340	260	340	260

Note:
* assumes runoff is 90% of rainfall and 100% of roof runoff recharges aquifer (250mm and 190mm recharge enhancement)
** estimated net irrigation requirements in deep sand profile and net recharge due to mains water irrigation
\+ assumes 70% of paved area runoff recharges aquifer in stormwater system sumps
++ neglects groundwater recharge and discharge from other land uses
\# assumed values.
\## mains consumption minus sewer discharge minus net groundwater recharge

From Table 1 which is only conceptual but thought to be indicative and subject to the assumptions listed, 340mm recharge enhancement from domestic rooves and paved areas was reduced to 260 mm as a result of decreased rainfall. Either amount is likely to exceed the recharge that would have occurred prior to urbanisation, and possibly accounts for most of the current recharge to the aquifer. It certainly assists in making possible the current practice of diverting garden irrigation supplies from mains water to groundwater. However in the light of climate change, the sustainability of that option warrants review. An increasing proportion of mains water use is within houses due to smaller lot sizes with smaller gardens and drilling of new domestic irrigation wells in established areas. Hence the proportion of sewage discharge to the mains' water supply is expected to increase. This represents a significant stable resource which if recycled for indirect potable reuse would help to secure supplies, stabilise groundwater levels and support Perth's urban growth. A MAR strategy that aimed at balancing groundwater extraction with recharge to the surficial aquifer would require investment in order to monitor groundwater levels and to increase the proportion of runoff that becomes an effective recharge to the aquifer, as well as limiting groundwater extraction where it is excessive.

Table 1 does not account for roads and footpaths or commercial areas which are expected to make a substantial contribution to runoff entering municipal scale drainage systems, and some of the assumptions are over-simplified and arguable so Table 1 should not be used on its own to determine options. However it does point to a vulnerability of groundwater-dependent ecosystems and possibly to coastal saline intrusion due to climate change under the current water management practice of pushing demand from main water systems to private wells drawing from a common groundwater system, due to declining recharge and increased discharge.

3 Stormwater Aquifer Storage and Recovery, Adelaide

Stormwater injection into confined aquifers containing brackish groundwater for the purpose of recovery for irrigation and industrial uses commenced in Adelaide in 1992. Figure 1 shows a schematic cross-section of urban stormwater harvested in a constructed wetland and recharged via a well into a confined aquifer initially containing brackish water. The stored water is recovered in the dry season for municipal irrigation or industrial use (Dillon *et al*, 1997).

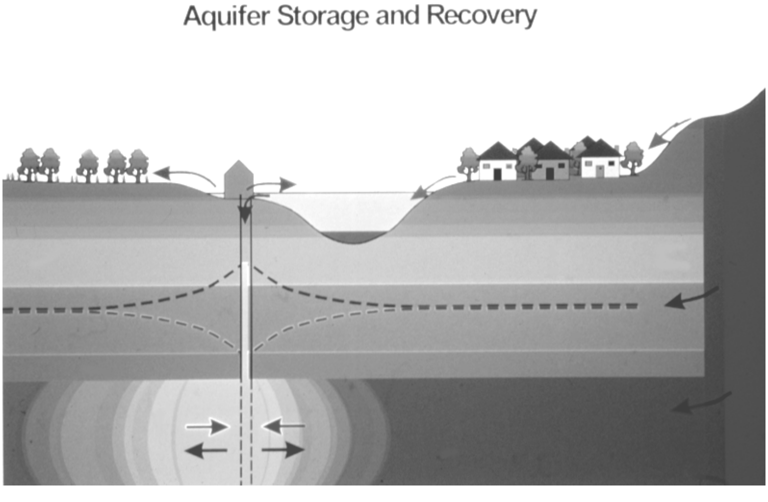

Figure 1: A schematic of aquifer storage and recovery of urban stormwater using a constructed wetland to harvest and treat the water prior to injection into a well accessing a confined brackish aquifer and subsequent recovery from the same well for irrigation or industrial use

While most of this ASR was for urban stormwater into limestone aquifers, several ASR wells are also completed in fractured rock aquifers. A recent review indicated that there is capacity for 25 to 50 million m^3yr^{-1} of injection and recovery in confined aquifers in the greater Adelaide area (Hodgkin, 2004), and the state government's strategic plan, 'Water Proofing Adelaide', aims for 20 million m^3yr^{-1} of harvesting and reuse of stormwater via aquifers by 2025 (South Australian Government, 2005).

Initial projects were not economical on the basis of their water supply benefits alone. The largest cost in an ASR project is for the surface detention storage which allows time for groundwater recharge. Invariably the cost of such storages is justified on the basis of flood protection for urban areas downstream. The additional costs to also provide a water supply are relatively small. These consist of basic water treatment prior to injection, the ASR well including pump and controls, and distribution systems for the points of water demand. To date the cost effectiveness of ASR has relied on having a concentrated high volume (typically 50 to 100 $*10^3m^3yr^{-1}$) of localised users of water of irrigation or industrial quality so that distribution costs are low. The initial uptake was slow but in recent years has accelerated (Table 2). Systems have been installed for council parks, sports fields, golf courses and intense industrial uses such as wool scouring. The number of large but localised uses of non-potable water in any city is finite.

Table 2: History of stormwater ASR in Adelaide

Year	**Volume ($10^6m^3yr^{-1}$)**
1992	0
1996	0.1
2000	0.6
2004	3.0
2008	15*

* 2008 figure based on ASR funding proposals approved by National Water Commission in 2006

One way to expand the potential for aquifers to contribute to the use of stormwater on a broader scale would be to demonstrate that the recovered water is fit to be injected into the city's drinking water distribution system. Experiences at ten well monitored sites (Dillon and Toze, 2005) suggest that water quality requirements are likely to be achievable in a well managed system. Further evidence from Mount Gambier, a city in South Australia, shows that after 125 years of urban stormwater recharging a karstic limestone aquifer that contributes directly to the city's drinking water supply no deleterious effect could be observed to the water supply (Cook et al, 2006; Gorey and King, 2005).

Hence an Aquifer Storage Transfer and Recovery (ASTR) project designed to demonstrate that urban stormwater can be managed to achieve consistent reliable drinking water quality has commenced at Parafield Gardens in the city of Salisbury, South Australia. Stormwater harvested from a drain and stored and treated in an existing constructed wetland will be injected into a zone within a brackish limestone aquifer to produce a supply that will be blended with reclaimed water in a third pipe system for toilet flushing and irrigation in the new residential development of Mawson Lakes. Water need not be potable to meet the intended uses, but monitoring and control systems will be put in place to demonstrate whether the recovered water continuously meets drinking water requirements.

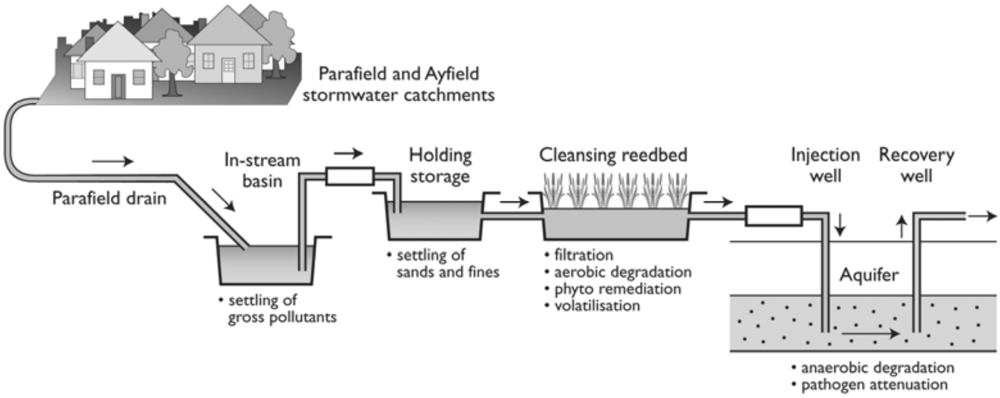

Figure 2: Schematic diagram of Aquifer Storage Transfer and Recovery (ASTR) of stormwater with the intention of recovering water suitable for drinking water supplies (from Swierc *et al*, 2005)

The project is described in a paper by Rinck-Pfeiffer *et al.* (2005). The ASTR project uses separate injection and recovery wells to ensure that there is adequate residence time of water in the aquifer to facilitate pathogen removal and attenuation of some organic constituents of stormwater. The pattern of wells required careful design to maximise the recovery efficiency while meeting residence time requirements (Pavelic *et al*, 2004). A risk management plan is evolving from experience gained though monitoring and commenced with a preliminary plan by Swierc *et al* (2005). The project is currently in construction and its operational performance will be monitored and results reported.

4 Reclaimed Water Infiltration, Halls Head

Sewage effluent is treated at nine plants along the western side of the city of Perth, generally on the coast, where most of the 120 million m^3yr^{-1} is discharged. 6% of the water is now in reuse (Radcliffe, 2004), mainly for industrial purposes at Kwinana, and the state has developed a Water Strategy that articulates plans to reuse 20% of STP discharge by 2012. Some of these uses would substitute for the use of potable water. One of the more recent water reuse projects developed in the greater Perth region is the Halls Head Indirect Reuse project.

This indirect reuse project is located at the Halls Head Wastewater Treatment Plant (WWTP) in Mandurah, 74 km south of the centre of Perth. The Wastewater Treatment Plant treats approximately $2.3x10^3$ m^3 of effluent a day to a secondary status using activated sludge. The non-disinfected treated effluent is then discharged via infiltration ponds to the shallow aquifer beneath the treatment plant. The indirect reuse project was initiated by recovering this infiltrated treated effluent from the aquifer via two recovery wells (SPB1 & 2) located 100m and 60 m respectively from the infiltration ponds. The recovered, treated effluent is then piped to a storage tank were it is held until used for the irrigation of green open spaces in the neighbouring residential development. The indirect project was monitored over a 24-month period for potential health and environmental risks from major contaminants, in particular the potential presence of microbial pathogens in the recovered water and the influence of treated wastewater on the local groundwater system (Toze *et al.* 2004).

A hydrogeological analysis and tracer tests undertaken during the monitoring period indicated that the aquifer beneath the Halls Head WWTP site consists of karstic limestone which is very heterogenous and strongly influenced by sea level variation at diurnal, seasonal and inter-annual time scales. The tracer tests indicated that particles were travelling at a rate of approximately 2.5 metres/day in the vicinity of tracer bores, suggesting that particles would take a minimum of 24 days to reach the closest recovery well (SPB2) located 60 metres away (Fig 3). It was also determined, based on Total Dissolved Solids (TDS) concentrations, that 80% of the recovered water was infiltrated treated wastewater, with the remainder being drawn from the background groundwater.

The water quality monitoring undertaken for health risks associated with the recovered water focused on the potential presence and numbers of enteric bacteria and viruses and the concentration of heavy metals in the recovered water. Over the entire 24 month monitoring period Thermotolerant Coliform (TTC) numbers detected in the recovered water never exceeded 1 cell/100mL and was only detected in the recovered water on two occasions. Coliphage and the human pathogenic enteroviruses group were never detected in the recovered water or the background groundwater despite always being detected in the treated effluent prior to infiltration. A series of experiments examining the factors responsible for removing the pathogens from the infiltrated treated effluent in the aquifer determined that all of the pathogens had a 1 log reduction time of less than 16 days and that the major removal process was due to the action of the indigenous groundwater microorganisms in the aquifer (for more details see Toze *et al.* 2004).

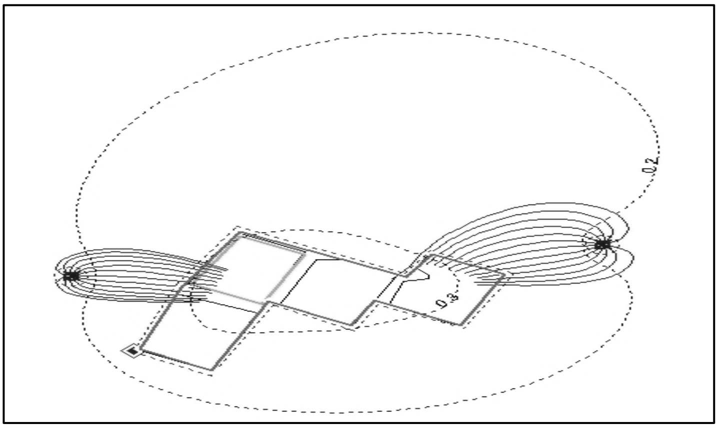

Figure 3: Groundwater modelling was used at Halls Head wastewater infiltration ponds to interpret mound height and travel paths and flow times to the two recovery wells used to supply landscape irrigation water (from Toze et al, 2002).

Analysis of heavy metal concentrations in the recovered water determined that the only trace metals measured above detection limits were zinc and lead. The maximum concentrations of lead and zinc were 0.0063 mg/L and 0.03 mg/L respectively. These concentrations, however, were all lower than the maximum allowable levels defined in the Australian Drinking Water Guidelines of 0.01 mg/L for lead and 3 mg/L for zinc (NWQMS 2004). The indirect reuse project trial has provided the scientific information to justify the continuation of the project to provide water for local landscape irrigation.

5 Reclaimed Water ASR, Bolivar

Bolivar reclaimed water Aquifer Storage and Recovery (ASR) demonstration site showed that water sourced from a sewage treatment plant and reclaimed to a quality fit for unrestricted irrigation of horticulture on the Northern Adelaide Plains, could be successfully used to recharge a brackish limestone aquifer during the winter months and thereby expand water supplies for summer. Over three injection and recovery cycles 364x10^3 m^3 were injected and 243x10^3 m^3 were recovered. This project was described in Dillon *et al,* (2003 and 2006) and the documents referenced in those papers. Subsequent papers describe clogging processes and water quality requirements to prevent clogging at this site (Pavelic *et al*, 2007) and the fate of organic matter during ASR at this site (Vanderzalm *et al*, 2006). The source water was derived from sewage effluent from the city of Adelaide, after it had been through biological treatment, followed by aeration lagoons, then dissolved air flotation and dual media filtration and chlorination. The aquifer is composed of Tertiary limestone containing sand, but is not karstic. The site was capable of operating in spite of using relatively low quality water (Table 3) compared with ASR projects elsewhere in the world because the carbonate aquifer dissolved slowly due to oxidation of injected organic matter. This refreshed the well-aquifer interface and avoided chronic clogging problems, assisted by management practices described in Pavelic et al (2007). Rates of dissolution are not sufficient to cause well or aquitard instability problems within the working timeline of the ASR well. The method was found to be cost effective for storing reclaimed water during the winter to augment horticultural irrigation supplies in summer.

Table 3: Quality of injected water, local ambient groundwater and recovered water at Bolivar reclaimed water ASR project site

↔	→		cycle 1		cycle 2	
Parameter (mg/L)	**Irrigation Guidelines (NWQMS)**	**Ambient Groundwater (n=17)**	**Injectant (n=24)**	**Recovered Water (final sample)**	**Injectant (n=14)**	**Recovered Water (final sample)**
Electrical Conductivity (µS/cm)		3592 ± 326	2265 ± 191	2470	1975 ± 92	2550
Temperature (^{o}C)		25.9 ± 1.0	20.4 ± 4.5	22.7	16.3 ± 3.6	21.1
pH	4.5-9	7.3 ± 0.1	7.1 ± 0.4	7.06	6.9 ± 0.3	7.31
Dissolved Oxygen		0.77 ± 0.79	4.4 ± 3.4	0	6.0 ± 1.4	0
Total Suspended Solids		12 ± 14	14 ± 13	1	-	-
Total Dissolved Solids (by EC)	1500	2006 ± 188	1267 ± 58	1470	1225 ± 55	-
Total Nitrogen		0.08 ± 0.03	19.9 ± 10.8	15.6	7.8 ± 2.5	4.12
Total Phosphorus		0.02 ± 0.001	0.72 ± 0.65	0.24	2.3 ± 0.9	0.24
Dissolved Organic Carbon		0.3	16.7 ± 2.1	10.5	19.5 ± 1.9	12
Total Organic Carbon		0.3	18.2 ± 2.3	10.6	20.1 ± 2.12	12.2
Chlorine residual - total		0	0.7 ± 0.4	0	3.0 ± 2.4	
E Coli. (cells/100mL)	1000	0 ± 0	42 ± 113	0	-	-

6 Conclusions

Water harvesting and reuse of urban stormwater and reclaimed water to substitute for existing supplies can increase the robustness of water supplies for growing cities facing climate change. Urban aquifers can play a major role in facilitating this reuse by providing storage and treatment with minimal use of land, infrastructure and energy. The options available for any city depend on the availability of aquifers, the existing groundwater quality and its suitability for various uses, the availability of land for capture and treatment of urban stormwater and for treatment of reclaimed water prior to recharge. Protection or enhancement of groundwater quality is essential to sustaining water supplies by these methods. Managed aquifer recharge where applicable can integrate urban water resources, facilitate reuse and allow substitution. These three elements are considered to be at the frontier of urban water management (Tejada-Guibert and Maksimovic, 2001). Use of mildly brackish groundwater rather than seawater can also reduce the costs of reverse osmosis and pipeline costs and combinations of recharge and extraction can provide long-term solutions for water imbalances and salt accumulation.

Acknowledgements

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Utilization and Protection of Groundwater in Beijing after Completion of South-to-North Water Transfer Project

南水北调水进京后北京市地下水管理与保护

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Abstract

The South-to-North Water Transfer Project will improve the groundwater quality in Beijing. Based on the analysis of the current groundwater situation, this paper will discuss the water resource situation in Beijing after completion of the project, the proposed strategy for the use of groundwater and relevant protection methods. Furthermore, it will also forecast the effects of groundwater exploitation and protection under these planed strategies.

摘要

南水北调工程为北京市地下水环境改善提供了水源条件。本文针对北京市地下水环境现状及存在问题，分析了南水北调后北京市水资源形势，提出了南水北调来水后北京市地下水开发利用方案和相应保障措施，预测了地下水开发利用和保护效果。

1 Introduction

Beijing is an international metropolis facing a rapid pace of development and it is the political and cultural center of China. But, Beijing is also a city with a severe water shortage, where the water amounts to less than 300 m^3 per capita. The serious shortage of surface water resources led to the exploitation of groundwater to meet the increasing demand. The percentage of groundwater in Beijing’s total water supply has risen to77% from 57% in the 1980's.

The excessive exploitation of groundwater in Beijing has caused the groundwater level to fall and the overall water environment to worsen. The construction of the middle line of the South-to- North Water Transfer Project will not only relax the water scarcity in Beijing but also change the structure of water resources. The Project will provide the conditions for Beijing to be able to alleviate the exploitation of groundwater improve the groundwater conditions.

2 The Groundwater Situation in Beijing

The total area of Beijing is about 16800 Km ^{2} including a mountainous area of 10400 Km ^{2} and a plain area of 6400 km ^{2} (not including the Yanqing basin). The mountainous area accounts for 62% of the total area and the plains area accounts for 38%. Most of the plains area will get more water from the South-to- North Water Transfer Project.

On the Beijing plains, the annual average replenishment quantity of groundwater is about 2.287 billion m^3 and the permitted level of exploitation is set at about 1.96 billion m^3. Since 1999, there has been a continuous drought in Beijing and the annual precipitation has been less than 22% ~37% of the annual average value. The continuous drought had caused a serious decrease in surface runoff and an increase in groundwater exploitation. The annual exploitation of groundwater was about 2.4 billion m^3 during those years.

The continuous overexploitation of groundwater has caused the following:
(1) A continuous decrease in the level of groundwater and a decrease in the level of groundwater reserves

According to the data, the groundwater level on the Beijing plains at end of 2005 was about 20m below ground, which is lower 14 m lower than the level it was at in 1980. The total groundwater reserves have been reduced by 7.1 billion m^3. Now, the total area being excessively exploited on the Beijing plains is 5659 km^2, 88% of the total plains area. Of the areas mentioned above, 2186 km^2 is being seriously exploited or 39% of the total area. The situation of groundwater exploitation is shown in figure 1.

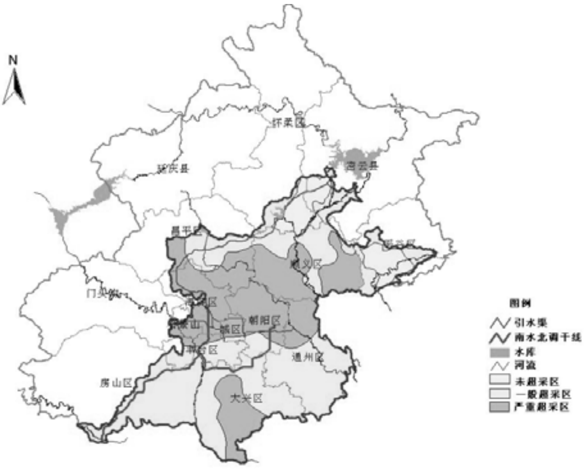

Figure 1: distribution of groundwater exploitation situation on the Beijing plains

(2)The cone of depression area

Currently, the cone of depression on the plains of Beijing has reached about 1000 km^2 from 322m^2 in middle of the 1980's. Some quaternary system aquifers with thin layers have been dry or half dry since the excessive exploitation of groundwater began.

(3)The worsening quality of groundwater

On the Beijing plains, the area with a standard of TDS (total dissolved solids),total hardness of groundwater, is increasing, which represents a deterioration of groundwater quality. The reasons for the worsening quality of groundwater include the direct pollution from production activity but also changes in the hydrological and geological conditions and groundwater flow fields due to the overexploitation of groundwater. For example, in the suburban areas, where the groundwater overexploitation is especially serious, the area with a high standard of hardness has expanded to about 300 Km^2 from 40 Km^2 in the 1950's.

(4) Ground subsidence

From 1955 to the end of the last century, the area of over 100mm of cumulative ground subsidence on the Beijing plains is about 1826 Km^2, while the largest value of cumulative ground subsidence is 722 mm.

3 The Water Resources Situation in Beijing after Completion of the South-to-North Water Transfer Project

It is forecasted that the water demand on the Beijing plains in 2010 will reach 3.78 billion m^3 and 3.93 billion m^3 respectively in a mean hydrological year and a partially dry hydrological year. But with the condition that no water is imported from other regions, the levels of water supply during the same years mentioned above are only 3.62 billion m^3 and 3.31 billion m^3 respectively, even if the reuse of waste water is taken into account. The gap between water demand and water supply will be 0.16 billion m^3 and 0.62 billion m^3 respectively. Furthermore, the gap will reach 0.74 billion m^3 and 1.17 billion m^3 in 2020.

According to the plan, the amount of water that will reach Beijing from the Middle Line Project in 2010 is 1.05 billion m^3.

Considering Beijing is a rapidly developing international metropolis, the water from the South-to-North Water Transfer Project will first be used to meet the domestic and industrial demands in the downtown area as well as in parts of newly built areas. The direct water supply covers a control area of 3247 Km^2. By jointly operating the Project with the Miyun and Guanting reservoirs, the total scope of the project could reach 5876 Km^2, covering 90% of total plains' area.

Beijing will continue to examine the potential for the reuse of treated waste water while continuing to transfer water from other regions. According to the Beijing Water Resources Integrated Plan, the total amount of reused water in 2010 and 2020 will reach 0.6 billion m^3 and 0.8 billion m^3 respectively, which will be mainly used for agricultural, environmental, domestic and industrial purposes.

Based on the analysis of water supply and demand in the Beijing plains area, after completion of the South-to-North Water Transfer Project, the water supply will be able to meet the water demand in a mean hydrological year. In partially dry hydrological years, the normal water supply would be less than the water demand and some excess groundwater exploitation have to take place, but the overall amount of exploitation will be less than the current level. Therefore, the completion of the South-to-North Water Transfer Project will help alleviate Beijing's supply and demand imbalances and an effective control over the depletion of groundwater, thus restoring and recharging the groundwater and improving the overall groundwater reserves.

4 Groundwater Protection in Beijing after the Completion of the South-to-North Water Transfer Project

Presently, the most severely exploited areas in Beijing are urban and suburban areas such as Shunyi district, Daxing district and Changping district, who (except Shunyi and Changping districts) are also the areas that will be getting water directly from the South-to-North Water Transfer Project. So, after completion of the Project, the new source of water should be used to alleviate the demands on groundwater. Especially in those areas being excessively exploited, groundwater exploitation should be strictly controlled and the replenishment and protection of groundwater should be strengthened.. According to the analysis of water supply and demand in Beijing's plains area, on the condition that 1.05 billion m^3 of water is supplied by the South-to-North Water Transfer Project, the annual groundwater exploitation of Beijing's plains in a mean hydrological year would be cut down 0.4 billion m^3 from the current exploitation value of 2,4 billion m^3. Of the 0.4 billion m^3, the 0.18 billion m^3 decrease would occur in the urban areas (including eight centre districts), and 0.22 billion m^3 would in suburban areas (including all of other plains area except the urban area). Basically, there would be no overexploitation in plains area of Beijing.

(1)The urban area

According to the structure of water supply in the eight urban districts, after completion of the South-to-North Water Transfer Project, the underground water exploitation controls will focus on self-construction wells w and secondly focus on the water plants which use undersground water as a source. With the increase of tap water supplied to urban areas, the underground water exploitation of self-contructed wells can be reduced by 0.15 billion m^3, based on the current water supply. Taking into consideration the decrease of the demand for water for agricultural purposes and the reuse of treated waste water in Haidian district and Fengtai district, the groundwater exploitation by the agricultural sector might be cut down 30 million m^3.

(2) The suburban area

The reduction of groundwater exploitation in suburban areas could be implemented in two ways: Firstly, irrigation should replace groundwater with reclaimed wastewater. According to this plan, about 0.8-1 million Mu of reclaimed wastewater irrigation areas will be established in suburban areas of Beijing from 2010 to 2020, and it is estimated that the groundwater exploitation in these irrigation areas would be reduced by about 0.15 billion m^3. Secondly, the use of groundwater for domestic and industrial use needs to be reduced. After completion of the South-to-North Water Transfer Project, the increase of surface water available in suburban areas could result in about a 70 million m^3 reduction in groundwater use.

However，for a developing metropolis, it is necessary to point out that cutting down on groundwater exploitation does not mean the abolishment of existing wells ,but to emphasize the need to reduce the reliance on groundwater and to reserve the use of wells for emergency needs.

5 Analysis of the Effects

(1) The groundwater level

According to the project on groundwater protection mentioned above, the future trends of changes in the groundwater table in urban and suburban areas are predicted in figures 2 &3.

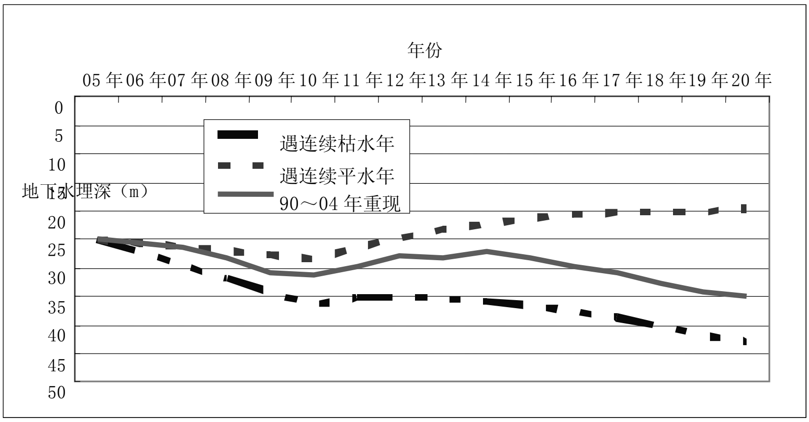

Figure 2: Forecast of changes in groundwater levels in urban areas

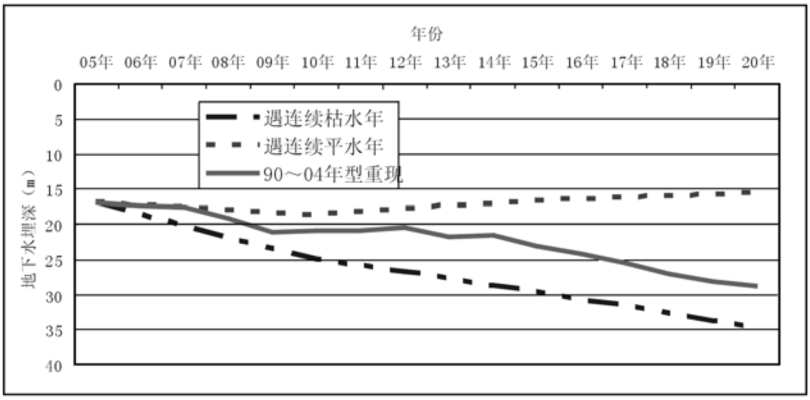

Figure 3: Forecast of changes in groundwater levels in suburban areas

As forecasting shows, on the condition the level of exploitation before completion of South-to-North Water Transfer Project is the same and groundwater exploitation is reduced by 0.18 billion m^3 in urban areas and 0.22 billion m^3 in suburban areas after completion of Project, and the conditions of a mean hydrological year are taken from now to 2020, the groundwater table in 2020 would rise about 5 m in urban areas and about 2 m in suburban areas. If conditions are taken for a partially dry year, the groundwater table would continue to decrease and it is predicted that the groundwater level in 2020 would be about 40 m below ground in urban area and about 35 m in suburban areas.

(2)The groundwater storage capacity
Considering the effects of cutting down groundwater exploitation and ignoring the influences of other factors, such as the seepage from surface water bodies and the recharge of rainfall, it is estimated that the groundwater storage capacity in Beijing plain could increase 0.3 billion m^3 annually in mean hydrological years. But in dry hydrological years, the groundwater storage capacity would still decrease because the total amount of groundwater replenishment would be less than the demand for exploitation.

6 Conclusion and Suggestions

After completion of the South-to-North Water Transfer Project, the continuous decrease of groundwater water levels on the Beijing plains will be restrained through control of exploitation. Over the long term, the groundwater level will increase in some extent. The Project will have the important effect of increasing the strategic water storage capacity of Beijing as well as making the city more ecologically-friendly.

In order to reinforce groundwater resource management and improve the groundwater environment, the suggestions put forward in this paper are as follows:

- Strengthen leadership, improve organization and enhance the management
  Firstly, a leading group should be established to control groundwater exploitation. Secondly, specific target reductions should be defined for each district, and a work responsibility system should be created. Moreover, a supervision and inspection system could be established in order to strengthen management of groundwater resources, strictly administer the approval system for groundwater-well construction and grant permission to exploit water.

  After the completion of the South-to-North Water Transfer Project completion, the pattern of multiple water sources, including the South-to-North Water, local surface water, groundwater, reclaimed waste water and rainfall will appear in Beijing. Therefore, it is necessary to develop a dispersion system for the multiple water sources to be able to adapt to changes in the supply and demand. Timely, quick and flexible water resources allocation can ensure the safety of the urban and rural water supply, which is very important for the implementation of underground water conservation plans.
- Perfect the monitoring system on groundwater dynamic and urban water supply
  In order to provide data for the water dispensation decision support team, the ability to monitor the city’s water supply should be expanded.
- Create a reasonable water pricing mechanism
  Groundwater has been a source of water that could be used at a relatively low cost, which contributed to excessive groundwater exploitation. Therefore, a reasonable price relationship between the different water sources should be established, and the prices should encourage the use of more reclaimed waste water and water from the South-to-North Water Transfer Project, in order to protect the groundwater.

A Test Study on Treatment of the Light-Polluted Wastewater in Rivers Based on Immobilized Microorganisms
固定化微生物处理河流微污染水体试验研究

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Abstract

In this paper，a pilot-scale experiment has been conducted on a new method for treating lightly-polluted wastewater in the Beijing Macao River based on an immobilized microorganisms-biological aerated filter （IBAF）. The performance of the IBAF reactor on lightly-polluted wastewater treatment in the river is examined through the analysis of inflow and outflow of COD， ammonia-nitrogen and TP. The results show that the effluent water can satisfy the IV grade of environmental quality standards for surface water in China， and the removal efficiencies of COD_{Cr}，COD_{Mn}，NH_3-N， and TP were above 60%， 30%， 90%， and 50%, respectively. Meanwhile， the Kjeldahl-Gunning method for nitrogen determination indicates that the mean immobilized biomass on the carrier is 35 g.l^{-1} （H_2O） in the system, which can improve the treatment efficiency. Only once the IBAF system has been domesticated can it meet the reuse requirements. In addition， the low temperature conditions of 5-15℃ cannot effect the NH_3-N removal efficiency， highlighting the importance of the study of nitrogen removal in low temperatures.

摘要

本文采用固定化微生物——曝气生物滤池（IBAF）系统对北京市马草河微污染水体进行了现场连续运转中试研究。通过对进水与出水 COD、氨氮和总磷的监测，研究了 IBAF 系统对河湖微污染水体的处理性能。结果显示：采用 IBAF 系统处理河流微污染水体，处理后主要水质指标可达到地表水 IV 类水体标准；各污染物的去除率分别达到：COD_{cr}60%以上、COD_{Mn}30%以上、氨氮 90%以上和总磷在 50%以上；克氏定氮法测定表明 IBAF 系统中的生物量为 35g/L，可极大的提高处理效率；IBAF 系统在驯化完成后，能够满足重复使用的要求；试验还表明在温度 5-15℃的条件下，IBAF 系统脱除氨氮性能未受影响，这对低温脱氮的研究具有重要的意义。

1 Principles and Characteristics of the Immobilized Microorganism Technique

Treatment of eutrophication in lightly-polluted rivers and lakes has remained a puzzle all over the world. Immobilized microorganism technique have been applied to the treatment of sewage with high concentrations of organic matter and ammonia- nitrogen, achieving higher removal rate of COD and especially ammonia-nitrogen than A/O craft. However, the treatment of lightly-polluted water based on immobilized microorganisms technique has yet to be reported. In this paper, a self-made functional macro-porous carrier FPU was used to immobilize microorganisms B11. The immobilized microorganisms were then placed in an aerated filter forming IBAF system, based on a pilot-scale experiment on the Macao River. The performance of the treatment by the IBAF reactor on lightly-polluted wastewater treatment in the river was examined through the analysis of inflow and outflow of COD， ammonia-nitrogen and TP.

1.1 Technique principles

Immobilized microorganisms technique is one type of biological film purification technique. Its principle is that bacteria, fungi, protozoa and metazoan in polluted water are attached to the carrier placed in water with high adsorption efficiency, grow and breed, and form a bio-film. In biological films, bacteria have large densities and have mass multiplication, forming a long food chain; organic pollutants-bacteria-fungi-protozoa-metazoan. When the polluted water circulates through the biological carrier, the contaminants in water are absorbed and then degraded by the microorganisms on the bio-film. The oxygen in the water is depleted gradually during the process, so artificial aeration is needed. During the process, microorganisms grow, breed and are licked up by protozoa and metazoans, which are also part of a fish's diet thus creating a complete aquatic ecosystem and the water is purified. The thickness of biological film will continuously increase after ripeness and to a certain degree, oxygen cannot move to the inner part. An anaerobic film is formed, which can remove nitrogen and phosphorus in the water. The principle is shown in fig1.

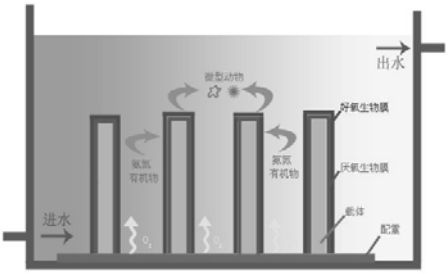

Figure 1: schematic diagram of river and lake purification by immobilized microorganisms

1.2 Technique characteristics

The immobilized microorganism technique has the following characteristics:

1.2.1 Process

(1) The possibility of sludge bulking that usually happens in traditional biological treatment techniques can be decreased because of a steady ecosystem and food chain, especially filamentous Sphaerotilus with high oxidation ability that can grow in the biological film.

(2) A dense biological net of special structures is formed for vast growth of filamentous, which acts as filtration and improves the purification effect when sewage runs through it.
(3) Continuous aeration on the surface of biological film is good for keeping it active and improving the availability of oxygen.

1.2.2 Operations

(1) Immobilized microorganism techniques have a strong adaptive capacity to shock loading and can maintain good treatment effects when run under conditions of intermittent operation.
(2) It is easy to operate, run, maintain and manage, and does not need sludge circumfluence.
(3) It has small sludge yield, with large sludge particles and settles easily.

1.2.3 Functions

The biological contact-oxidation treatment technique has several purification functions. In addition to removing organic contaminants, it can also remove nitrogen and phosphorus when functioning properly.

2 Materials, Equipment and Method

2.1 Materials

Macro-porous netty carrier FPU； special microorganism B11， including 28 kinds of special microorganisms and fiber enzyme、amylase、lipase and hydrolase, a loading density of 0.6-0.8g/$cm^3$and the quantity of microorganisms was 3-5 billion per gram. C.P.(chemical pure) and A.R. (analytical reagent) are used also.

2.2 Process and equipment

The technological chain is shown in fig 2. The self-designed BAF, with an available capacity of 1.9m^3 is 2100mm(L)×1000mm(W)×1000mm(H), is divided into two rooms and a deviator is set in the middle to prevent short flow. The carrier FPU is backfilled with a volume of 1.3m^3 in the reactor and its depth is 900mm. Water flows in from the bottom of the reactor and leaves from a collecting vat at the top. Each aeration tank has 12 air-blast-heads, which works through an aerator with 16 pores. Another similar type of equipment without FPU carriers becomes a non-treatment control.

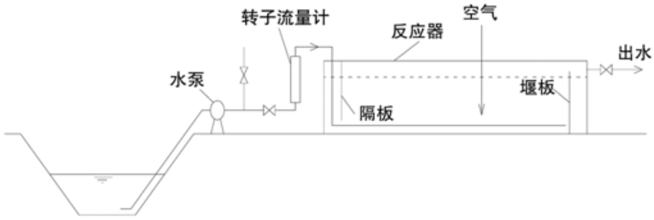

Figure 2: Flow chart of process

2.3 Method

The experiment can be divided into two stages: the first one is domestication and immobilization of microorganisms lasting 7 days; and the second stage is research on technological parameters and an operational check lasting 90 days. The experiment's steps are as follows:

Firstly, river water is pumped into the BAF and aerated to keep DO at 3-5mg/L, with 100g B11 added into each room. Then from the second to the seventh day, 100g、50g、50g、30g、30g and 20g is added into each room in turn. The reactor is operated at the flow rate of 250L/h and after 3 days' aeration, COD and ammonia nitrogen of the influent and effluent is tested at the same time everyday，and the microbial biomass of the carrier is measured by the Kjeldahl-Gunning method as well. When the COD and ammonia nitrogen levels in the effluent is over 40%, an indication of the end of the first stage, the influent flow rate is increased gradually. Then it comes the second stage and several water quality indexes are continuously used to measure influents and effluents.

2.4 Instruments

COD quick determination instrument (COD/CSB), BOD_5 determination instrument (BSB/BOD), NH_4^+-N determination instrument (HI93715), dissolved nitrogen determination instrument (YSI55), pH online detection instrument (DP5000), NO_3^- determination instrument (HI93728), total phosphorous determination instrument (HI93706), NO_2^- determination instrument (HI93708).

3 Analysis of Test Results

3.1 Removal effect of COD_{Cr} by immobilized microorganisms

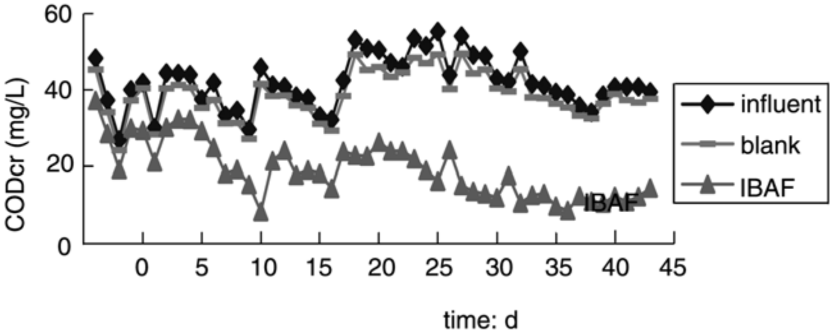

Figure 3: Removal effect on COD_{Cr} by immobilized microorganism

Figure 3 shows COD_{Cr} removal effects by the IBAF system and blank reactor. COD_{Cr} removal rate is low during the early days as the results of small microbial biomass. As the experiment goes on, the microbial biomass attached to carriers increases, and the removal rate consequently increases. The influent COD_{Cr} levels was between 40 and 50mg/L, in effluent was between 9 and 20mg/L and the removal rate was between 60% and 70%, with a maximum of 78%. Effluent water satisfied the IV grade of environmental quality standards for surface water in China, which indicated that the immobilized microorganism technique can remove non-degradable COD_{Cr} from lightly-polluted river water effectively. The COD_{Cr} removal rate by blank equipment is only about 5%, which shows that COD_{Cr} in the river cannot be degraded naturally, in other words, the river's ability to purify itself is poor.

3.2 Removal effect on COD_{Mn} by immobilized microorganisms

Figure 4 shows the removal effect on COD_{Mn} by the IBAF system and blank reactor. The COD_{Mn} in influents was between 8 and 12 mg/L, in effluents was between 6 and 8 mg/L, satisfying the IV grade of environmental quality standards for surface water in China. Removal rate by immobilized microorganisms was between 30% and 40% with a maximum of 50%, and the blank reactor has little effect on the removal of $COD_{Mn.}$

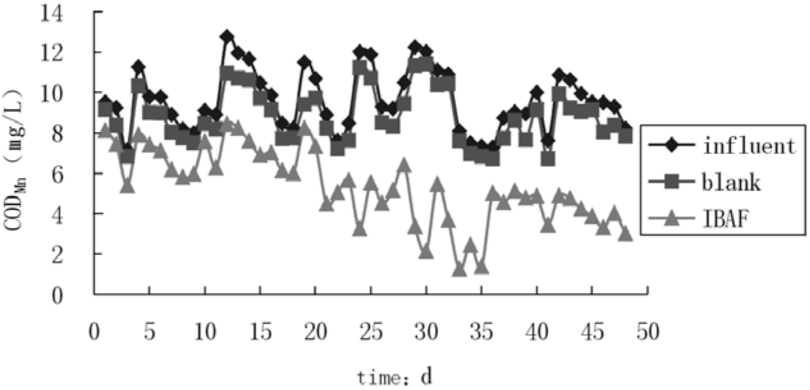

Figure 4: The removal effect on COD_{Mn} by immobilized microorganisms

3.3 Ammonia nitrogen removal effect by immobilized microorganisms

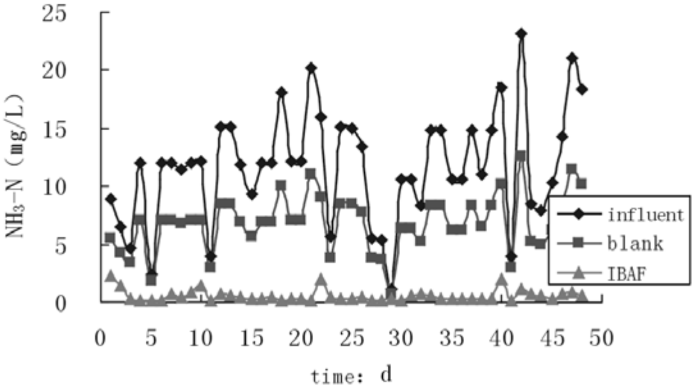

Figure 5: the removal effects on ammonia nitrogen by immobilized microorganisms

Figure 5 shows IBAF's removal effects on ammonia nitrogen. Nitrobacteria became dominant after 3 days of domestication of immobilized microorganisms, which was due to the fact that microenvironments supported by macroporous carriers are good for growing nitrobacteria, therefore, the ammonia nitrogen removal rate was high. The ammonia nitrogen in influents was between 5 and 20 mg/L, in effluent was between 0 and 0.3 mg/L and the removal rate was above 90%, satisfying the III grade of environmental quality standards for surface water in China. The amount of ammonia nitrogen in effluents was about 0.5mg/L at the temperature of 5-15℃, showing excellent efficiency of nitrogen removal by immobilized microorganisms in low temperatures. The non-treated control showed that it also had a certain removal rate of ammonia nitrogen, which resulted from aeration and protein synthesis.

3.4 Total phosphorous removal effect by immobilized microorganisms

Figure 6 shows the IBAF system's total phosphorous removal effect. Figure 6 shows that the removal of total phosphorous is not evident during the first 15 days. After 15 days, total phosphorous in the effluents was stable. The total phosphorous in influent was between 0.73 and 1.09 mg/L, in the effluent it was between 0.2 and 0.3 mg/L and the removal rate was between 50% and 70%. In addition, to traditional mechanisms for removing phosphorous, immobilized microorganisms and carriers can enrich metal ions and chemically precipitate the removal of phosphorous, so the immobilized microorganisms technique achieved a higher efficiency. But due to the disturbed carbon, nitrogen and phosphorous balance, the function of IBAF on phosphorous removal is limited. It has to be combined with other techniques to remove phosphorous completely. The removal rate for blank reactors was only 13.98%, due to organism multiplication.

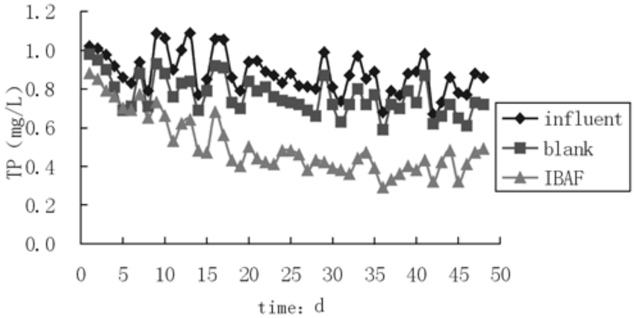

Figure 6: Total removal effects on phosphorous by immobilized microorganisms

4 Testing and Analysis of the Performance of Immobilized Microorganism

4.1 Determination and characterization of immobilized microorganisms' biomass

Some carriers taken from IBAF were dried to constant weight , filtered and washed by distilled water 2 or 3 times. The nitrogen content of microorganisms in the carrier is determined by the Kjeldahl-Gunning method, and the results were converted into microbial biomass and the value per liter of water was 23-42g/L (H_2O) with an average value of 35g/L（carrier volume is 50% of water, resulting in a much bigger volume of microorganisms than other biological techniques yet which has the ability to improve treatment efficiency and decrease area.）

Figure 7(a) is an EM (electron microscope) picture of the FPU carrier (100 times magnified). Figure 7(b) is an EM (electron microscope) picture of microorganisms immobilized on carrier FPU after theIBAF ranfor 2 months（1000 times magnified）. From Figure 7(b) we found that the carrier was loaded with a great deal of microorganisms, the pores of the carrier were still expedite, which can avoid the consequences of a decline in mass transfer driving force, a decrease in the carrier’s surface area, and a lower treatment efficiency by organism multiplication, like the other carriers (such as activated carbon).

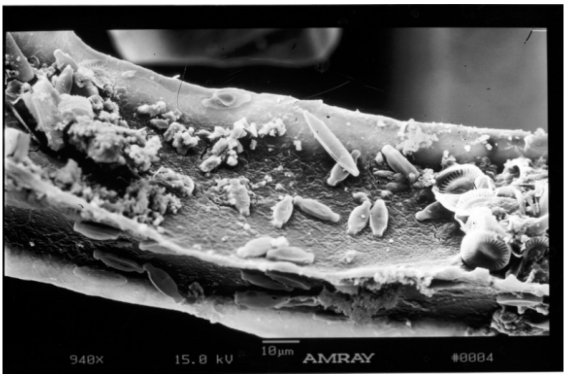

Figure7 (a): EM picture of FPU carrier

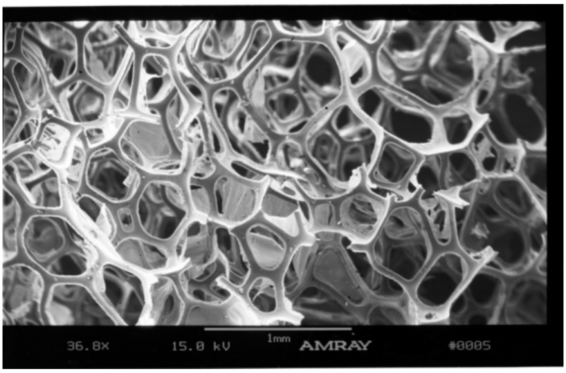

Figure 7(b): EM picture of microorganisms immobilized on carrier FPU

4.2 The reusability of immobilized microorganisms

The IBAF system had good bioactivity at the temperature of 5-28℃ after domestication and continuously operating for 3 months without adding microorganisms. COD_{Cr} and ammonia nitrogen in the effluent did not rebound; the system ran more and more steadily, which proves that IBAF doesn't make its biological activity lost so that it can meet the requirement of reuse.

5 Conclusion

(1) The IBAF system with a macroporous reticulated carrier FPU and immobilized microorganisms was used to treat lightly-polluted river water and the effluent waters tested could satisfy the IV grade of Environmental quality standards for surface water in China.
(2) The removal efficiency of COD_{Cr}， COD_{Mn}， NH_3-N， and TP by the IBAF system was above 60%， 30%， 90%， and 50% respectively.
(3) Ammonia nitrogen in the effluent was about 0.5mg/L at the temperature of 5-15□ therefore showing excellent efficiency at nitrogen removal by immobilized microorganisms at low temperatures
(4) The Kjeldahl-Gunning method for determining nitrogen levels indicated that the mean immobilized biomass of the carrier was 35 $g.l^{-1}$ （H_2O） in the system which can improve the efficiency of the treatment.
(5) It's not necessary to supply microorganisms to IBAF system after the completion of domestication since the biological activity is not lost and it still can meet the requirements for reuse.

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Study on Groundwater Modeling in the Plains Area of Beijing
北京市平原区地下水数值建模研究

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Abstract

Based on the analysis of the hydrogeological conditions of the plain area in Beijing, the corresponding hydrogeological conceptual model of groundwater system was built. The method for determining the boundary of the groundwater system is described, and the calculation of the recharge from the mountainous area with a Soil and Water Assessment Tool is discussed. A numerical simulation model was built with FEFLOW software, based on finite-element theory and the model was then calibrated. The measures for sustainable utilization of groundwater are put forward. The results indicate: the annual average recharge capacity of groundwater is $22.98*10^8m^3$; there is potential for groundwater exploitation in the area of Pinggu while the groundwater has already been overexploited in Mihuaishun plain, the city zone and the suburbs; the countermeasures to promote groundwater should include rain water utilization, groundwater recharge, wastewater treatment and recycling, strictly enforced water saving, and reasonable development of karst water.

摘要

本文详细分析了北京平原区的水文地质条件，建立了相应的水文地质概念模型。阐述了地下水模型中地下水系统边界的确定方法，用流域水文模型 SWAT 计算山前侧渗量，采用基于有限元的 FEFLOW 软件建立了地下水流数值模拟模型，并进行了参数率定，讨论了水资源可持续利用对策。研究表明，多年平均地下水补给资源量为 22.98 亿 m^3；平谷地区地下水还有开采潜力，密怀顺平原和城近郊区地下水已过量开采。北京市水资源的可持续利用应致力于雨洪利用、地下水回灌、污水资源化、厉行节水与合理开发岩溶水。

1 Regional Hydrogeological Conditions

Groundwater is Beijing’s the main source of water in Beijing, and accounts for 80% of the total water supply in low flow years. It is very important to strengthen groundwater management, analyze groundwater recharge, runoff and discharge conditions, and study countermeasures for sustainable utilization of groundwater in order to secure Beijing’s water supply. In this paper, data on the groundwater table, groundwater exploitation, drill holes, and techniques such as remote sensing, GIS, geophysical prospecting, were incorporated to construct a groundwater numerical simulation model with FEFLOW.

1.1 Delimitation of the Beijing plains’ groundwater system

To the west and north of Beijing are bedrock mountains, and to the southeast are alluvial plains. The western and northern boundaries of the groundwater system are the shed lines between bedrock and plains. In order to calculate the recharge on the boundaries conveniently, the western and northern boundaries of the groundwater system are set on the loose formation of the quaternary system with a depth of 10 meters, where the corresponding height is 70 - 100 meters above sea level. The southeast boundary is administrative boundary showed on Fig.1. The area of region of interest is 6,214 square kilometers (Figure 1).

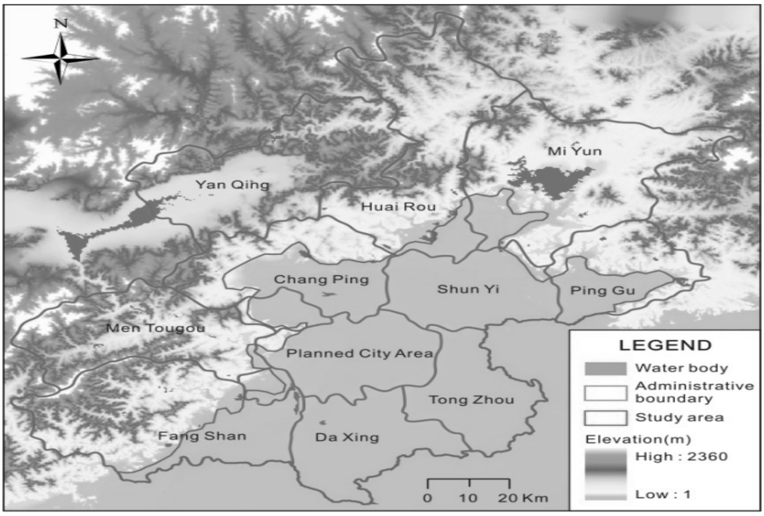

Figure1: DEM and boundaries of groundwater system in Beijing plain

1.2 Hydrogeological conditions of Beijing plains

Beijing’s plains are formed by the alluviation and diluvion of Yongding River, Chaobai River, Ju River, Wenyu river, Juma river, and Dashi river. Alluvial and pluvial fans are interbedded sediment and cutout each other, which leads to the complex lithologic characters of vadose zones and aquifers. Though the sediment depth and lithologic characters vary at different locations, the general rule is that, from piedmont to plain, sediment depth ranges from thin to thick, the skeleton grain ranges from coarse to fine, the lithologic characters range from single sandy gravel layer to polystromatic interbeds of sands and clay, the buried depth of the water table goes from deep to shallow, and the type of groundwater ranges from single phreatic water to polystromatic confined water. According to the recharge, runoff and discharge conditions of groundwater, lithologic characters, structure and the buried depth of the aquifers, the whole plain is divided into 4 subareas; piedmont, top, middle and low plains of alluvial and pluvial fans.

(1) The Piedmont area lies around the shed lines between mountainous area and plain. There is a large slope gradient, and the aquifer is mainly made up of clay and

debris from alluviation and diluvion. The depth of the groundwater table is great, and main recharge is precipitation infiltration and lateral mountain seepage.

(2) The top of the alluvial and pluvial fans is found under the piedmont area. The aquifer is mainly made up of sand, gravel and pebbles and has a depth of 3 - 5 meters, and whose conductivity is greater than 100 meters per day. The main recharge of groundwater is due to the infiltration of precipitation and river infiltration, and it belongs to phreatic water. This sub-area mainly contributes to the groundwater exploitation.

(3) The aquifer in the middle of the alluvial and pluvial fans is made up of multi-layer sandy gravel and sands. The main recharge is precipitation infiltration. It is phreatic-confined water.

(4) The aquifer in the low plain of the alluvial and pluvial fans is made up of interbedded sands with fine skeleton grain and low permeability. The main recharge is precipitation infiltration and irrigation infiltration, and the water abundance is poor.

2 Numerical Simulation Model of Shallow Groundwater

2.1 Hydrogeological conceptual model

Based on the analysis of drill holes and an investigation on groundwater exploitation, the main mining depth is less than 120 meters, covering the phreatic water and semi-confined aquifer. In the piedmont area and top of the alluvial and pluvial fans, there is only one phreatic aquifer, and one phreatic aquifer and many semi-confined aquifers in the plains area. There are no complete aquifuges between phreatic aquifer sand semi-confined aquifers. Therefore, for simplicity, they are taken as an aquifer group with the same hydrogeological parameters in the model.

All side boundaries are the second boundary, or flow boundary. The bottom board of the aquifer group is taken as the no-flow boundary. The top boundary is a free water surface where vertical water exchange takes place between the groundwater system and exterior.
The conceptual model of the groundwater system in the Beijing plains captures a heterogenous, anisotropic, non-steady groundwater flow system.

2.2 Water balance calculation

The recharges to the groundwater system come from precipitation, piedmont side seepage, irrigation water, rivers, canals and surface water bodies. The main discharge is exploitation. In all sources and sinks mentioned above, the recharge from mountainous areas is difficult to measure and calculate.

In general, there are two methods to calculate the recharge capacity of the mountainous area: Darcy's law and the water basin budget. The hydraulic gradient and the parameters of a hydrogeological cross section are required for calculating recharge with Darcy’s law. It is difficult to describe the formation of aquifers for due to lack of borehole data in piedmont; furthermore, the main recharge capacity is in rainy seasons, and it is difficult to acquire the data on the groundwater tables during this period. Therefore, the water basin budget is adopted to calculate the recharge from mountainous areas. The water balance in the mountainous area consist of precipitation, evapotranspiration, runoff, exploitation and groundwater side outflow, namely recharge from mountainous areas. The data of precipitation and runoff are from observation stations, and exploitation is acquired by measuring wells in mountainous areas. It is very important to accurately evaluate evapotranspiration related to soil moisture and vegetation. Actual evapotranspiration can be evaluated with remote sensing technology; however, it is difficult to obtain accurate data as the technology is limited by the time it takes the satellite to travel around the area. Many factors, such as weather, hydrology, vegetation, etc., are taken into account in the SWAT (Soil and Water Assessment Tool) to calculate the runoff of a watershed (Arnold, et al, 1995). SWAT is a distributed hydrological model, and several physical processes are taken into account; precipitation, evapotranspiration, canopy interception, depression interception, and soil infiltration, and so on (Neitsch, et al, 2002). A serial of daily rate of evapotranspiration can be obtained with the SWAT model.

As precipitation descends, it may be intercepted and held in the vegetation canopy or fall to the soil surface. Water on the soil surface will infiltrate into the soil profile or flow overland as runoff. Runoff moves relatively quickly toward a stream channel and contributes to a short-term stream response. Infiltrated water may be held in the soil and later evapotranspire, or it may slowly make its way to the surface water system via underground paths. The potential water movement pathways simulated by SWAT are illustrated in Figure 2.

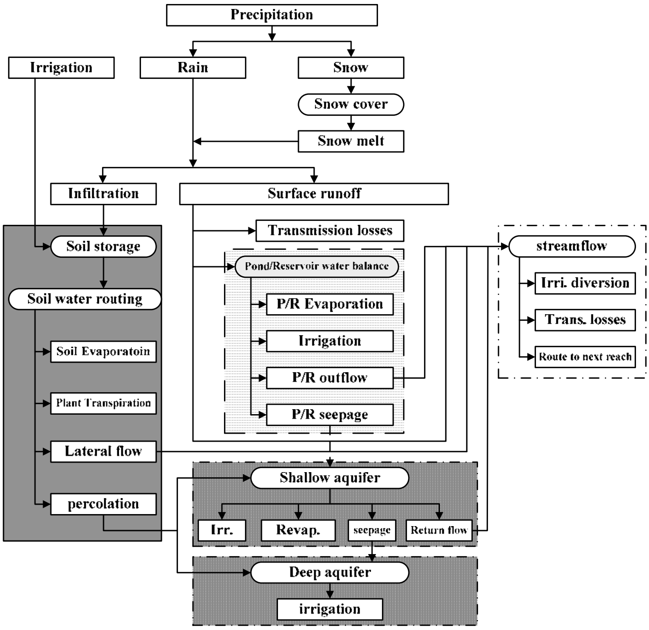

Figure2: Schematic of water movement pathways available by SWAT

When the water storage of a soil profile is greater than its field capacity, and the underside soil profile is unsaturated, infiltration takes place. The final rate of infiltration is equivalent to the saturated hydraulic conductivity of the soil. Water percolating past the bottom of the root zone is partitioned into two fractions-every fraction becomes recharge for a phreatic aquifer or a confined aquifer. In addition to the base flow, water stored in the shallow aquifer may replenish moisture in the soil profile in very dry conditions or be directly removed by plant. Water in the shallow or deep aquifer may be removed by pumping.

Evapotranspiration includes evaporation from rivers and lakes, bare soil, and vegetative surfaces; evaporation from within the leaves of plants (transpiration); and sublimation from ice and snow surfaces. The model computes evaporation from soils and plants separately as described by Ritchie (1972). Potential soil evaporation is estimated as a function of potential evapotranspiration and leaf area index. Actual soil evaporation is estimated by using exponential functions of soil depth and water content. Plant transpiration is simulated as a linear function of potential evapotranspiration and leaf area index.

2.3 Groundwater numerical simulation model and its validation

The methods for groundwater modeling include mainly finite elements and finite differences, whose representative software are FEFLOW and GMS, respectively. In this study, FEFLOW from WASY is adopted to model groundwater flow in the Beijing plains area. The merits of FEFLOW are its friendly user interface, handy operation and convenient output (HE Guoping, et al, 2003).

The parameters of the aquifer are generally hydraulic conductivity and specific yield. The equivalent permeation tensors for each borehole are based on lithology and the weighted average thickness of borehole. Then, the distribution of equivalent hydraulic conductivity in the whole study area is obtained by Kriging interpolation techniques, which is used as the initial value of hydraulic conductivity in the FEFLOW model.

To build a reasonable numerical stimulation to describe the real behavior and state of aquifers, the FEFLOW model must be calibrated and validated. The main principal principles are that the contour of groundwater level or dynamic characteristics of groundwater from FEFLOW model should be basically consistent with the measured data, that the groundwater budget in the model should reflect the actual situation， and that the parameters in the validated model should be consistent with the local hydrogeological conditions. The simulation period of the model was from 2000 to 2003 and30 observation wells were adopted to calibrate the model.

3 The Application of Groundwater Simulation Model

3.1 Water budget analysis

There were continuous low flow years from 2000 to 2003. The amount of precipitation from 2000 to 2003 was 386.7, 434.1, 425.5 and 486.5 mm, respectively， and the amount of recharge was 1.70、1.87、1.88 and 2.03 billion m^3。The proportion of recharge from the precipitation was more than 40%, and one of recharge from mountainous area seepage is more than 20%. The main discharge of groundwater system was exploitation. The discharge of groundwater system was mainly under artificial exploitation conditions, which accounts for over 95% of the total discharge.

The water budget of groundwater system from 2000 to 2003 is -0.77, -0.60, -0.60, -0.44 billion m^3, respectively, and decline of average groundwater table is 1.53, 0.19, 1.09, 0.83m, respectively.
The annual average recharge of groundwater is 2.30 billion m^3 in the Beijing plains area.

3.2 Exploitation potential analysis

Exploitation potential index *P* is used to analyze the regional exploitation potential, and *P* is defined as follows:

$$P=Q_1/\ Q_2$$

Where, *p* is exploitation potential index (dimensionless), Q_1 is annual average amount of allowable groundwater exploitation, and Q_2 is the amount of groundwater exploitation at present.

Connecting with groundwater dynamic, the Being plains area is divided into three zones on the basis of *P* value.

(1) Exploitation potential zone
It includes Pinggu and Changping. The *P* in Pinggu is equal to 2.2. The amount of groundwater exploitation in Pinggu in 2000 is 0.12 billion m^3 and the amount of annual average recharge is 0.26 billion m^3. The *p* in Changping is 1.3. The amount of groundwater exploitation in Changping in 2000 is 0.18 billion m^3 and the amount of annual average recharge is 0.24 billion m^3.

(2) Groundwater balance zone
It includes Tongzhou, Fangshan and Daxing, where recharge of groundwater is approximately equal to discharge, and the *p* is from 0.8 to 1.2.

(3) Overexploitation zone
It includes Miyun-Huairou-Shunyi plain area, urban area and suburb area, where the discharge of groundwater is greater than recharge, and p is less than 0.8.

4 Countermeasures for Sustainable Utilization of Water Resources

On the basis of above analysis, the recharge capacity of the groundwater system in Beijing is less than its discharge capacity. The contradiction between water supply and water demand is very serious in dry years. There was a fall of 8.12 meters in groundwater table, and 4.157 billion cubic meters in groundwater reserve from 1980 to 2000. Before the south-north transfer of water into Beijing, it was important to use reservoirs as aquifers to ensure a safe water supply and a sustainable development of society and economy.

(1) Build emergency groundwater well-fields to ensure the safety of Beijing's water supply
Emergency groundwater well-fields are not implemented until the water supply is

insufficient during the dry years. As emergency well-fields consume static reserves from aquifer, they must be located where depth of the aquifer is thick, conditions of reserves are good and recharge is sufficient. At present, there are three emergency well-fields; Huairou, Pinggu and Zhangfang. These emergency well-fields were designed to have a yearly output of 0.12, 0.1, and 0.07 billion cubic meters, respectively. The Machikou emergency well-field, designed to have a yearly output of 0.04 billion cubic meters of is under construction.

(2) Carry out rain and flood water utilization, artificial groundwater recharge, build a groundwater reservoir, and jointly utilize surface water and groundwater.
Compared with surface water reservoirs, groundwater reservoirs possess many advantages, such as wide distribution capabilities, strong potential for regulation, and the provision of good quality water. The depth of aquifer in the city zone, suburbs and Mihuaishun plain is thick, and the aquifer is mainly made of sandy pebbles and coarse sands. In the past twenty years, groundwater has been continuously over-exploitated, and the groundwater reservoirs have large storage capacities, which is good for groundwater recharge projects. The Wenyu River Water Resources Utilization Project under argument aims to make the most the Wenyu River water resources by transferring water from the Wenyu River to the Chenbeijian River during the flood period and performing treatments before flowing into the Chaobai River. Firstly, it will improve the increasingly worsening state of the environment due to a lack of water from the Chaobai River. Secondly, the local groundwater will be replenished, and land subsidence will be more under control. Based on preliminary studies, 80-90% of water transfers will recharge the groundwater, and yearly recharge is greater than 0.03 billion cubic meters. The project is not only good for addressing the lack of local water resources, but also an example of sewage reclamation.

(3) Establish reasonable water prices, and strictly enforce water saving
Currently, under the current status for a water shortage the guideline for water utilization is set down, and it is “compress agricultural water, control industrial water, ensure domestic water and increase water use for environment”. The effect of the guideline is obvious. Big changes have taken place in the composition of water utilization over the past 5 years, and water efficiency has increased greatly. Industrial output value has preserved rapid growth over the past 10 years, but industrial water has continued to decrease. Compared with developed countries, there is potential for saving industrial water. In terms of agricultural water use, efficient water irrigation was utilized for 82% of the total farm land in Beijing, among which, more than 50% of farms are irrigated by sprinkling irrigation and drip irrigation technology. But agriculture is still the biggest user of water, and thus the structure of agriculture should be adjusted. Although Beijing has made many achievements regarding water saving, water continues to be wasted. The current tasks will be to raise civil consciousness on issues of water saving and establish reasonable water prices that are suitable for the development of society as a whole.

(4) Promote the reuse of sewage and expand the use of recycled urban sewage
Water for industrial use, agricultural irrigation, environmental sanitation and urban

landscaping, which requires a lower water quality, accounts for more than 60% of total urban water use. This is a promising field for treated water. At present，the annual amount of wastewater from Beijing is about 1.1 billion m^3. In 2005, the total amount of reused, treated water was 0.26 billion m^3, of which 0.12 billion m^3 was used for agriculture irrigation. The amount of reused treated water will be 0.6 billion m^3 in 2008. This technology could be popular given its low cost, steady water flow and easy access. The reuse of treated water increases the utilization efficiency of water and is a countermeasure against the use of karst aquifers which will benefit the sustainable development of a water-scarcity city.

(5) Increase exploitation and utilization of karst water

The area of carbonate rock in Beijing's mountainous areas totals 2900 km^2. Experts believe the annual recharge of karst groundwater to be about 0.5 billion m^3, while the annual amount of exploitation is currently only at 0.15 billion m^3. Karst groundwater is an important reserve of water with the valuable characteristics of rarely being contaminated, provides a stable source of water as well as other beneficial qualities. Therefore, a reasonable plan for the exploitation of karst groundwater would be exploit karst water for water-scarcity Beijing. On the basis of hydrogeological investigations, the karst water found in front of mountains where karst fissure are developed, had good recharge conditions and could be effectively exploited. On the other hand, karst water found on the plains, where recharge is more limited, should not be exploited.

5 Conclusions

The hydrogeological conditions of Beijing's plains areas were analyzed in detail, and a groundwater numerical simulation model was built. On the basis of the calibrated model, an evaluation of groundwater resources was carried out. Finally, the strategies for reasonable exploitation of groundwater were discussed.

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The Application of SAT to Wastewater Treatment

SAT 技术在污水处理中的应用

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Abstract

In order to investigate the influence of SAT on the quality of groundwater, this paper examined gray water (the secondary effluent was treated by coagulation, sedimentation and sand filtration) from the Gaobeidian WWTP in Beijing as a case study. The grey water was pretreated by GAC adsorption and the effluent from the GAC treatment process flowed through the SAT system. The water quality monitoring at observation wells at various distances from the recharge field showed that the SAT achieved perfect removal of organic matter, ammonia, nitrogen, nitrate-N and pathogenic microorganism , however the TDS concentrations increased.

摘要

为了考察土壤含水层处理工艺（SAT）对地下水水质的影响情况，以北京高碑店污水处理厂中水（水厂二级出水经混凝、沉淀、砂滤后的出水）为处理对象，用活性碳吸附工艺作为 SAT 的预处理工艺，活性碳出水进入 SAT 系统，通过对距离回灌池不同距离观察井中的水质监测后，发现 SAT 对水中的有机物、氨氮、硝态氮以及病原微生物均有较好的去除效果，但出水中的 TDS 有所增加。

1 Introduction

Inadequate water supplies and deterioration in water quality represent serious contemporary concerns in many parts of the world, particularly in relation to economic and social development. One of the solutions to these problems is the reuse of wastewater. Prior to reuse, wastewater was treated at treatment plants to the required standards of quality. Present advanced treatment technologies are capable of treating wastewater even to potable standards, but the cost of advanced wastewater treatment is high.[1] Underground water recharge based on SAT can enhance recycled water quality. The SAT can not only prevent the decline of ground water table caused by over exploitation[2] but also cost less than other methods.

The SAT system is widely used for wastewater treatment in the USA and other countries throughout the world. After 20 years of operation and extensive study, no measurable impact on groundwater quality or human health was reported in Los Angeles (Nellor *et al.*, 1985). In order to investigate the mechanism of SAT and check the reliability of SAT system as applied in China, a pilot SAT system was established in the Gaobeidian WWTP in Beijing. Coagulation and precipitation of the secondary effluent from the WWTP was treated by applying GAC infiltration and the treated wastewater ultimately went through the SAT system. The emphasis was put on the water quality from the Unsaturated Zone, aquifers and groundwater.

2 Materials and Methods

2.1 The experimental system

The SAT system consisted of the pretreatment equipment (which included coagulation, sedimentation, GAC infiltration and the ozone oxidation), the sand filtration tank, the recharge well, the pumping well and the observation well. The depth of the sand filtration tank was 1m. The effluent from the sand filtration tank was collected by pipelines and connected to the recharging well located in aquifer through gravity flow. The total area of the three recharge tanks was 400m^2. Five observation wells were installed. Observation well #6 was located in the middle of the recharge tank and wells #1, 3, 4, 5 at rectilinear distances of 40m, 60m, 70m and 80m from well #6. The intake depth of observation well #2 reached the second aquifer. The profiles of the wells are shown in Figure 1.

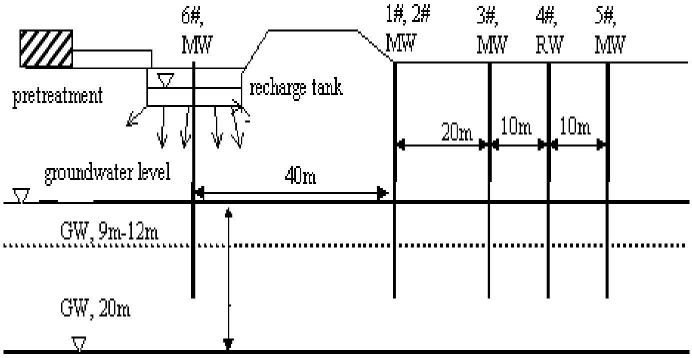

Figure 1: Simplified vertical transect showing the position of the observation wells and reuse wells

2.2 Wastewater and soil conditions

Table 1 gives the secondary effluent quality from the Gaobeidian WWTP during the experimental period.

Table 1: Secondary effluent quality during the experimental period

Sample	DOC mg/L	UV254 m^{-1}	SUVA m^{-1}/mg/L	PO_4^+-P µg/L	NO_2^--N+NO_3^--N mg/L	AOX µg/L
Secondary effluent	7.0	13.99	2.0	1549.81	15.5	43.97

The Unsaturated Zone in the Gaobeidian district was 9.6m deep, and covered by 1m of soil on the top. The unsaturated zone was composed of powdered clay and powdered silt had a uniform texture. Under the unsaturated zone was a thin layer of fine sand. The brownish-yellow color of the zone showed good ventilation and that aeration conditions were satisfied. The gray layer was 9.4m deep and indicated that the soil was saturated and part of the alternation zone of phreatic groundwater layer. The phreatic groundwater layer was 7.9m deep but with depths that range from 7.6m to 17.5m, and which consisted of 4.4m of fine sand in the upper layers and 3.5m of round gravel in the lower layer (Table 2）.

Table 2: Soil conditions at the test site

depth(m)	thickness(m)	Soil character	category	void ratio
0-9.6	9.6	Soil in the uppper layer, powdered Clay in the lower layer, powdered silt in the middle layer	unsaturated zone	0.591
9.6-14.0	4.4	Fine sand	aquifer	0.632
14.0-17.5	3.5	round gravel		/
17.5-24.8	7.3	powdered clay and powdered silt	isolation layer	0.678

2.3 Results and discussion

TN

The TN concentration in gray water was 25-30 mg/L. 2-4 mg/L TN was removed by the GAC and sand filtration. The TN concentrations in well #4 showed a decrease in effluents to about 5mg/L. The results indicated that the SAT could be removed from the TN effectively and obviously decreased the TN in the effluent.

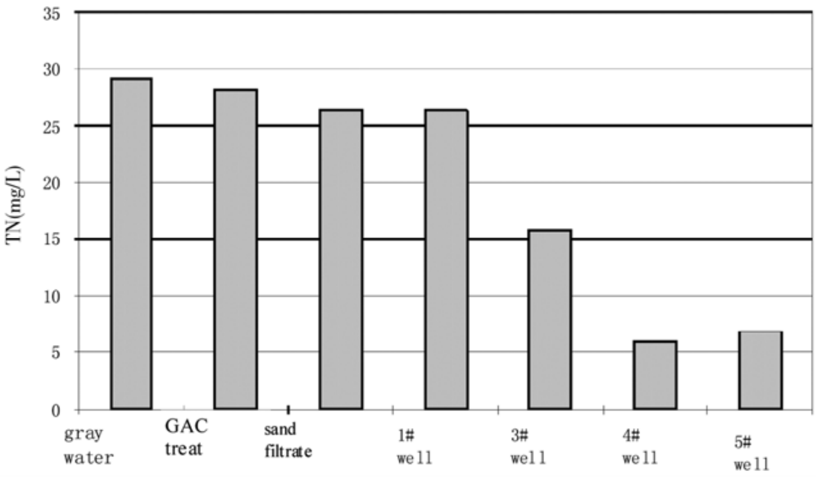

Figure 2: Efficiency of TN removal

Ammonia, Nitrogen and nitrate

The nitrogen removal capacity of the unsaturated zone was related to the water quality of the recharge water, soil characteristics and the operational conditions. The COD (chemical oxygen demand) for removing ammonia and nitrogen is very low due to the low ammonia and nitrogen concentrations in the influent water of SAT system. The removal rate of nitrate in the unsaturated zone is around 30%.

TDS

The total dissolved solids increased after SAT, predominantly due to the leaching of salts from the unsaturated zones and the dissolving of the salt in the aquifer. Otherwise, the evaporation and transpiration in the dry climate of Beijing caused the salt enrichment in the soil. The nitrate in the influent water was another reason for the TDS increase (Figure 3).

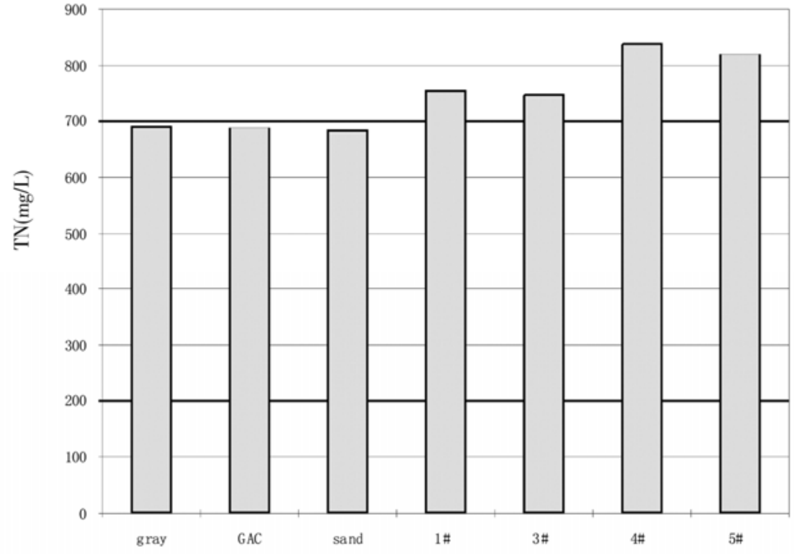

Figure 3: Efficiency of TDS removal

DOC

The SAT can partially remove DOC. The DOC removal efficiency and the DOC effluent in well #5 were 37.7% and 2.6mg/L respectively (Figure 4). The DOC concentrations in the different wells decreased the greater the distance from the recharge tank. The mechanism of organic degradation in the unsaturated zone was biological degradation and physical adsorption, but the biological degradation was the significant removal mechanism. 65% of the residual refractory compounds were not biodegradable during SAT and were similar to humic and fulvic acids and had probably formed in the activated sludge treatment or were already present in the drinking water [3]. Much more attention should be paid to the concentration of DOC than other pollutants.

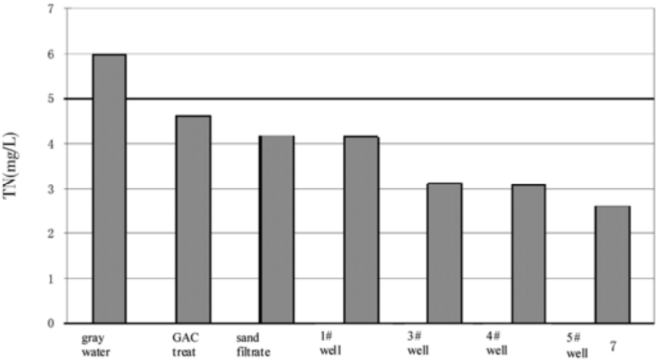

Figure 4: Efficiency of DOC removal

Bacteria

The removal efficiency of pathogenic bacteria was satisfactory in the unsaturated zone. According to the disinfection data, the total bacteria count and the total fecal coliforms in well #6 satisfied potable water standards. The total bacteria count and the total fecal coliforms in the gray water was 10^4-10^5/mL and 10^4-10^5/L, respectively. 99.9% of the total bacteria count and the total fecal coliforms were removed at a depth of10m in the unsaturated zones. The expected reason for the efficient removal of bacteria was the large specific surface area of the fine soil which had a strong adsorption abilities and a slow recharge velocity.

The fecal coliforms were found in the aquifer; therefore the reused recharge water should be disinfected according to the reuse purposes and effluent quality.

AOX

AOX (absorbable organic halogens) indicated the organic chlorine, bromine and iodine in the water. The levels of AOX are expressed in equivalent weight of chlorine. AOX is rarely naturally found in water. The concentrations of AOX can be used as a indication parameter on water pollution. [4] The AOX is an international water quality parameter. The AOX in the groundwater comes mainly from industry and sewage wastewater. Most of the AOX are disinfection byproducts (DBP) from the chlorine disinfection process for drinking water.

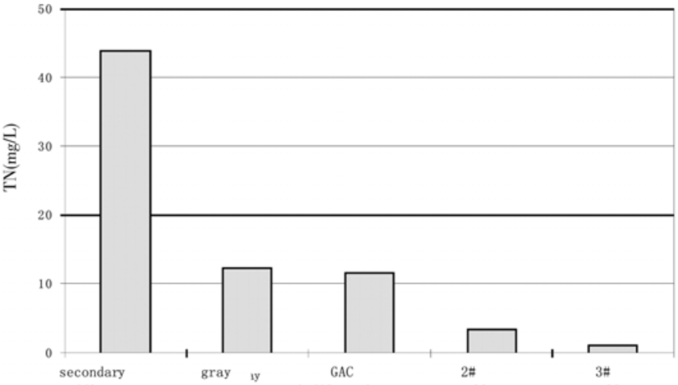

Figure 5: Efficiency of AOX removal

The removal of AOX using GAC is low, see figure 5. The weak GAC adsorption ability of the AOX is due to the strong polar compounds in AOX. Meanwhile, the GAC adsorption of AOX interfered with and competed with other polar organisms in the water, which inhibited the removal efficiency of AOX.[5] The AOX concentration in well #3 decreased to 1.12μg/L and which satisfied the recharge water standard, recommended by Tsinghua university to be 30μg/L.

Heavy metal

The concentration of heavy metal in the observation wells satisfied the potable water standards and was consistent with groundwater standards.

3 Conclusion

The reclaimed water infiltrated though the vadose zone in the SAT system. The water quality improved due to removal mechanisms in the soil that included filtration, biological degradation, physical adsorption, ion exchange, and precipitation. These mechanisms can be effective at removing nitrogen, phosphorus, biochemical oxygen demand (BOD), suspended solids, organic compounds, trace metals, bacteria and viruses. TDS increased after SAT predominantly due to the leaching of salts from the unsaturated zones, evaporation and transpiration.

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Technology for Prevention and Control of Eutrophication in Rivers, Lakes and Reservoirs
河湖水库副营养化防治技术与方法

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Abstract

Prevention and control of eutrophication in bodies of water is a hot topic globally and it is also one of the main issues facing water conservation efforts in Beijing. The article summarizes the approaches and experiences with prevention and control technologies for eutrophication in rivers, lakes and reservoirs, both at home and abroad, classifies the technologies and introduces in detail the principles, characteristics and application of physical, chemical, biological and integrative technologies for prevention and control of eutrophication in rivers, lakes and reservoirs in Beijing, which provides a reference to the technicians and managers in the fields of water conservancy and environmental protection.

摘要

水体副营养化防治是世界性的热点与难点问题，同时也是当前北京市水利工作的一项中心工作。本文概述了国内外河湖水库副营养化防治的技术途径与基本经验，对河湖水质改善技术进行了归纳与分类，并详细介绍了适宜于北京市河湖水库副营养化防治的物理类、化学类、生物类与综合类技术的原理、特点与应用，可供水利与环境领域技术与管理人员借鉴参考。

1 Introduction

Under conditions of rapid economic development and urbanization, more and more untreated wastewater and wastewater that does not meet standards, flows from residential communities and industrial areas into bodies of water resulting in a continual increase in nutrients. Furthermore, non-point pollution makes the situation even worse. According to the survey from national authorities, 75% of lakes and 90% of rivers in China are facing different water pollution problems. The high nutrient content has lead to 56% of lakes, such as Chao Lake, Tai Lake, Dianchi lakes, and some rivers to suffer from eutrophication problems. The result of the eutrophication will be explosions of algae, a disruption of the water's original ecological system, a decrease in the water body's functions and this situation has already been impacting global economic and social development.

In recent years, eutrophication has been occuring in water bodies in Beijing due to a decrease of inflow from upstream and reduction in the purification function of water bodies themselves. The explosion of algae since 2001 led to a campaign on pollution control in Beijing's bodies of water.

2 International Technologies for the Control of Water Pollution

The problem of water pollution exists in almost all lakes and water bodies in the world that are facing the challenge of algae outbreaks. The removal of nutrients requires relevant technologies and large financial investments over a long time period. The USA, Japan, Germany and Sweden and other developed countries have been taking measures to control eutrophication. Some positive results have already been achieved. Using pre-treatment processes to collect and remove nutrients through the large-scale WWTP it is possible to efficiently avoid or reduce the threat of eutrophication.

Most of lakes on the plains and tablelands in China have various degrees of eutrophication problems, especially the scenic lakes near cities, which badly need to be controlled. The Chinese government has invested lots of manpower and finances into pollution prevention and control strategies on the West Lake in Hangzhou, Dianchi Lake in Yunnan and Tai Lake in Jiangsu province, among which, the West Lake has been dredged twice and diluted by diverting water from Qiandang River. The daily influent water volume is equal to 1/33 of total water volume of the West Lake. A positive result is expected in the near future in contrast to the control measures in Dianchi Lake and Tai Lake which were very slow despite the technical measures.

Taking prevention methods for unpolluted lakes and for lakes that are already experiencing eutrophication is the general consensus amongst professionals based on several studies.

2.1 Control of nutrient input

It is no doubt that the input and accumulation of nutrients in lakes are the main reasons for the explosion of algae. The methods for the prevention of nutrient input include wastewater treatment (Sweden, Germany, Australia, Finland and USA), oxidation pond technology (former USSR), land treatment systems (USA), biological dephosphorization (USA), pre-storage methods (Germany), limitation of phosphorus content in synthetic detergent (European union, Japan and Canada), new environmental standards for nutrients (Japan) and water plant filtration (Japan, China).

2.2 Nutrient removal from water bodies

For lakes and reservoirs experiencing eutrophication, they should not only control the input of nutrients, but should also remove nutrients. The methods include, deep water ventilation (North America, Denmark, Sweden, Germany, Austria, Japan), phosphor sedimentation and sediments sealing (USA, Sweden, Holland, Canada, Austria), dilution and washing (USA, Canada), deep layer water abstraction (Poland), choice discharge (USA), covering the bottom of the lake with boulders (USA), water level control (USA, Austria).

3 Algae Treatment in Bodies of Water

The physical and chemical measures for algae treatment after an explosion of algae in a body of water include, direct filtration for the removal of algae (Germany), ventilation to removal of algae by ventilation (South Korea), chemical medication method (USA, Austria, Dianchi Lake (China)), fisheries (Wuhan's east Lake, Tai lake), mechanical algae removal (USA), microorganism methods (Dianchi Lake) and so on.

4 Classifications of Water Body Control Technologies

The target of the pollution control was to reduce contamination and nutrients, to strengthen the purification capacity of a body of water so that it can balance nutrients levels as well as try to destroy the growth environment conducive to algae. All methods can be classified into four categories.

Physical method: using physical methods to separate pollutants from water or creating corresponding environments to restrain the growth of algae, which include oxidation methods, water movement methods, physical absorption, micro-filtration methods, ventilation methods, water exchange and mechanical harvest method and so on.

Chemical method: separating and reclaiming pollutants from a water body through chemical reactions or creating an environment to limit and kill algae, and which includes chemical phosphor elimination and chemical algae removal methods.

Biological method: converting the dissolved, colloid pollutants into stable and harmless matters by using the metabolizing function of biology or by creating conditions for algae removal, which include aquatic plants recovery methods, floating plants bed methods, fishery control methods, microorganism preparation and biological oxidation methods.

Integrated method: converting the dissolved, colloid pollutants in bodies of water and sediments into stable and harmless matters through integrated physical, chemical and biological methods or through preconditioned creations of algae removal, which include pre-reservoir methods, shallow water zone methods and constructed wetland methods.

5 Principals,Characteristics and Applications of the Technologies

5.1 Physical technologies

5.1.1 Aeration technology

The aeration technology aims to increase the concentration of DO in a body of and to mix dissolved oxygen with the body of water sufficiently, furthermore, providing the oxygen needed for biological growth in order to achieve water purification. This technology is suitable for stable bodies of water or low, flowing bodies of water with low DO concentrations under 4mg/L normally. The aeration technology can raise DO concentrations rapidly so that the removal rate of organic matter and NH4-N can be 50% or above. The efficiency indicator for estimations on aeration equipment is the oxygen transfer rate and oxygenated power-efficiency, for instance, the power consumption rate for eutrophicate water should be kept at more than 2.0kgo$_2$/KW·h. The relevant aerators include blast aeratior, mechanical aeratior and jet aeratior. At present, the mechanical aerator has been installed in rivers and lakes, such as in Beijing's northern river.

5.1.2 Water movement technology

The technology is meant to increase the movement of water pushed by press equipment in water, to increase DO concentrations, which can restrain the growth of algae cells for algae control.

The technology has the following advantageous characteristics: reliable, little noise, easy maintenance and no secondary pollution. The disadvantage is that it has a high-energy consumption. This kind of technology requires a stable water body, a water level range between 1.5m and 2.5m, to strength the internal water movement.

5.1.3 Physical adsorption

The adsorption technology is a technology that uses porous media to adsorb one or many kinds of contaminants during the treatment process. The force of the molecules plays a main role, even in normal and low water temperatures, it does not consume power, is easy to operate and maintain, and usually used for bodies of water with high organic content and NH4-N concentrations or low, movable bodies of water, but the adsorbing material will reach its saturation point after adsorbing a certain amount of pollutants.

The active carbon and zeolite are often used as an adsorbing material for the prevention of eutrophication, because the activated carbon has a high surface area with a range of 500—1700m^2/g, good for the removal of organic matter and nutrients. The zeolite is easy to get in nature with high removal capacity of NH4-N, which has already used in north city river of Beijing.

The physical adsorption mainly removes the organic matter and inorganic nitrogen as well as heavy metals such as Fe, Mn, As and sulfate. The removal rate for stable water bodies can reach 40%.

5.1.4 Air flotation technology

The air flotation technology is a technology for the separation of liquids and solids. The air flotation equipment can generate large amount of micro bubbles. These bubbles conglutinate to solid or liquid particulate pollutants that have a similar density to the water and become floating bodies with lower densities than that of water and float on the surface of water for the separation process.

The advantage is the ability to gather lots of suspended solids in a body of water, especially the collection of algae, which is suitable for bodies of water with certain suspended solids, colloid matter or low, movable bodies of water..

The ventilation technology classifies into dispersion and dissolvable technologies, which need structured designs for large open water areas. The technology is helpful for the removal of nutrients.

5.1.5 Internal water exchange technology

This technology promotes internal water exchange between surface water and bottom water using mechanical equipment. The rising bottom water mixes with the surface water then the water temperature rises and the water diffuses simultaneously diffuses horizontally to change the anaerobic water conditions so pollutants can be degraded in process. The rising bottom water would lead to a decrease in the surface water temperature and restrain the speed of growth for algae cells. Parts of the algae get into deeper water, but their ability to survive in that environment causes them to die and therefore eutrophication will be improved.

The characteristics of this technology are: simple principals, simple equipment, easy to operate, no secondary pollution, and able to be used to control the water quality of deep water bodies such as lakes or reservoirs.

5.1.6 Mechanical algae harvest technology

The mechanical harvest equipment consists of a device for collecting floating algae, a filtration device, a storage device, and a power supply device, as well as a control part. After they are collected by harvest equipment, the floating algae are pumped into rotary filter for primary dewatering. Then the compressed algae are stored in collection tank and transported to belt press filter for further dewatering and then transported to landfill site.

The technology used to control the large-scale algae explosion is easy to operate and has no negative impact, but the cost is relatively high. It is suitable for the pre-treatment of reservoirs, lakes, drinking and industrial water.

5.2 Chemical technology

5.2.1 Chemical phosphor elimination technology

There are three kinds of chemical materials used for the elimination of phosphor;, lime, AL^{3+} and Fe^{3+}. The phosphate converts into hydroxyl phosphorite sediment after reacting with lime. Aluminum sulfate reacts with phosphate, converting phosphoric aluminum sediment. The iron ion material has iron trichloride, iron protochloride, iron sulfate and so on, which forms iron phosphate for sedimentation after its reaction with phosphate. The high rate of phosphor removal can reach more than 85%.

The advantage of the chemical phosphor elimination is that it can remove the dissolved and colloid phosphates, adaptto stable bodies of water, lakes and reservoirs, but its disadvantage is its high cost and the possibility of secondary pollution. This technology is banned in protected drinking water areas.

5.2.2 Chemical elimination of algea

The technology provides an easy way to use chemical materials to kill algae during the oxidation process of the chlorphyII-A cells or during the destruction process of the algae’s cell functions. The efficiency of the chemical algae elimination technology can be seen in 1 day or several hours, but it is difficult to get long term results therefore, this technology is usually used for emergency situations in algae aggregation zones or in low, flowing bodies of water.

5.3 Biological technologies

5.3.1 Technology for the recovery of aquatic plants

The aquatic vegetation consists of submerged plants, floating leaf plants, floating plants, wet plant communities and so on. The aquatic plants have important functions, like terrestrial plants. In the shallow lakes, the aquatic plants are not only part of preliminary productivity, but can also improve the water quality, create beautiful scenery and maintain the water's nutrient balance..

The recovery process for aquatic vegetation is done by rebuilding the system combined with existing aquatic vegetation, including the restoration of lake environments and rebuilding aquatic vegetation. The pre-condition for using this technology is that the nutrient input has to be controlled. It is a systematic project and needs multi-disciplinary cooperation.

5.3.2 Floating plant bed technology

The floating bed technology was used early on for growing rice. Given the adsorption of the rice roots, the water quality improved, which provided a scientific foundation for eutrophication control later on.

Besides adsorption, restriction of algae and the settlement function of terrestrial plants, the terrestrial plants have high productivity with a higher content of dry matter, 1.5 times more than aquatic plants, hence, it has good efficiency at improving water quality. For instance, Canna, dry umbrella grass, balsamroot grass and hollow vegetables are usually used in areas around Beijing.. In contrast, the floating bed of plants has an impact on transportation and flood control yet complex implementation requirements remain a disadvantage.

5.3.3 Microorganism preparation technology

The microorganism preparation technology chooses effective bacterium for wastewater treatment, based on enzyme reactions. As an activator, the special protein produced in microorganisms can degrade sediments and reduce the effluvium to improve quality.

The microorganism agents can increase the concentration of microorganisms in wastewater to raise the degradation rate of microorganisms; in addition, the investment of this technology is relatively lower with effective removal rates and easy operation. Keeping the water quality high requires continual input of the agents. It is suitable for stable and low, flowing water body.

5.4 Integrated technology

5.4.1 Shallow lake technology

The shallow lake area is a transition zone between aquatic and terrestrial environments, consisting of a bank zone, water level change zone and a shallow water zone.

Based on the field survey, zone function classification and estimations of environmental indicators, reconstruction of artificial structures would be able to restore the degrading ecological system and restore balance to the system. The design includes basement design, the choice of plants, biological community construction, growth period design and scenery design. Balsamroot grass, reed and cattail have been used as vegetation in lakeside zones and have been used in general with a width range of 30 to 50m.

5.4.2 Constructed wetland technology

The quality of wastewater after treatment by wetlands would improve due to the multiple functions of the wetlands. Wetlands, as combination ecological systems, integrate the functions of plant adsorption, substrates adsorption, sedimentation by chelation and microorganism degradation. It is a substrates-plants-microorganisms ecosystem, which combined the physical, chemical and biological purification functions. It is subdivided into natural wetland and constructed wetland.

Estimated as an effective technology, wetland have low investment and operation requirements, are easy to maintain, but the disadvantage of this technology is it requires large areas so it can be used to purify polluted rivers where both sides extend of the river extend widely.

Urban Rainstorm Harvesting Application in Beijing
北京城区雨洪利用的实践及探讨

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Abstract

Beijing is a megacity with a water shortage. Due to the uneven yearly distribution of rainfall, and rapid urbanization, drainage and flood controls in Beijing are under threat. This paper analyzes the domestic and international rainstorm harvesting technologies, as well as the problems of rainstorm harvesting in Beijing. It also deals with utilization principles. To combine the relationship of rainfall and runoff, the relationship between water quality and quantity, hydrological conditions, the paper points out the typical models and key technologies for the beneficial use and recharge, in order to apply rainstorm harvesting technologies widely.

摘要

北京是水资源短缺的大都市。由于降水量年内和年际间分布极不均匀，以及城市化进程加快，给城市排水和防洪构成巨大压力。本文研究了国内外雨洪利用的技术，分析了当前北京城市在雨洪利用方面存在的问题。探讨了城区雨洪利用的原则。结合北京城区降雨径流关系、水质与水量规律、水文地质条件，具体提出了城区代表型下垫面及雨水的市政杂用、入渗回灌等典型模式和关键技术。旨在推动雨洪利用技术的进一步深化和广泛应用。

1 Introduction

Beijing is a megacity with a water scarcity. The per capita renewable water resources are less than 300 m^3. The growth of the city and increase in living standards increased the gap between supply and demand. Additionally, because of the continuous dry and lowered water table, water resources are bottlenecked for the city.

Influenced by topography and climate, Beijing’s yearly rainfall is extremely uneven. 80% of rainfall occurs during the flood season. The maximum annual rainfall is 4 times that of the minimum. According to the statistics, the outflow of Beijing in recent years was 840 million m^3 per year and the floods out of Beijing were 216 million m^3, nearly 6% of the total rainfall.

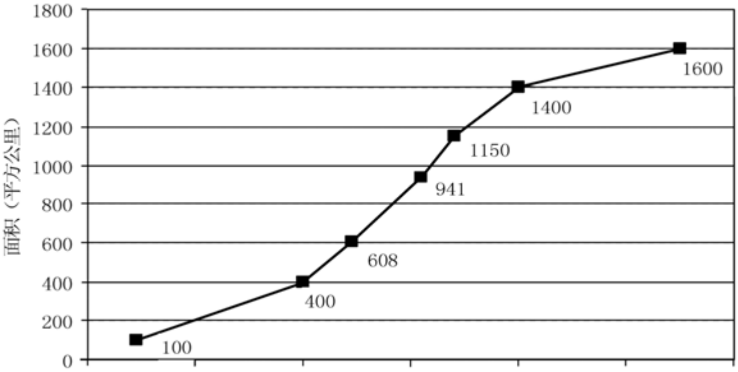


Figure 1: Construction land 1949-2050

Meanwhile, due to urbanization, impermeable surface areas have greatly increased. Based on the 'Strategic Study on Special Development of Beijing', constructed land areas extended extensively, especially since 1996. Considering the ongoing development opportunities, urbanization will keep increasing. According to estimates, construction will cover 1150km^2(as shown in Figure 1) in 2008. Because of the increased impermeable areas, the comprehensive runoff coefficient increases as result, the flood peak is advanced and floods increase. Taking the data from the Yuejia Huayuan Hydrological Station as an example, the flood peak was 246 m^3/s when the rainfall in the city was 100mm on July 10, 2004 whereas, the flood peak was only 166 m^3/s when the rainfall in the city was 120 mm on July 21, 1959 and the runoff coefficient increased to 0.6 from 0.45. The previous rainstorm resulted in a discharge of 1 million m^3 of sewage water and 1.5 million m^3 of rain water which made water resources useless and caused pressure on urban drainage and flood control. In addition, the shape of the current cross-sections of urban river systems was basically settled, and which restricts change or expansion of the river system thereby limiting the increase of runoff from urban rainfall.

It is very important to use the rainstorm water resources to address the water shortage, recharge ground water and provide safety from flood events.

2 Conditions For Rainstorm Harvesting

2.1 Foreign Rainstorm Harvesting Technology

In many countries, rain water is called 'Sky Juice'. There are millions of hits on Google related to rainstorm harvesting (hereafter called "RSH"). In Africa, RSH is considered a good way to approach solving the water shortage problem. For example, 6 RSH projects were constructed from 2002, and some benefits were recorded. In some developing countries, RSH attracted a lot of attention. For example in Sri Lanka, RSH projects were beneficial to municipal and sanitary projects, 15 thousand RSH system are operating, and new technology is being explored.

RSH in developed countries has the following characteristics: a long history of research and study, appropriate technologies, as well as specific laws, and rules. In Germany, rainwater is collected by a public system, and treated to meet certain standards, and then used for toilets and irrigation. Meanwhile, rules stipulated that certain RSH projects should be constructed at the same time as new buildings.

2.2 RSH in Beijing

RSH in Beijing has a long history. There are many RSH projects in ancient buildings and parks. The typical example is in Tuancheng in Beihai Park. Tuanchen is an area of higher land, 4.6 meter above the ground. Although there is no rrigation system, the trees are luxuriant and numerous. The oldest trees are over 800 years old. The ground is paved with deep blue, trapezium bricks. The drainage system is made by the surface slotsamong the bricks and underground tunnels. Rain water can penetrate the bricks into ground, for the trees.

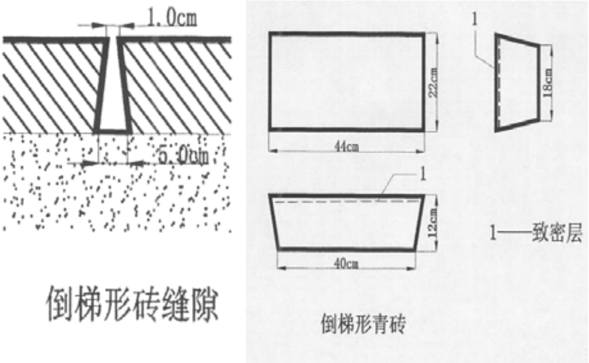


Figure 2: Bricks and pavement in Tuancheng

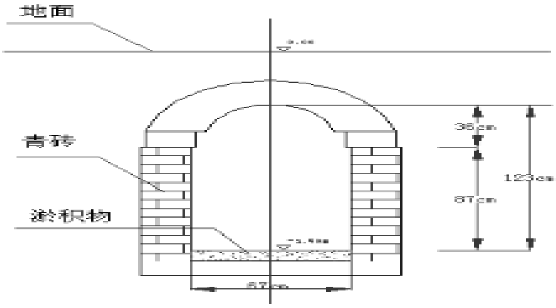


Figure 3: Underground Tunnel

Since 1949, 85 reservoirs were constructed. The total capacity of these reservoirs was 9.4 billion m^3. 70% of mountain area of where rainfall occurred was controlled by reservoirs.

In the 1990s', the Beijing Hydraulic Research Institute (BHRI) and Tsinghua University started researching the relationship between rainfall and runoff, the function of roofs and wells, the effects of low grasslands and measures of RSH. Due to the economic context, the technologies were not applied.

In 2000, BHRI, Beijing Hydrologic Center, ESSEN University and DORSCH CONSULT collaborated on a ‘Rain Water Control and Utilization’ project in the Beijing Urban Area. The objectives of the project were to analyze the hydrological and geological conditions, study the technology and equipments of RSH and build 3 different demonstrative societies.

From 1980, the Beijing Water-saving Office developed some studies on RSH, such as studies on impermeable and ventilating pavement, the storing effects of grassland, rain water quality, etc.

To apply the RSH technology, the Temporary Code for RSH of Construction Land was issued. The collection, penetration, storage and utilization measures are stipulated to apply in order to no increasing of flood peak and outflow after hardness.

2.3 Recent Problems

By the end of 2005, the RSH projects were 51, and collected 0.9 million m^3 of rainwater. Anyway, the average available rainwater is estimated to 96 million m^3. The gap is so big by the following reasons:

a) no feasible plan or detailed measures for RSH;
b) no comprehensive, integrated systems of RSH. E.g. no deep research on the rainwater quality on auto-mobile pavement.
c) no systemic products of RSH. E.g. no effective equipment to remove the articles and pollutants in rainwater.
d) no right system to evaluate effects of RSH. E.g. how to evaluate the effectiveness of eco-environment, safety of flood control.
e) no stimulating and controlling policy to use rainwater.

3 Technical Requirements, Basic Models and Key Technology

3.1 Technical requirements

The objectives of RSH are to release the problems of flood control and water shortage in Beijing, to coordinate the eco-environmental, economical and social benefits.

There are 2 ways of RSH. First is Beneficial Use. i.e. to collect rainwater for municipal uses, such as irrigation, car washing, etc. Second is Drainage Control. i.e. to recharge the rain water to the ground, or cut the flood peak by storage and control measures to decrease the flooding pressure to the rivers.

Plans for RSH should meet the following requirements: a). overall plan for flood control included in the Overall Plan for the city of Beijing; b). Overall Targets of local sustainable development; c). ecological aesthetics.

The technological requirements are, a) no increase in coefficient of runoff after construction; b) no negative effects on ecology and environment; c) no pollution to the ground water; d) low operational and management costs for example, constructing RSH projects using topography so as to move rainwater by gravity; e) easy to construct f) to combine RSH and recycling projects into one system.

3.2 Basic models

Based on the practices of RSH in Beijing, 4 different successful models are recommended:

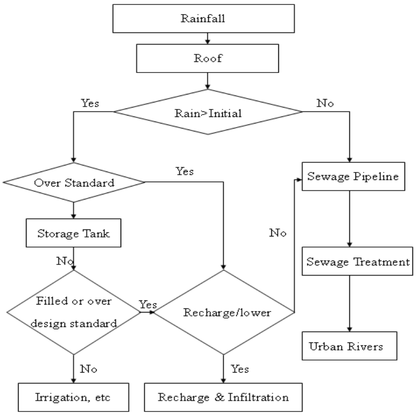


Figure 4: Models of RSH

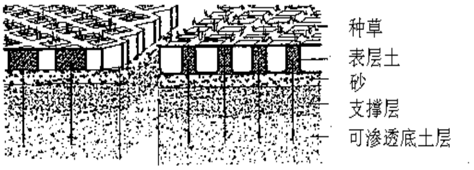
3.2.1 Roof model

Having been collected through roofs and rainwater downpipes, the water is directed towards three uses: Firstly, the water can be directed for reuse. After proper treatment, rain water can be stored and then used for irrigation, toilet flushing various environmental needs, and spraying roads. Secondly, the water can be directed for recharge. If rainwater surpasses the initial water needs, the additional water is used to recharge groundwater, so as to improve the quality and increase the water table. Thirdly, is drained. Rainwater, collected through sewage drains, is treated to appropriate standards and discharged into rivers/lakes.

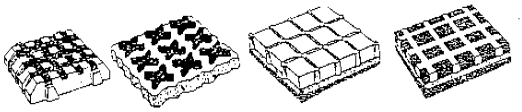
This model is suitable for situations of steady daily water consumption. It can increase the utilization of rainwater and with no significant effects on the design of the downstream rainwater pipe network.

3.2.2 Pavement model

Pavement surfaces include courtyards, squares, footways, car parks and some non-automobile lanes. A common RSH measures is paving surfaces with permeable materials, including permeable surfaces and permeable underlays. The coefficient of permeable surface must be over 0.5 mm/s, and over 0.5 mm/s for the underlay also , so the rainfall penetrates directly into the ground. The pavement should be 5-10cm higher than ground level and sloped towards the surrounding grasslands. When the soil gets saturated the excess rainwater will flow to grassland. Figure 5 shows the pavement on squares, footways and some non-automobile lanes. Figure 6 shows the penetrating structure of certain types of pavement.



栅格型草坪砖路面结构示意图



各种草坪砖形状示意图

Figure 5: Grass pavement

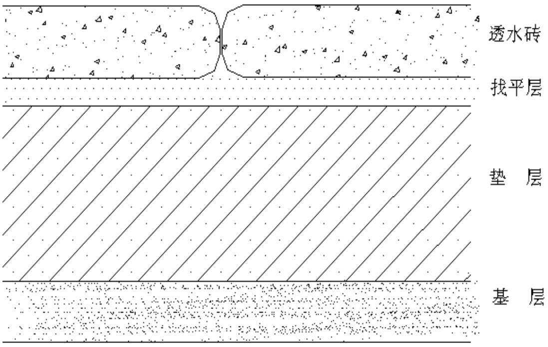


Figure 6: Penetrating structure

The rainwater that penetrated into the ground is collected, treated and stored for municipal use, recharging ground water, or draining to rivers. The flowchart is similar with Figure 4.

3.2.3 Grassland model

There are 2 patterns of grassland models that will be covered. The first is sunken grasslands. For rapid penetration of water underground, the grassland is sunken 10cm below the surrounding surface. Rainwater from surrounding surfaces pours onto the grasslands through gravity. The design standards can meet the requirements of harvesting rainfall once every 2-5 years.

Another pattern is sunken grassland + penetration facility. For common and/or bad underground penetration, some penetration facility needs to be built into the sunken grassland, so that the grassland can store or facilitate the penetration of some rainfall. The penetration facility includes penetration gutters, wells, etc. A gully is necessary to drain the rainfall over 5 years of floods to municipal drainage pipelines to keep the grass from submerging.

3.2.4 Traffic road model

There are 2 patterns of traffic road models. First is the permeable footways + sunken grassland + outlet for rainfall. The footways by the driveway are paved as permeable, and then extended to the sunken grassland. The ecological gully in the automobile lanes drains the initial rainfall and some severe pollutants to the drainage pipeline.

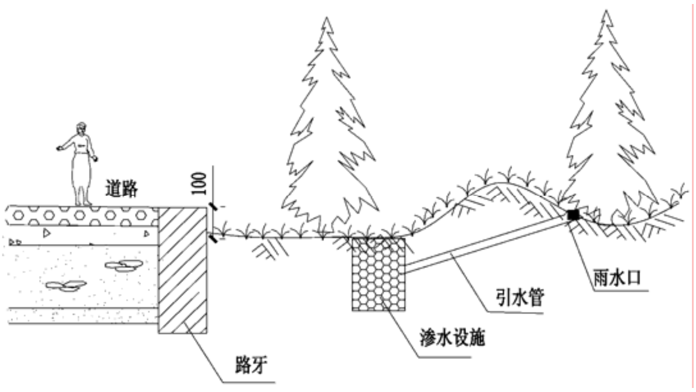


Figure 7: Sunken grassland + penetration facility

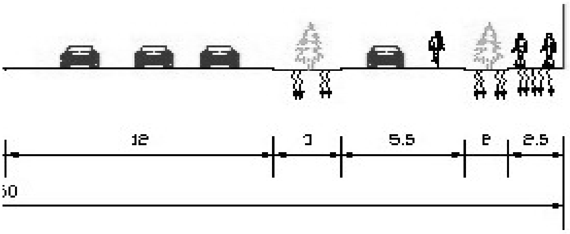


Figure 8: urban pavement structure

The second pattern is a two- sided permeable footways + sunken grassland + grassland gully. The difference between the first patterns is the built gully into the grassland. Figure 8 shows this kind of measures.

3.3 Key technology

3.3.1 Storage tank

The storage tank has the function of controlling flood peaks, decreasing drainage, and also plays a multi-functional role in rainwater harvesting and water pollution reduction. Constructed above ground, it is an aesthetical example of civil engineering.

The structure's design is related to the following data: hydro-geological data, such as soil texture and groundwater quality; hydro-meteorological data, such as figures on the duration and intensity of rainfall, the relationship between rainfall quality and time; the conditions of the underlying surface such as proportion, utilization, etc.

The volume is mainly affected by available rainfall in the region, users' utilization and/or recharge actions, construction costs, operation and maintenance costs, etc.

The available rainfall in the region is simply calculated as follows:

$$W = P_p \times \sum_{i=1}^{n} S_i \times K_i$$

in which：W ——available rain water，m^3

P_P ——annual precipitation when P=p%，mm

S_i ——rain water collection area for No.i material，m^2

k_i ——effectiveness for No.i material, related to rain patterns, material and slop, %

n ——number of all materials.

3.3.2 Initial rain water

Urban RSH is not only affected by rainfall and its distribution, but the quality of rain runoff. Recently, some studies were done in Beijing on the quality of rainwater. They showed that the organic matter in initial rain water was low and pH, total hardness, sulphates and so on met a standard of class Ⅲ of Surface Water Quality; nutrition was high and was a new source of eutrophication in the city's rivers. Normally, the initial runoff of 1-3 mm, or the initial natural rain fall of 10-15min is called 'initial rainwater'. The initial rainwater in grassland had a high turbidity and nutrient load, the water from roof surfaces had severe organic pollution, and the water from road had almost the same level of organic pollution as domestic sewage.

Table 1: Initial rain water quality（mg/L）

indicator	*Natural rain*		*Grassland*		*Roof surface*		*Footway*		*Automobile lane*	
	M	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*
CODmillion	3.6	III	4.0	III	25.5	V$^+$	36.2	V$^+$	68.0	V$^+$
CODcr					96	V$^+$	96	V$^+$	212	V$^+$
SS	30	V								
NH3-N	1.54	V	2.20	V$^+$	2.15	V$^+$				
TN			5.13	V$^+$	3.50	V$^+$	4.2	V$^+$	6.3	V$^+$
TP			0.33	V						

*** M=Mean; S=Standard*

Due to the high density of pollution in the initial rainwater, it is difficult to treat. The main control measure for the initial rain water is to discard it. There is some equipment that can be used, based on the flow and removal of initial rainfall and space requirements.

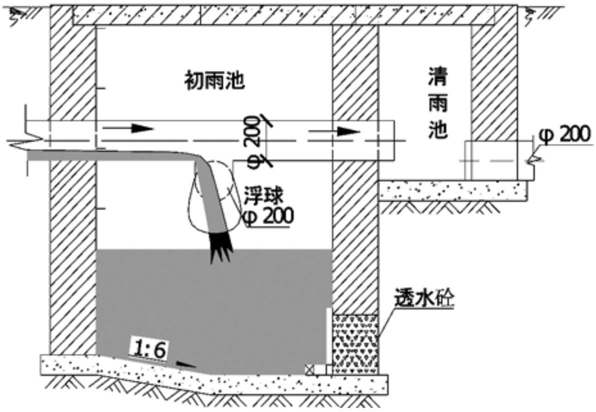


Figure 9: Abandoning tank

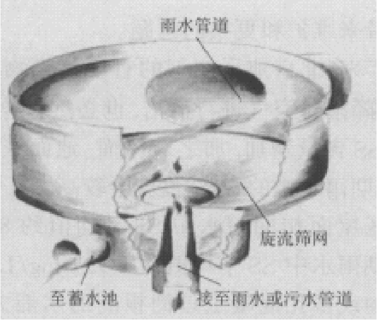


Figure 10: Abandoning equipment

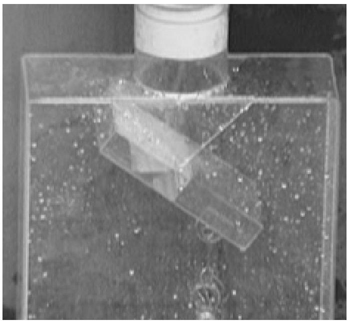


Figure11: Separating device

Moreover, the direct way to treat rainwater is by penetrating the soil. As shown in Fig.12, when the COD load is 9 mg/m^2.s, the removal ratio of COD increases with the depth of soil. When the depth is 1.0 m, 65% of COD is removed and when the depth increases to 1.5 m, 75% of COD is removed. If the depth increases, the ratio of COD removal does not increase significantly.

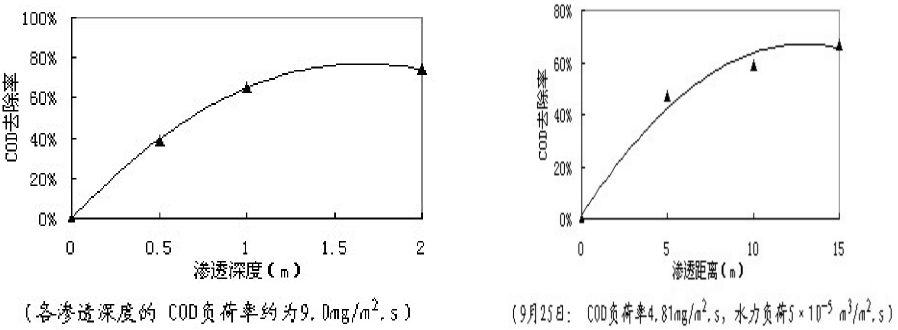


Figure 12: Removal effects on COD based on depth and length of penetration

Source：Soil Penetration of Rainwater from Roofs, by Wang Heizhen, Ou Lan

The bio-chemical characteristics of rainfall from roads and roofs are poor, so physical and chemical methods are applied. For low standards of outflow, the treatment technology may be simple and practical. Coagulation, filtration, sedimentation and other measures are recommended.

3.3.3 Infiltration and Recharge

The infiltration and recharge of rainfall are very significant for RSH. These actions decrease the variability in flood peaks, decrease runoff and recharge groundwater. On one hand, the rainfall maintains the groundwater as a very important economical source and keeps the water table from decreasing. On the other hand, good quality rainfall can dilute the density of groundwater, and improve groundwater quality and germ activity.

The process of designing the structure of recharge facilities, the collection of data on hydro-geology, hydro-meteorology, land utilization, etc. is needed. For the layout, a sound recharge pattern and a suitable recharge location are required.

For centralized recharge, the rainfall beyond the initial rainwater level is collected and transported to storage tanks or infiltration facilities, and then infiltrated to the surrounding ground. The volume of storage tanks can be calculated by analogue computation. The rainfall beyond the level of the design standard is drained to municipal rainstorm pipelines.

For dispersive recharge, rainfall is collected separately in nearby grasslands, lakes or wetlands. Recharge wells are constructed in grasslands to infiltrate rainfall beyond the level of initial rainwater.

Figure13: Recharge by big-caliber well

Figure14: Permeable bricks on pavement

Figure15: Gully in grassland

There is 171Km^2 of grassland in the Beijing urban area. RSH is significant if it will be used to recharge groundwater. The Beijing Hydraulic Research Institute, Tsinghua University and other institutes have finished a study on urban RSH. The study showed: from a water storage perspective, flat grassland is able to store all rainfall; outflow from higher elevation grasslands was 5.6% - 11.1% of the total rainfall and80 - 100 mm was drained over 2 years; low grasslands not only store all rainfall, but outflow from grassland.

Table 2 shows that infiltration in low grassland is 29.8% of inflow (total rainfall and total recharge), 1.61 times greater than flat land and 4.88 times the level of high grasslands. The soil texture in Beijing is mainly sand loam. The infiltration rate is 100 - 300mm/d. Normally, there is no logged water in the rainy season. When P=10% - 5%, namely when the 24 hours of rainfall of which once in 10-20 years reaches 201mm - 259mm of water, even two days of continuous submergence that reaches 15mm will not happen. Therefore, given the strong submergence tolerance, it is worth it to apply concave grasslands and it will not impact on its growth or the urban landscape.

Table 2: Grassland and Infiltration

kind *Item*		*High grassland*	*Flat grassland*	*Low grassland*
Income (mm)	Rain fall	936.6	936.6	936.6
	Irrigation	0	115.0	113.6
	Total	936.6	1056.1	1050.2
Infiltration (mm)	at 1m below the surface	57.6	194.6	312.7
Ratio of infiltration to income (%)		6.1	18.5	29.8
Note :Income from high grassland to low grassland is neglected.				

4 Macro-Measures of RSH

Since Urban RSH is not only focused on urban areas or one regional measure. The following aspects should be balanced to achieve effect rainfall utilization.

4.1 Coordinating the flood control system in urban rivers with RSH for urban communities

The urban area of Beijing is 1085 Km^2, including 43.675 Km^2 of rivers and lakes. In 2005, 3 RSH projects were constructed; the Liangshui River, Tonghui River and Chaobai River Projects. The urban rainstorm water was collected and directed towards the river system on the plains. 34.5 million m^3 of rainfall was stored by the above projects; 30.3 million m^3 in the Chaobai River Project, 1.2 million m^3 in the Liangshui River Project, 3.0 million m^3 in the Tonghui River Project. From June to September 2005, outflow through the Beiyun River was 186 million m^3, an increase of 24 million m^3 compared with in the outflow in 2004.

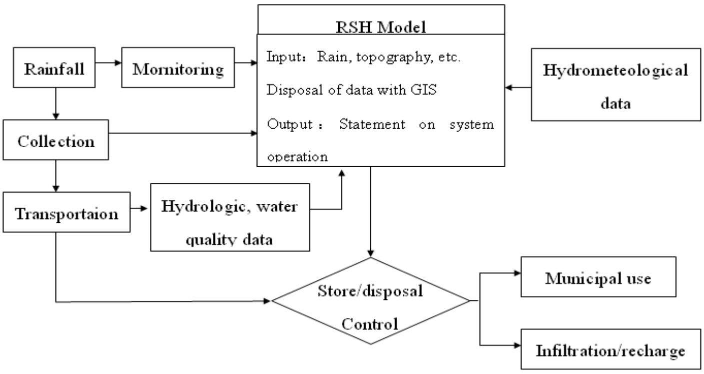


Figure 16: Urban RSH model

To make good use of the river system for RSH, storage in Yuyuantan Lake and Lianhua Lake should be expanded, especially for Yuyuantan Lake. Planning has shown that Yuyuantan Lake is important for RSH. It is located downstream from the Nanhanhe, Yongding, Jingmi and South-to-North Diversion Projects and upstream of downtown rivers. In case of torrential rain, Yuyuantan Lake may store rainstorm, so as to decrease the burden of river flooding.

Also, the urban drainage system needs to be perfected, to increase the drainage ability and meet the flood control requirements.

With regards to non-engineering measures, rainfall forecasting and rainfall information processing should be enhanced and the urban rainfall harvesting system should be managed and controlled together.

4.2 Coordinating urban and rural RSH

With the construction of new village, the requirement for water resources in rural area is increasing day by day. Especially in continuous dry years, the frangibility is more significant. Objectively, the optimum water resources allocation needs to construct some RSH projects. The available rain water ratio on highway road, concrete surface, gravel on plastic membrane, roof and courtyard is 23.3%, 79.9%, 75.4%, 42.4%, 62.1% respectively.

The effectiveness of RSH in rural areas is considerable due to its large rainfall collection area. The RSH projects are constructed ecologically, and combined with agro-measures.

4.3 Coordinating recycled water reuse projects with RSH projects

Based on the observation and research at Beijing Hydraulic School, after rainwater is collected from the roof (and the first flush is removed), it penetrates through sand and gravel ditches, is treated by filtration ponds, and its qualitity improves: CODcr was less than 30 mg/L, SS was almost 0 mg/L, ammonia-nitrogen concentration was 2 mg/L, better than Class V standard of Surface Water Quality, TP was less than 0.1 mg/L, and met Class Ⅱ standard of Surface Water Quality. To match the Standard for Water Quality of Secondary Domestic Use (CJ25.1-89) and the Reuse of Urban Recycling Water and thewater quality Standard for Scenic Environmental Use (GB/T18921-2002). The water quality in the storage tank was good enough to meet the standards for scenic and entertainment purposes. On the other hand, outflow from domestic treatment systems was over Class Ⅱ Drainage Standards. The system does not operate during the approximate month-long summer and winter academic vacation periods. When RSH projects and sewage treatment projects are combined, it is a win-win situation.

5 Conclusion and Recommendations

RSH technology is an important way to reduce the stress on the city's water resources and flood controls. Recommendations include spreading RSH technology to roofs, grasslands, roads and pavemen.; Implementing demonstrative areas for key RSH technologies by combining drainage, water resources, hydrology, and city planning; Establishing regulations, rules and technical standards for RSH.

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Water Resources and Sustainable Utilization in Beijing
北京市水资源及可持续利用

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Abstract

With a severe shortage of water, the exploitation of water resources in Beijing has caused problems such as a deterioration of the water environment, a decrease in strategic water storage capacity and an increasingly sharper contradiction between water supply and demand. In order to maximize the benefits of water use and achieve a harmonious development of the water resources system, the socio-economic system and the natural ecosystem, integrated measures including water resources utilization and protection should be undertaken and the open-looped structure of water development changed into a closed-loop structure.

摘要

北京市水资源严重短缺，长期的水资源过渡开发导致了地表地下水环境恶化、战略储备水量减少、水资源供需矛盾加剧等问题。对此，应从水资源开发利用的各个环节入手，采取综合措施，变水资源开发利用过程的开环结构为各环节相互影响的闭环结构，最大限度发挥水资源的利用效益，实现水资源系统、社会经济系统、自然生态系统的协调统一。

1 Introduction

Beijing is a large city with a severe shortage of water and especially since the 1990s, the water scarcity has been increasingly worse. After completion of the South-to-North Water Transfer Project, the water scarcity was partially addressed, but from a long-term perspective, the conflict between limited water supply and increasing water demand persists in Beijing. Therefore, the study of sustainable water utilization, accounting for the specific characteristics of water resources in Beijing, will be necessary to ensure the sustainability of the water supply and to realize societal and economic sustainable development.

2 Water Resources and Its Characteristics in Beijing

Beijing is located in the Haihe valley and belongs to a semi-arid and semi-humid climate region where most of water resources rely on rainfall. According to the data from 1956 to 2000, the annual precipitation in Beijing was 585 mm, the volume of rainfall was 9.8

billion m^3, which formed a total water storage of 3.8 billion $m^{3,}$ including surface runoff of 1.4 billion m^3 and groundwater storage of 2.4 billion m^3.
With less than 300m^3 per capita of water resources, Beijing is faced with is 1/8 of national levels and 1/30 of world levels, making it one of the largest cities with a severe water shortage in the world.

Considering the influence of physical geography and climate conditions, the precipitation in Beijing is characterized by uneven spatio-temporal distribution and a constant alternation between dry and wet years. The time interval between dry and wet years is about 2 or 3 years. Historically, the longest duration of continuous wet years was 6 years and the continuous duration of dry years was 9 years while the longest duration of a water shortage was 20 years. Since 1999, a continuous drought occurred in Beijing and its surrounding regions with an average annual precipitation of 450 mm. Thus, it has been more difficult to use water resources in Beijing.

Furthermore, a characteristic of water resources distribution in Beijing has been a mismatch between the allocations for economic and societal development. The main watersheds are located in the mainly mountainous western and northern areas of Beijing. The main area of water consumption are in the eastern and southern areas of the city as well., It is due to the mismatch mentioned above that the implementation of a more effective joint water dispatch and water resources management is necessary for Beijing.

3 Status of Water Resource Development and Water Problems

With the rapid pace of economic and social development, the water demand in Beijing has been increasing. In order to meet the increasing water demand, the water stored in the reservoirs and groundwater had to be used and exploited. Presently, the proportion of groundwater in relation to the total water supply has reached 77%, up from 57% in the 1980s. Take the data of 2004 for instance, the annual precipitation was 539mm and formed water storage of 2.16 billion m^3. The total annual water supply was 3.46 billion m^3, among which rivers and reservoirs supplied 0.57 billion m^3, groundwater supplied 2.69 billion m^3 and rain and reclaimed water supplied 0.2 billion m^3. The total water usage was 3.46 billion m^3 with 1.28 billion m^3 used for domestic water needs and accounting for 37% of total water usage. Industry consumed 0.77 billion m^3, or 22%, and agriculture and the ecological environmental water demands were 1.35 billion m^3 and 60 million m^3 respectively, accounting for 39% and 2%.

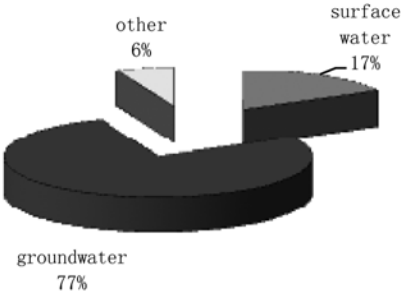

Figure1: The Constituent of Water Supply Sources in 2004

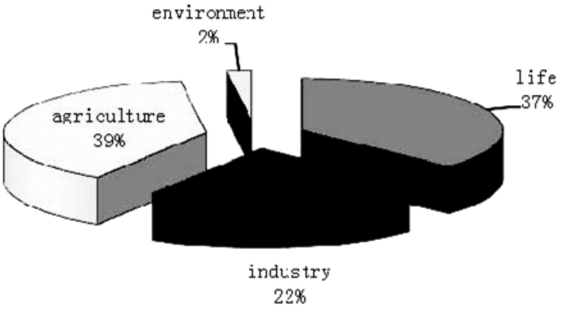

Figure2: The Constituent of Water Consumption in 2004

The water shortage and excess exploitation of water in Beijing has caused a series of water problems, including:

(1) Imbalance between an increasing demand for water and decreasing supply
Beijing is an international metropolis experiencing rapid development. The water demand in Beijing is increasing as population economic development and construction increases. According to the Beijing Water Resources Integrated Plan, by 2020 the water demand in Beijing will be up to 5.1 billion m^3 for a normal year. However, the total capacity of existing water supply projects is only 3.5 billion m^3, thus, the gap between water demand and water supply in 2020 will reach 1.6 billion m^3, a gap that will be even larger during dry years.

(2) A worsening water environment
Beijing is a capital with an ancient civilization and profound water culture and the water system in Beijing was very developed throughout history. But, in recent years, due to the water scarcity, most of the water has been used for household or industrial needs resulting in a damaged natural ecological environment. Presently, most rivers in Beijing lack water flow and parts of rivers are almost completely dry in non- flood seasons. Even if some rivers have water flow, especially those in the lower reach of the city, most of water is usually waste water. On the plains, the groundwater has been partially polluted and the overall water quality is bad.

There are 100 km of river ways and 700 km^2 of lakes in the city center. Presently, the annual volume of water, including clean water and reclaimed water used to recharge rivers and lakes in the city centre is about 80 million m^3, which may only be able to renew the natural flux of water due to evaporation and leakage, but cannot meet the water demands that are required for keeping the water at a high quality or maintaing a good visual appearance. Therefore, the water quality in rivers and lakes is worse due to the water scarcity.

(3) Decrease in strategic water storage
At present, the water supply in Beijing mainly depends on two sources: surface water and groundwater. The Miyun and Guanting reservoirs supply 2/3 of the surface water. But in recent years, due to continuous drought, excess groundwater was exploited and the water storage in reservoirs was used up to meet increasing demand and resulting in a decrease in strategic water storage and threatening Beijing's water security.

According to the data, the water storage in the Miyun and Guanting reservoirs decreased by 1.4 billion m^3 since 1999, and the groundwater level on the plains fell by 14 m since 1980 while the relevant groundwater storage capacity decreased by 7 billion m^3.

4 Tactics for Sustainable Utilization of Water Resources in Beijing

Given the characteristics of water sytems, open, scattered, dynamic and non-structured, they are increasingly affected by human economy activity. Usually, the process of water resources development and utilization includes five steps: analyzing of demand, water exploitation, water usage, sewage production and treatment, sewage discharge. In the past, much attention was paid to water exploitation, and less to other sectors. The process of water resources development and utilization was regarded as an open-loop structure without any feedback loops. Meaning, as the demand for water increased rapidly in pace with economic development, much more new water had to been exploited and used as the water shortage worsened. Simultaneously, with the increase in water use, more sewage was produced and discharged, which not only worsened the river's water quality of but also polluted some clean water sources thus making the water shortage even more acute. The vicious circle that has been created is, the more economic development, the more water used, the more sewage produced and discharged, the more severe the water pollution and then the more serious the water shortage.

So, to achieve multi-benefit of water utilization and realize the harmonious development of water resources system, social-economy system and natural eco-system, the importance should be attached to all of sectors of the water resources development process, especially to the management of demand and wastewater treatment and the integrated measures including water resources utilization and protection should be taken and the open-loop structure of water use should be changed into a closed-loop structure (show as Figure 3) .

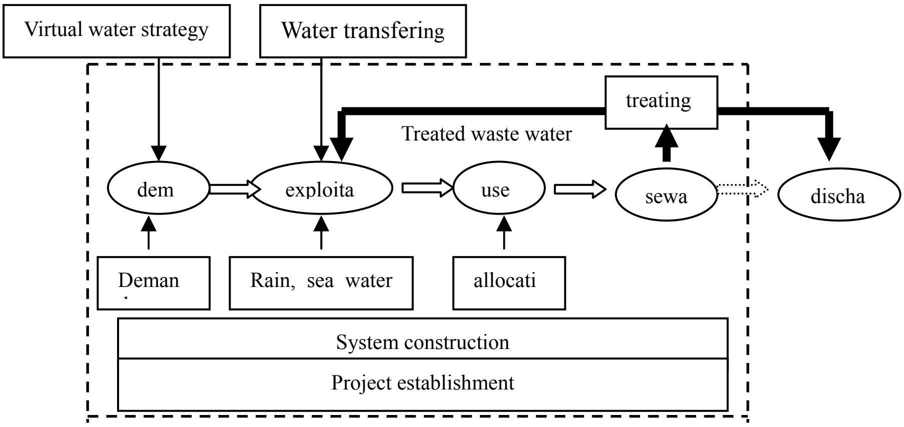

Figure3: The process of water sources development

In order to solve Beijing's water problems, following efforts should be made:

4.1 Management of water demand

The management of water demand is the first sector of water resources development and which aims to control the increase in water demand. In the past, when water demand increased, much emphasis was put on the exploitation of the water source during construction, but less emphasis was put on the management of the demand for water that would improve the efficiency of water use, promote water saving and decrease water demand through economic and market mechanisms. This resulted in the co-existing situation of a water shortage and water being wasted simultaneously. The core of the management of water demand would be a change from an exploitation mode focusing on supplying water into a saving mode that focuses on the management of demand. Over the last few years, many efforts have been made to save water in Beijing and obvious effect have resulted.. From 2001 to 2005, there was rapid societal and economic development, a population increase from 13.67 million to 15.38 million and a GDP increase from 284 billion yuan to 681 billion yuan. But in same period, the total water consumption in Beijing decreased from 3.89 billion m^3 to 3.45 billion m^3 and the water consumption per 10000 yuan GDP decreased from 137 m^3 to 50 m^3. So, intensifying the management of water demand will remain one of the important measures needed to solve the water problem for a long time to come. Based on societal, economic and water use trends,, the key aspects of water demand management in Beijing include: (1) practicing water accounting depending on water quota and strictly controlling of the water use index, implementing measurements of water used, water supply planning accounting of quotas, and controlling the total volume. (2) continuously improving the industry structure and restricting industries with high water consumption. (3) extending water saving technologies and improving water use techniques and processes and promoting efficient water use. (4) establishing a reasonable water pricing system to encourage a positive water saving attitude amongst society at large. (5) strengthening the system construction and policy propaganda, and promoting the social consciousness on saving water with the aim of creating a more conscious society.

4.2 Water supply management

With a purpose of enhancing the guarantee ratio of water supply, water supply management is an important part of assuring the safety of the water supply. Decision-makers need to know about changes in both natural conditions and city movements, and the neglect of any change would destroy the water supply’s safety. So, it is the trend in modern city management to build an effective water supply management system for forecasting and controlling the changes in climate, water sources and water demand.

4.3 Water resources exploitation

Beijing is a large city with a water resource shortage. Currently, Beijing’s basic water demands are met but at the cost of a worsening environment and by using reserved water storage. Looking towards the future, it will be increasingly difficult to meet the increasing water demands only by relying on existing water resources, even if some measures are taken regarding the management of demand. Inevitably, various water resources must be further exploited. Firstly, the south-to-north water transfer project is an important measure to abate the water shortage in Beijing. According to the project plan, water from the Yangtse River will be transferred to Beijing in 2010. Before that happens, it will be necessary to import water from regions around Beijing. Secondly, rain water should be actively put to use by methods such as detention of rainwater which could be used to recharge the groundwater. At present, there exists a groundwater table descend funnel of about 1000 km^2 on the Beijing plains due to excess groundwater exploitation. Therefore, on the condition that there was no other source of water, rainwater could be used to recharge the groundwater to prevent a drop in the groundwater table. Thirdly, reclaimed water should be actively used. The waste water treatment and use could not only offset the lack of clean water but also reduce waste water discharge and improve the river's water quality. The annual amount of reclaimed water currently used in Beijing is about 200 million m^3, and will reach 800 million m^3 in 2020 under the current plan.

4.4 Water allocation

Beijing is a large city with multiple water sources, multiple water users and a complex water supply system. How to allocate the water to all the users scientifically, according to the differences in types of resources and water quality and user demand is the key to manage water effectively and enhance water use efficiency. For Beijing, before the completion of south-to-north water transfer project, there is no new water source to supply Beijing. Although ground water over-extraction are serious, after taking water-saving measures, the gap between water supply and water demand needs to be filled by underground water. After the project's completion, in view of sustainable utilization and environmental improvements, the reclaimed water should be the first source to be followed by the water from the new project. The next source could be suitable surface waters including rainwater and flood water. Groundwater should be used as little as possible and as the last resort. Simultaneously, groundwater should be restored by artificial or natural recharging schemes. When the groundwater table has risen to a suitable level, then more groundwater could be exploited. At that time, by allocating the various water resources, the groundwater table could be maintained at a suitable level.

4.5 Virtual water strategy

In order to solve water problems in Beijing, on the one hand, more water should be introduced from other areas through water projects, but on the other hand, the virtual water strategy should also actively attempt an adjustment of the industry structure. In fact, much virtual water has been a result of imported goods which need water in recent years in Beijing, which under the conditions of water scarcity play an important role for development. For example, according to the data on imported products (including food, meat, egg and aquatic produce only), the annual virtual water imported in 2000 is about 4 to 5 billion m^3. In the future, a virtual water strategy should be implemented more extensively.

4.6 Regional cooperation mechanism

Because of the regional characteristic of water and the externalities involved in water activities, the solution to water problems should not only focus on local areas but on larger areas as well. In Beijing, about 2/3 of the surface water supply is from the Miyun and Guanting system, and most of the reservoirs' water come from Hebei province and Shanxi province, located near the upper reaches of Beijing. The exploitation of water in these provinces has a direct influence on the water flow and water quality in Beijing. In order to alleviate the water scarcity in Beijing, there have been several emergency water deliveries from Hebei province and Shanxi province carried out in the last few years. According to the plan, in future years water will be dispatched from the Gangnan reservoir, Huangbizhuang reservoir, Dayang reservoir and Wangkuai reservoir located in Hebei province. Furthermore, the implementation of a virtual water strategy also needs to cover a larger area. So, with the increasing improvement of water rights and a water market system, a complete regional cooperation mechanism, including water source protection, water allocation, water transfer rights t, economic support and mutual industry supplements etc., should be built.

4.7 Establishing improved water policy and institutions

The completed policy and system is an important guarantee for scientific water management and sustainable water utilization. Not only engineering, administration and techniques are needed but also policies and laws are needed to solve water problems. Currently in Beijing, the new ideal of using recycled water is being put into practice howevera series of policies and laws, covering the development and protection of water, water conservation, the reuse of waste water, a water pricing system and so on need to be included.

5 Conclusion

Water shortages, the deterioration of the water environment and a decrease in water reserves are the key water problems facing Beijing. In order to solve these problems, the water management needs to change. While addressing water dispatches from outside sources and the more effective uses of rainwater and flood waters, the management of water demand should be intensified and the mode of water management that focuses on exploiting the water supply should be changed a mode of management that focuses on saving water and managing demand. The integrated approaches including engineering, administration, technique, economics and law should be used for allocating water, enhancing efficient water use and controlling the increase in demand for water. Secondly, the treatment of waste water and the reuse of reclaimed water should be reinforced, so as to change the open-loop structure of water development into a closed-loop structure and promote the recycling of water. Thirdly, the regional cooperation mechanism should be built up and the virtual water strategy should be implemented as a new solution to water problems.

Necessity of Sustainable Water Management in Shanghai
上海市可持续水管理的必要性研究

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Abstract

People recognize freshwater shortages and serious water pollution as signs of environmental failure, but rarely acknowledge them as the results of management failures. The problem is not the shortage of the water itself; it is the problem of irresponsible water management by human beings. Water management is a holistic combination of water supply, use, discharge and recycling practices by administrative institutions, enterprises, public interest groups and the general public. The core of water management is composed of saving water, conservation of water resources including evaporation, water recycling and risk management. The importance of good management is, of course, not restricted to environmental decisions. These water management issues affect the core of social and economic progress. Several paradigms of sustainable water management have been set up throughout the world. Sustainable water management considers the whole river basin as an integral system, reducing the conflicts between mainstream and tributaries, upstream and downstream, and between different bureaus with overlapped authorities. In order to implement sustainable water management with efficiency, the principles and objectives for sustainable water management is advocated. In this paper, a review on sustainable water management in Shanghai is stated, with the introduction of Shanghai's water crisis and disadvantages of the traditional water management. In addition to a review of the situation, personal opinions and understanding towards the framework of sustainable water management indicator system in Shanghai are put forward.

摘要

人们认为水资源短缺和严重的水污染是环境破坏的标志，但很少认识到它们是管理失败的结果。问题不是水资源短缺本身；而是人类不负责任的水资源管理。水资源管理是由政府机构，企业，公共利益团体和普通公众共同参与的供水，用水，排水，和水循环的整体行为。水资源管理的核心是节水和保护包括大气中的水在内的任何水资源、水循环和风险管理。好的管理的重要性当然并不局限于环境决策，而是我们社会、经济发展的中心。世界上已经建立了几个可持续的水资源管理的范例。可持续的水资源管理把整个流域视作一个完整的系统，减少主流和支流，上游和下游，以及职能交叠的不同部门之间的矛盾，为有效的实施可持续的水资源管理，提出了原则和目标。本文论述了上海的可持续水资源管理，同时也介绍了上海水危机和传统的水资源管理的缺点。此外，本文还提出了对上海可持续水资源管理指示系统框架的个人意见和理解。

1 Introduction

Sustainable Water Management (SWM) is the management of water use that will ensure supplies without compromising natural hydrological recycling and ecosystem integrity for future generations. . However, while sustainable water management objectives may be generalized, solutions can not. Sustainable solutions only can be found by considering specific conditions of each case. Different scales have different sustainable solutions.

Over the past few decades, governments throughout the world have reviewed their policies to achieve more sustainable water resources. Shanghai's government has also made much progress in water management. Firstly, this paper will introduce basic information on the city of Shanghai. Then it will explore experiences of sustainable water management indicator systems around the world. Lastly, a sustainable water management indicator system will be discussed. Although the specific indicator system is focused on Shanghai, China, the framework will be universal.

Shanghai, or "Hu" alternatively, located at 31º 14' north latitude and 121º 29' east longitude, is bordered by the Yangtze River to the north, the East China Sea to the east, the Hangzhou Bay to the south and Jiangsu and Zhejiang Provinces to the west as shown in figure 1 .[1]

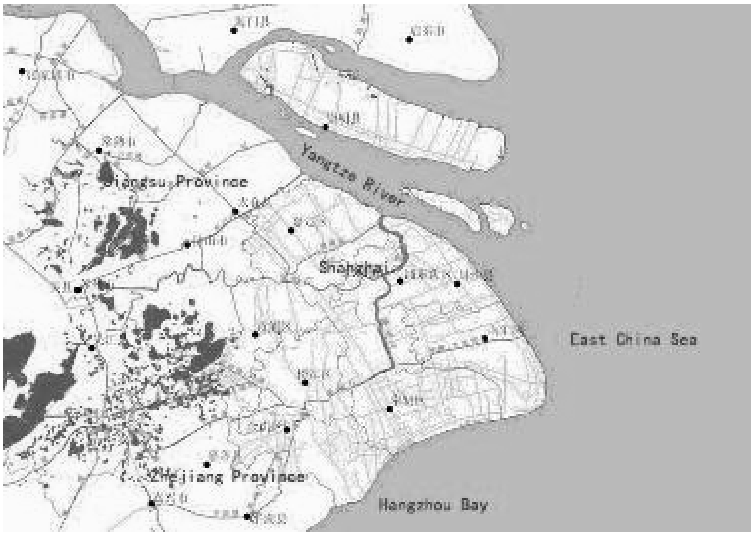

Figure 1: Location of Shanghai

The city is situated on the eastern edge of the Yangtze River Delta, which is in the centre of China's north to south coastline. Located at the mouth of the Yangtze River, Shanghai enjoys convenient communications and a favorable geographical location with a good harbor and a vast hinterland as shown in figure 2. Shanghai averages about 4 meters above sea level and its territory is a part of the broad flat alluvial plain of the Yangtze River Delta with few remnant hills in the southwest.

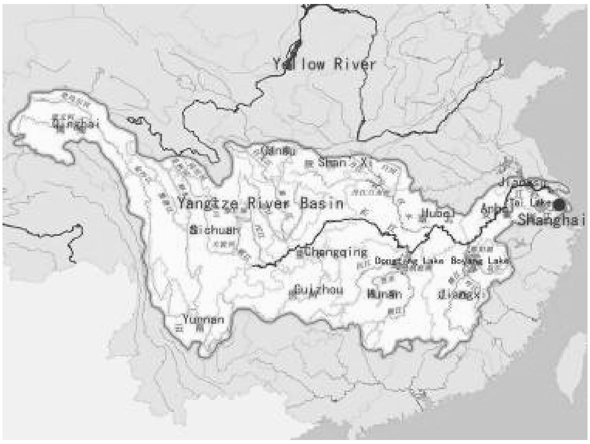

Figure 2: Location of Yangtze River Basin

Shanghai covers an area of 6340.5 square kilometers, of which 6218.65 square kilometers is land area and 121.85 square kilometers is water. The city is about 100 kilometers wide from east to west and 120 kilometers long from north to south. Most of Shanghai sits on early strand plains, which are primarily constructed by waves and tidal currents from currents washed down the Yangtze. Relief is low at about 3 to 5 meters above sea level. The ground is mainly composed of coarse silts and sandy mud. Cultivation of this region has resulted in soil losses that have lead to an acceleration of the coastline's advance to about 37.5 meters per year. Shanghai is also very flat as a result of its formation process as shown in figure 3.

Figure 3: Land use in Shanghai (2003) by remote sensing [2]

Shanghai lies in a subtropical climate zone and is thus characterized by mild annual temperatures, high humidity, and distinct seasons. The climate characteristics of Shanghai are shown in Table 1.

Table 1: Climate characteristics in Shanghai from 1971-2000[3]

(Year 1971-2000) Standard Climate Values (Shanghai Station number 58362)								
Monthly Average	Air pressure (0.1hpa)	Temperature (0.1°C)	Tiptop Temp (0.1°C)	Lowest Temp (0.1°C)	Humidity (%)	Cloudage (%)	Wind Velocity (0.1m/s)	Precipitation (0.1mm)
1	10261	47	192	-55	75	60	30	753
2	10242	60	264	-45	72	56	31	437
3	10202	92	261	-7	78	72	33	1176
4	10152	147	322	24	75	66	32	632
5	10109	203	349	94	74	65	33	852
6	10065	238	368	160	82	77	32	2116
7	10049	280	377	200	80	66	32	1418
8	10064	278	378	199	81	65	34	2301
9	10123	244	367	139	77	58	33	761
10	10193	192	322	65	74	56	29	635
11	10233	135	265	-19	74	55	30	426
12	10265	78	203	-77	73	50	29	337
Yearly Average	Air pressure (0.1hpa)	Temperature (0.1°C)	Tiptop Temp (0.1°C)	Lowest Temp (0.1°C)	Humidity (%)	Cloudage (%)	Wind Velocity (0.1m/s)	Precipitation (0.1mm)
	10163	166	378	-77	76	62	32	11844

Data source (http://cdc.cma.gov.cn/shuju/preview.jsp)

The Yangtze Delta could well be described as the powerhouse of China, with Shanghai as the focus of attention. Although, in population terms, the Yangtze Delta only has about 80 million, or 6.15% of the country's 1.3 billion total, the region contributes about 20% of the country's GDP. Actually, current water management practices in Shanghai are not able to solve all the problems. The interrelated water functions are split up and formally assigned to contending bureaus: main stream and tributaries, upstream and downstream, quantity and quality, in-stream and out-of-stream use, construction and maintenance, water conservancy and hydropower, as well as management and planning. Sustainable water management considers water as an integral system. Consequently, an indicator system for sustainable water management in Shanghai should be set up. It will be an effective tool to ensure the assessment of the present state of management and analyze the potential for future developments.

2 Water Assessment in Shanghai

2.1 Rainfall

Shanghai is considered a rainy city. Rainfall in Shanghai is abundant with 129 rainy days annually and average annual rainfall is about 1,184.4 mm. The monthly rainfall in Shanghai varies greatly from month to month as shown in figure 4. More than fifty percent of rainfall typically occurs between June and September during what are known as ‘plum rains’. [4]

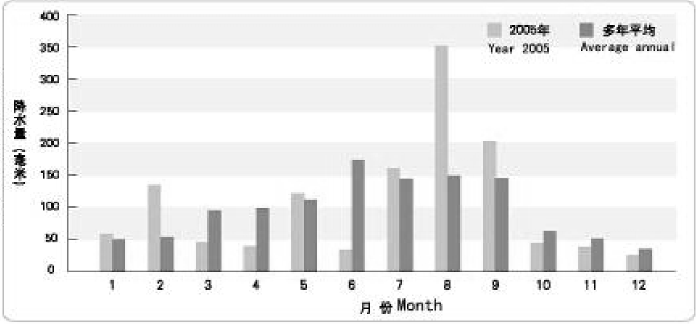

Figure 4: Monthly precipitation in Shanghai

The distribution of precipitation varies across Shanghai; the City Center and the Jinshan district have more precipitation than other areas while the Nanhui district and Chongming Island receive less than the average rainfall, as shown in figure 5.

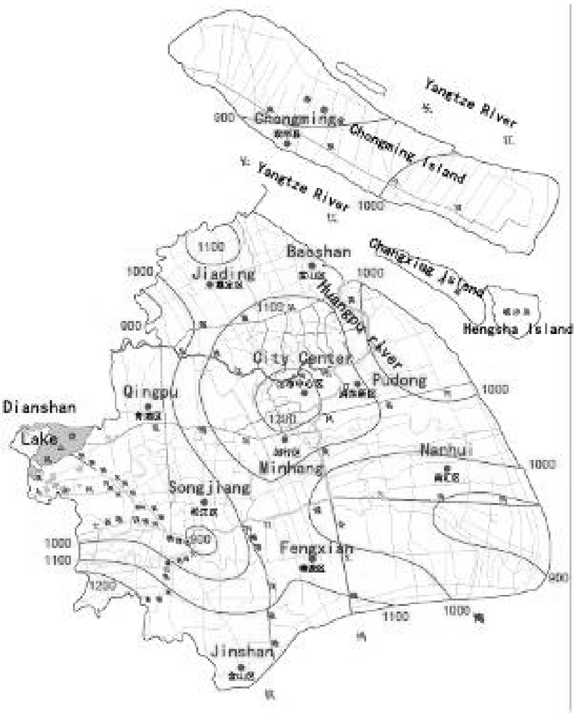

Figure 5: Isoline of the yearly precipitation distribution in Shanghai (Year 2005, Unit mm)
Data source: Shanghai Water bureau, annually water resource report (2005)

2.2 Available surface water

The average annual local available surface water resource is 2.415 billion cubic meters. The average annual available surface water from Tai Lake is 10.66 billion cubic meters.

The average annual available surface water from the Yangtze River is 933.5 billion cubic meters. The main rivers and lakes are shown in figure 6.

Figure 6: Rivers and lakes in Shanghai [5]

2.3 Available ground water

The water table along Shanghai's coast is shallow at about 80 to 120 cm below the surface. Groundwater is abundant and widely distributed. A dense surface water network also means that the average distance to discharge points is short. Groundwater in Shanghai is recharged through rainfall, infiltration from surface water, irrigation, recharge and tidal water. It is lost through evaporation, human use, and discharge into surface water. [6] Shanghai's groundwater may be drawn primarily from six sources: a shallow phreatic layer, and five confined aquifers.

- Phreatic Layer: This layer occurs close to the surface, usually around 3 to 4 meters, with a depth of around 1 to 20 meters. Its proximity to ground level means that it is easy to access but also that it is polluted by the infiltration of wastewater. The poor quality of this layer means that it is rarely tapped into.

- First Aquifer: This is the first layer of groundwater beneath the phreatic layer. It typically lies 25-53 meters below the surface, with a depth of around 3 to 18 meters. However, water from this layer is not exploited because it is not abundant and poor in quality: this layer is made of fine, sandy particles.

- Second Aquifer: This layer is 60-70 meters below the surface, contains marine facies deposits and widely distributed, and slightly saline or semi-saline (except in the northeast, where the water is fresh). The abundance of water in this layer has lead to its rapid exploitation in the past. The main cause of land subsidence in Shanghai is due to over-pumping groundwater and corresponding drawdown of piezometric head. Groundwater is being removed from the aquifer faster than it can be replenished. From 1921 to 1965, the mean subsidence level in the city was 1.76 meters – at one place, the ground had subsided 2.63 meters! As a result of subsidence, extraction of water from this layers “is more limited.” as shown in figure 7.

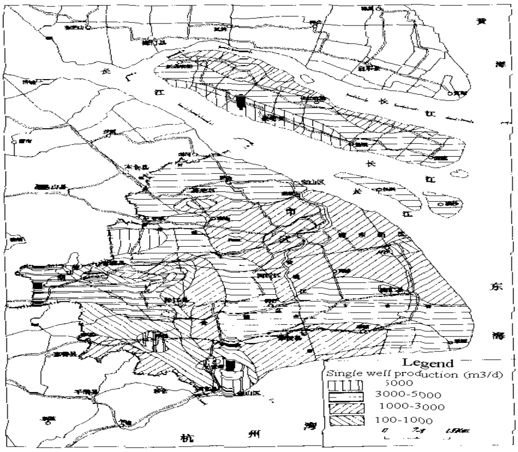

Figure 7: Second aquifer groundwater in Shanghai [7]

- Third Aquifer: This aquifer is 100 to120 meters below the surface, with a thickness of around 20 to 30 meters. While the third aquifer covers an extensive area and has a large volume, it is never exploited because the water is saline.

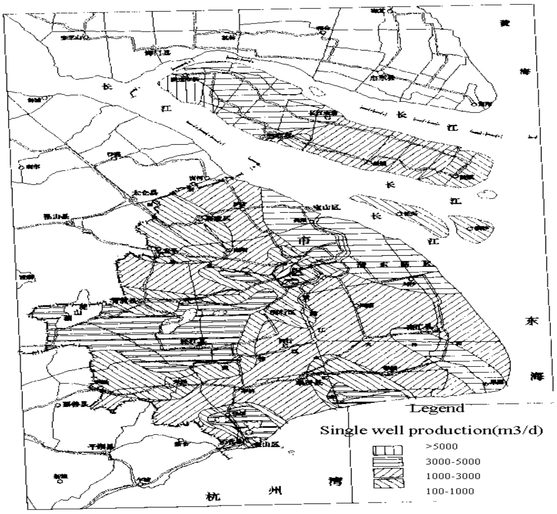

Figure 8: Third aquifer groundwater in Shanghai

- Fourth Aquifer: Currently, the most exploited layer of groundwater is the fourth layer. This aquifer can be divided into two parts; the first part is 160-180 meters below the surface, with a depth of around 20-30 meters, while the second part is 200-220 meters below the surface, with a depth of around 10-20 meters. The water is abundant and of high quality, as shown in figure 9.

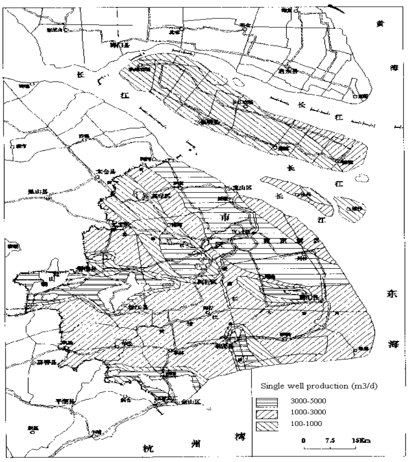

Figure 9: Fourth aquifer groundwater in Shanghai

- Fifth Aquifer: This layer is the deepest layer of groundwater. It is 250-280 meters below ground with a depth of 10-80 meters. The water is also abundant and of high quality, as shown in figure 10.

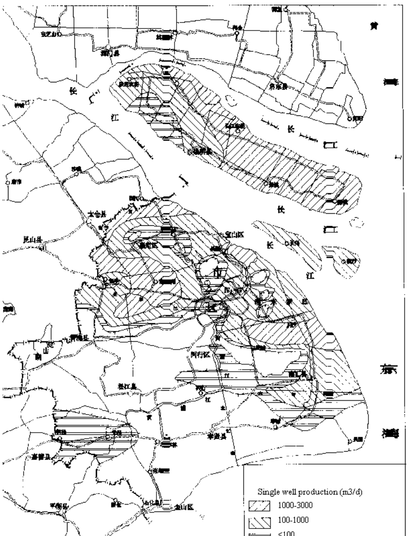

Figure10: Fifth aquifer groundwater in Shanghai

Shanghai's Department of Geology has estimated that exploitable groundwater only amounts to 0.142 billion cubic meters, accounting for to economic and geological limitations.

3 Water Quality in Shanghai

3.1 Rain water quality

Shanghai is plagued by problems resulting from high ambient concentrations of sulphur dioxide in the air. High SO_2 and suspended particulate levels stem from Shanghai's reliance on coal-burning. The average pH value of precipitation was 4.93 and the occurrence of acid rain was 40% in 2005, an increase of 7.3% over 2004.

The annual daily average of SO_2 in the urban area was $0.061 mg/m^3$ in 2005, which slightly exceeded the 2^{nd} standard level specified in the National Ambient Air Quality Standard (GB3095-1996) since the upper limit of the 2^{nd} standard level of SO_2 emissions as specified in the National Ambient Air Quality Standard is $0.006 mg/m^{3.}$ SO_2 emissions in 2005 were lower than in 2004, which mean the SO_2 emission was lower than $0.006 mg/m^3$ in 2005. Over 49 days, 13.4% of the year, SO_2 ranked as the top pollutant. The recent five-year monitoring data showed that except for the year 2005, the annual daily average of SO_2 in urban areas in the past four years was lower than the 2nd standard level. However, the increasing SO_2 emission level can be linked to the rapid economic growth and the resulting increase in demand for energy consumption. [8]

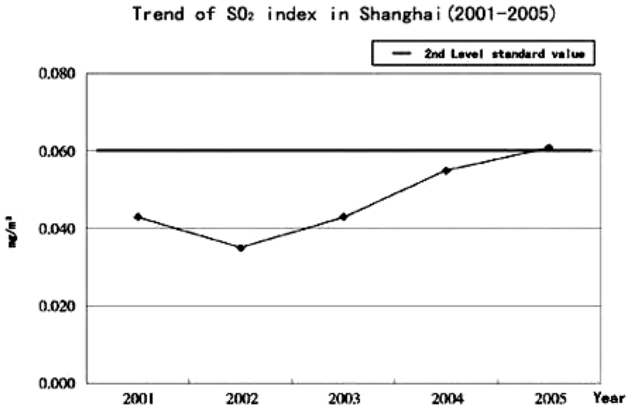

Figure 11: Trend of SO2 index in Shanghai (2001-2005)

The annual daily average of NO_2 in the urban area was $0.061 mg/m^3$ in 2005, which was compliant with the 2^{nd} standard level specified in National Ambient Air Quality Standard (GB3095-1996), and which was $0.001 mg/m^3$ less than in 2004. There were 6 days, 1.6 % of the year, monitored when NO_2 ranked as the top pollutant. Data from the past 5 years showed that the annual daily average of NO_2 in the urban area was lower than the 2nd standard level. The overall level of NO_2 emission was maintained.

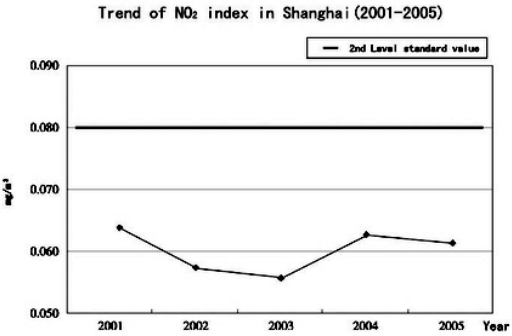

Figure 12: Trend of NO2 index in Shanghai (2001-2005)

3.2 Surface water quality

For the assessment of river water quality we use the indicator of the Percent of Slight and Non-contaminated River Length to Total Monitoring River Length to illustrate the pollution level of the main rivers. The main river quality measurements from 1998 to 2005 are shown in figure 13 and figure 14.

Table 2: Definition of the indicator Percent of Slight and Non-contaminated River Length to Total Monitoring River Length

Title	Percent of Slight and Non-contaminated River Length to Total Monitoring River Length
Definition	Ratio of the length of slight pollution and non-pollution to total river length.
Type	State indicator
Object	To indicate the seriousness of surface water pollution, and expect to this indicator can provide decision maker with pollution control strategy.

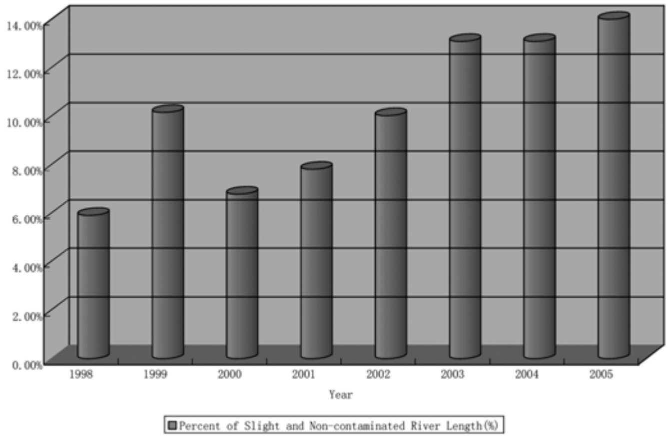

Figure 13: Status of the river water quality in Shanghai (1998-2005)

3.3 Lake quality index

For the assessment of the lake water quality, we use the Dianshan Lake's Calson's Trophic State Index to illustrate the Eutrophication level of the Dianshan Lake. The Dianshan Lake water quality is shown in figure 14.

Table 3: Definition of the indicator Lake quality index

Title	Lake quality index
Definition	Dianshan Lake's Calson's Trophic State Index.
Type	State indicator
Object	Eutrophication indicates the extent of lake pollution. This indicator represents the pollution level of the lake.

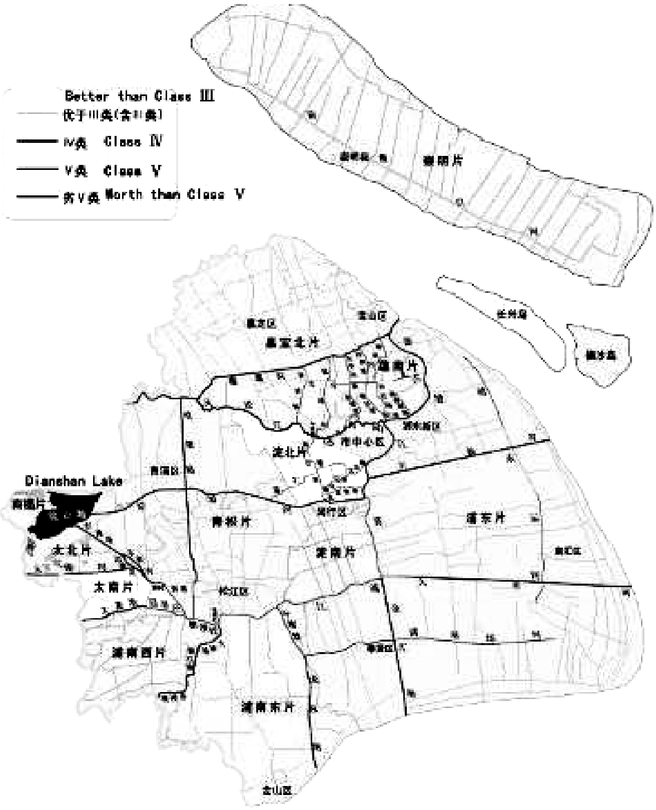

Figure 14: Surface water quality of Shanghai in 2005

3.4 Ground water quality

We have already noted that the phreatic and the first and third aquifers are unsuitable for extraction due to poor water quality. The fifth aquifer is uneconomic to tap. This leaves the second and fourth aquifers which both contain abundant high quality water. However, this pristine water may have been degraded in the 1980s. In reaction to rapid subsidence of 3 mm a year, the government pumped surface water into the aquifers. This action contaminated the aquifers with polluted surface waters and once contaminated aquifers are extremely difficult to clean. The groundwater quality in 2003 is shown in

Table Table 4.

Table 4: Groundwater quality of Shanghai in 2003 [9]

Year2003	Item (mg/l)						
Layer	**Na**	**Ca**	**Mg**	**Cl^-**	**SO_4^{2-}**	**HCO_3^-**	**NO_2^-**
Phreatic layer	96.1	97.5	41.9	109.3	101.9	448.6	24
Second layer	106.5	100.4	36.8	265.1	6.3	316.5	0.707
Third layer	89.4	50.6	19.2	75.4	6.7	346	0.545
Fourth layer	148.7	53.4	23	119.7	15.5	443.1	0.087
Fifth layer	195.1	48.7	25.2	177.4	14.9	457.3	0.007
Layer	**NO_3^-**	**NH_4^+**	**Tfe**	**Mn**	**Mineralization**	**Manganese**	**COD**
Phreatic layer	0.871	0.42	0.207	0.309	715	415.8	2.12
Second layer	2.9	0.26	0.948	0.257	680	402.5	1.85
Third layer	1.7	0.4	0.635	0.107	419	205.5	1.89
Fourth layer	0.8	0.21	0.807	0.077	585	228	1.23
Fifth layer	1.9	0.04	0.586	0.107	693	225.3	0.81

For the assessment of the ground water quality, we use the indicator of the qualified rate of groundwater quality as shown in Table 5.

Table 5: Definition of the indicator Qualified Rate of Groundwater Quality

Title	Qualified Rate of Groundwater Quality
Definition	Case number of qualified groundwater inspection as a percent of total groundwater inspection cases.
Type	State indicator
Object	To indicate the state of water environment as well as environmental safe and sanitation.

3.5 Qualified rate of drinking water

The Huangpu River is one of the main sources of drinking water in Shanghai, as shown in figure 15. About 76% of the total amount of raw water is pumped from Songpu Bridge—the upstream section of the Huangpu River andsupplies the central district of Shanghai. The Huangpu river is a tidal river of medium size, with 300m^3/s of annual average discharge. The upstream section of the Huangpu River joins three major tributaries-Xietang, Yuanxiejin and Damaogang-at Songjiang and subsequently crosses the urban area before entering the sea at Wusong. The water quality of Songpu Bridge pumping station is shown in Table 6.

Table 6: Water quality at the Songpu bridge cross section ——2001 to 2005 (mg/L) [10]

Year	Parameters	DO	COD_{Mn}	NH_3-N	volatile phenolics	TP	Cd	BOD_5	anionic synthetic detergents
2001	Average	4.6	6.1	0.90	0.002	0.17	0.002	1.87	0.16
	Category	Ⅳ	Ⅳ	Ⅲ	Ⅰ	Ⅲ	Ⅱ	Ⅰ	Ⅰ
2002	Average	4.9	6.0	1.16	0.003	0.12	0.001	1.93	0.14
	Category	Ⅳ	Ⅲ	Ⅳ	Ⅲ	Ⅲ	Ⅰ	Ⅰ	Ⅰ
2003	Average	6.30	6.30	1.18	0.003	0.21	0.001	2.70	0.19
	Category	Ⅱ	Ⅳ	Ⅳ	Ⅲ	Ⅳ	Ⅰ	Ⅰ	Ⅰ
2004	Average	4.90	6.20	1.30	0.005	0.19	0.003	1.85	0.20
	Category	Ⅳ	Ⅳ	Ⅴ	Ⅲ	Ⅲ	Ⅱ	Ⅰ	Ⅰ
2005	Average	5.10	5.90	1.20	0.002	0.24	0.001	2.68	0.26
	Category	Ⅲ	Ⅲ	Ⅴ	Ⅰ	Ⅳ	Ⅰ	Ⅰ	Ⅳ

The water quality of the upper reaches of the Huangpu River (Songpu Bridge) was in the Ⅲ-Ⅳ category. The major pollutants were TP, COD_{Mn}, NH_3-N, volatile phenolics, etc. And also the DO was in category Ⅳ.

Figure15: Drinking water sources and the main distribution network in Shanghai [11]

4 Water Use in Shanghai

4.1 Intensity of surface water use

Table 7: Definition of the Intensity of Surface Water Use indicator

Title	Intensity of Surface Water Use
Definition	Ratio of annual surface water use to annual runoff
Type	Driving indicator
Object	To indicate the situation of surface water use

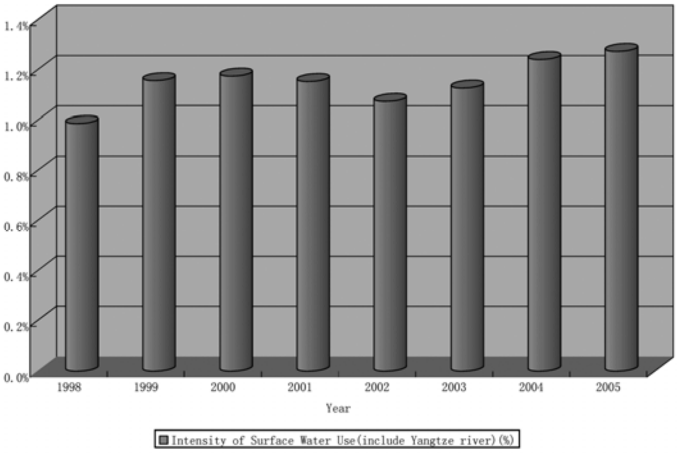

Figure 16: Intensity of surface water use including the Yangtze River [12]

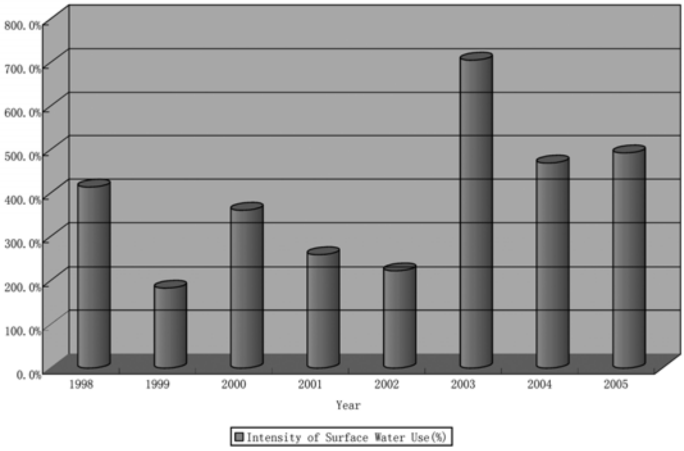

Figure 17: Intensity of surface water use excluding the Yangtze River

4.2 Intensity of ground water use

Table 8: Definition of the Intensity of groundwater use indicator

Title	Intensity of groundwater use
Definition	Ratio of annual groundwater use to annual available groundwater
Type	Driving indicator
Object	To indicate the situation of groundwater use

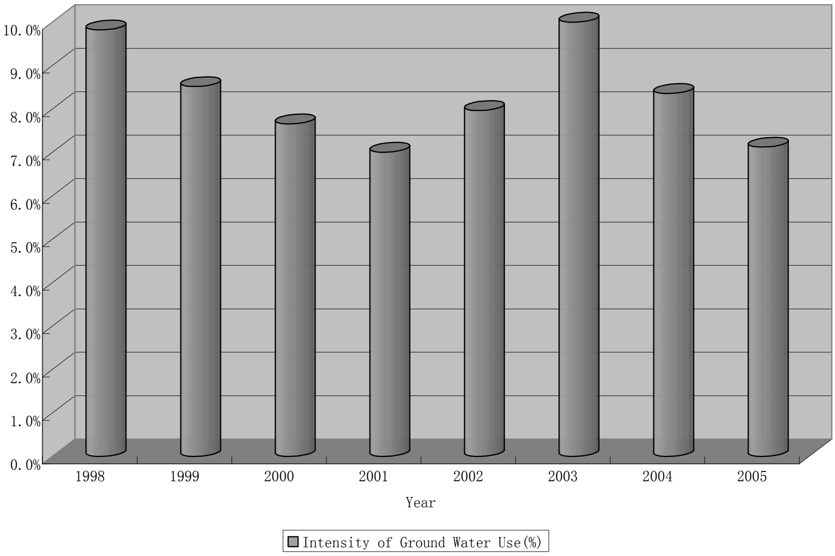

Figure18: Intensity of ground water use

4.3 Daily household water use per capita

Table 9: Definition of the Daily household water use per capita indicator

Title	Daily household water use per capita
Definition	Including daily residential consumption and urban livelihood consumption. Residential consumption includes personal use in drinking, bath, cooking, washing and others such as flower watering. Urban livelihood consumption includes business water use, such as restaurant, department store, hotel and swimming pool, and public water use, such as institute, company and fountain, and fire control water use.
Type	Driving indicator
Object	To assess avail water supply and personal demand of water and build up a future plan for basic demand of water.

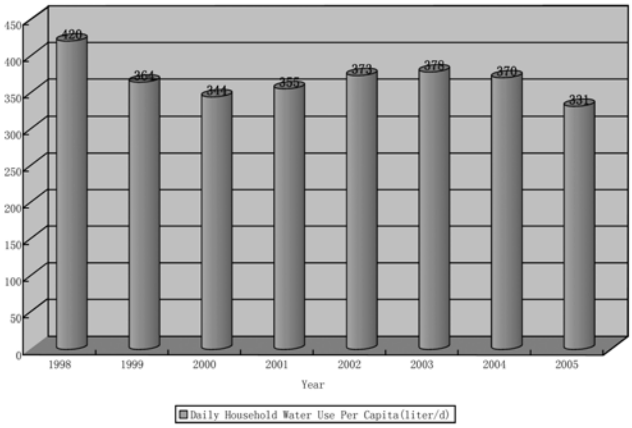

Figure 19: Daily Household Water Use per capita in Shanghai

4.4 Reuse rate of industrial water

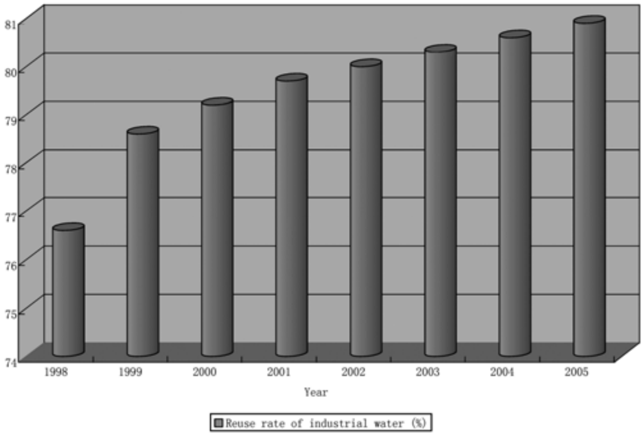

Figure 20: Rate of industrial water resuse in Shanghai

4.5 Agricultural water Consumption

Table 10: Agricultural water consumption

Title	Agricultural water consumption
Definition	Agricultural water consumption includes the water demand of crop, forest, aquaculture, pasturage and leisure business, which can be classified into irrigation, cultivation and poultry water use.
Type	Driving indicator
Object	To assess the basic demand of agricultural water, and to establish a plan for water demand in the future.

4.6 Water consumption structure

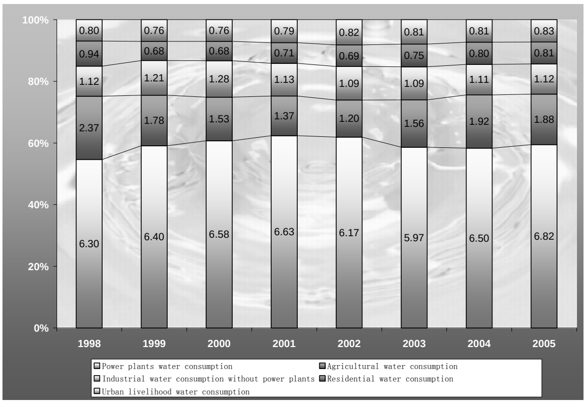

Figure 21: Water consumption structure in Shanghai (1998-2005)

5 Water Service in Shanghai

5.1 Percentage of the population with access to safe drinking water

In 1996 a project was completed in order to provide 20% of Shanghai's water from the Yangtze River.

Currently, two pumping stations, the Chenhang Reservoir and 40 kilometers of 2.7m diameter pipelines deliver 1.1 million cubic meters of water daily from the Yangtze River to Shanghai users. The Yangtze supplies residents of Baoshan, Hongkou, Zhabei, Yangpu, Putuo and Pudong with clean water (Class 2 or 3). These areas were formerly drawing purely on water from the polluted Huangpu River.

100% of Shanghai residents have access to drinking water in or very near their homes. However, some pipes and distribution infrastructure are known to be old and dilapidated.

Table 11: Definition of the Percentage of population with access to safe drinking water indicator

Title	Percentage of population with access to safe drinking water
Definition	Ratio of residents or nearby residents with access to safe drinking water to total population. Prevalence rate of population with access to piped water can be adopted to substitute for this indicator in Shanghai.
Type	Response indicator
Object	To measure the improvement and progress of percentage of population with access to safe dinking water.

6 Sewage Treatment Rate

Table 12: Definition of the Sewage treatment rate indicator

Title	Sewage treatment rate
Definition	Sum of the prevalence rate of public sewage system, the prevalence rate of special sewage system and installation rate of construction sewage facilities.
Type	Response indicator
Object	The function of the sewage system is to collect and treat urban sewage for improving urban environmental sanitation, promoting a high quality of life, preventing the basin from being polluted and ensuring good quality of water.

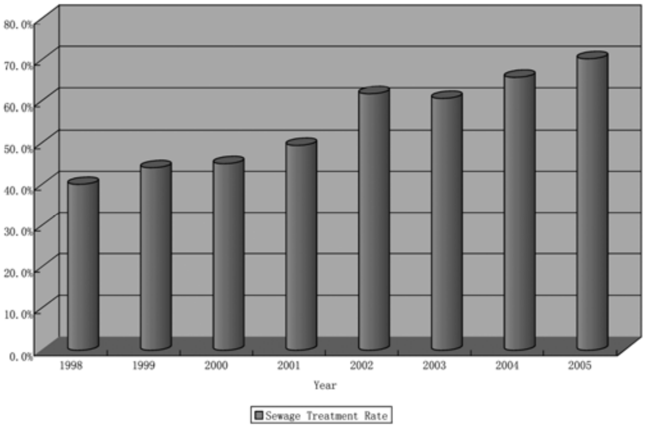

Figure 22: Sewage Treatment Rate

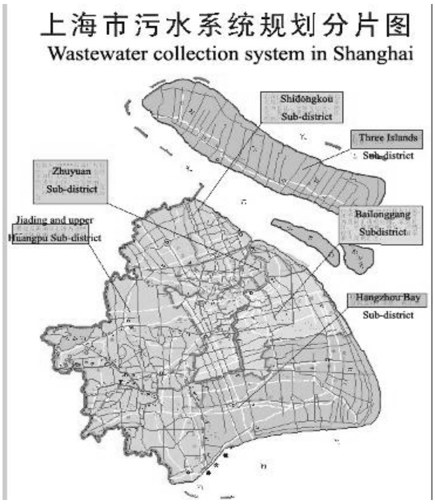

Figure 23: Wastewater collection system in Shanghai [13]

7 Drainage System in Shanghai

The drainage system in Shanghai is divided into 15 sub-basins, and the distribution within the areas and administrative districts of the sub-basins are shown in Table 13 and Figure.

Table 13: Sub-basins of the drainage system in Shanghai [14]

Name	Area （km^2）	Administrative district
North JiaBao	691	Jiading、Baoshan
South Yun	203	Baoshan、Zhabei、Yangpu、Hongkou、Putuo
North Dian	179	Changning、Xuhui、Minhang
South Dian	187	Minhang、Songjiang
Pudong	1977	Pudong、Minhang、Nanhui、Fengxian
QingSong	750	Qingpu、Songjiang
North Tai	85	Qingpu
South Tai	100	Qingpu、Songjiang
East Punan	479	Jinshan、Songjiang
West Punan	293	Jinshan、Songjiang、Qingpu
Shangta	32	Qingpu
Chongming	1183	Chongming Town
Changxin	76	Baoshan
Hengsha	50	Baoshan
City center	50	Huangpu、Jin’an、Luwan、Changning

Figure 24: Water conservancy system planning of Shanghai

8 Water Management in Shanghai

8.1 Laws and legislations

8.1.1 National water law of China, 2002

Implementation of this water law has helped China improve its water use efficiency, perfect its water resources administrative rules and fight against floods and droughts.

Originally promulgated in 1988, the National Water Law marked the beginning of China using legal means to manage water conservation. The revised water law, put into effect on Oct. 1, 2002, has offered legal support to help alleviate and solve China's three major water problems in the new century.

Under China's newly revised national water law, the country's vital water resources will be brought under integrated administration and management. Water authorities throughout China will control water supplies, the construction of key water projects, and help with resource distribution and planning to optimize regional water sources, control pollution and create a water-saving society.

After the validation of the revised National Water Law, more and more new regulations and guidelines were created. These actions have demonstrated that the central and local governments have paid more attention to integrated water management and tried to pave the way for an institutional mechanism to cope with water-related disputes.

Although, according to the newest water law, water authorities throughout China will control water related issues, in fact, management by separate departments is still the mainstream practice in China. Each department is driven by its own profit which has resulted in buck-passing among the departments. For example, on the provincial level, the water conservation bureau is in charge of the water quantity, the environment protection bureau is in charge of the water quality and the construction commission is in charge of the construction and operation of water related plants. These are all obstacles for the efficient enforcement of the "perfect" national water law. [15]

8.2 Tariff

Most of the funds supplied to the city of Shanghai for their water supply come from water tariffs. Water tariffs are calculated on a sectoral basis with some sectors paying a heavier tariff than others. In spite of progressively higher tariff rates, water tariffs in Shanghai are still low for both residential and industrial use. While data on the actual marginal cost of water supply is unavailable for Shanghai, we can assume that it is higher than the tariff charges by comparison to other Chinese cities. [16]

Table 14: Tap water tariff in Shanghai (2005)

Classification			**Price（Yuan/m^3）**
Domestic			1.03
Industrial and administrative			1.3
Commercial			1.5
Special function	Sauna	Charge<60Yuan/per capita	10
		Charge>60Yuan/per capita	15
	Foot massage		10
	Car washing		5
	Beverage producing		2.5

Table 15: Source water tariff in Shanghai (2005)

Classification		**Price（Yuan/m^3）**
Groundwater intake		0.1
Surface water intake	Private Establishment	0.06
	Public Establishment	0.021
	Others	0.06

Table 16: Wastewater emission tariff in Shanghai (2005)

Classification		**Price（Yuan/m^3）**
Residential consumers	Below the baseline	0.9
	Above the baseline	1
Others	Administrative units	1.1
	Average users	1.2
	Key inspected users	1.4

Table 17: Deep well groundwater withdraw tariff in Shanghai (2005)

Classification		**Price Yuan/m^3**
Public water supply companies		0.3
Direct users	within the public water supply service area	1.95
	out of the public water supply service area	1
Beverage producing	got the permission of ground water taken but without the permission of mineral taken	5
	got both the permission of ground water taken and the permission of mineral taken, and pay the compensation for mineral taken	1.00-1.95

9 Governance Structure

9.1 National agencies

In the past 40 to 50 years, China has carried out large-scale water conservancy projects, and made remarkable achievements. However, the allocation and management of water resources, particularly the systematic quantitative management is often overlooked. Due to historical reasons and management structure, China's water resources management has been fairly extensive but it usesoutdated management ideology, management technology, and quantitative measurement facilities that are unable to meet the management needs of water resources. Water administration departments can't implement effective supervision and management of the utilization and protection of water resources. Consequently, on one hand it makes the limited water resources, on the other hand usage efficiency is not high, pollution is severe and its renewable nature is greatly affected.

China's water management is often referred to as the 'nine dragon administer the Water': Ministry of Water Resources, SEPA, the Ministry of Construction, Ministry of Agriculture, Ministry of Forestry, National Development and Reform Commission, the State Power Corporation and the Ministry of communication. Multi-sectoral 'collaborative water management' is to collect multi-sectoral efforts to achieve effective water management. China's major water management agencies and their related functions (departments) are shown in Table 18.

Table 18: National Agencies Related to Water

Departments	**Content of management**	**Main functions**
Ministry of Water Resources and Conservancy (MOW)	Surface water, groundwater and river basin management, flood control, water and soil conservation	Utilization and protection of water resources planning, flood control, soil conservation, water districts planning and management of water resources
National Environmental Protection Agency(NEPA)	Water Pollution Prevention	Protection of the water environment, water quality zoning, the total amount of pollution control standards and develop water environmental standards
Ministry of Construction (MOC)	Urban water for industrial, urban water supply and drainage	The drainage and sewage treatment projects, urban water supply planning, construction and management
Ministry of Agriculture (MOA)	Water for agricultural, fishery water environment	Control of non-point source pollution and protect the environment of fishing waters and aquatic wildlife habitat
Forestry Administration Bureau (FAB)	Water Conservation	Watershed ecology, water resources protection and management
Ministry of Electric Power(MEP)	Hydropower	Construction and Management of large and medium-sized hydropower project
National Development and Reform Commission (NDRC)	Involved in the preparation of water resources and ecological environment construction plan	Water resources development, the layout of productive forces and ecological environment construction planning, convergence balance agriculture, forestry, water conservation planning and policy development
Ministry of Transportation(MOT)	River shipping vessels, sewage control	River shipping management and pollution control
Ministry of Public Health (MPH)	Supervision and management of environmental Hygiene	Supervision and management of drinking water standards
Ministry of Geology and Minerals (MOGM)	Groundwater	Explores and documents groundwater resources.

9.2 River basin commissions

Although China has seven major river basin management institutions, the focus of the work of these agencies are to protect against floods, droughts and soil erosion, the prevention of water pollution in border region and so on. They don't have the right to manage administrative and economic issues, and the Environmental Protection Agency and other departments in dealing with environmental issues; there is no way towards a sectarian approach to management systems, and as a result are not really playing the role of watershed management. Although NEPA is fully responsible for the protection of the water it shares the right with other organizations. Environmental policies dealing with water, low water prices and free use of water is not conducive to water conservation. In addition, there are still serious fragmentation problems between the various government departments, enterprises and businesses.

Figure 25: Major river basins in China

9.3 Shanghai (provincial and municipal) agencies

The highest governmental level in Shanghai is the Shanghai's People's Municipal Government (SPMG or SMG). The SMG is responsible for provincial duties such as planning, surveying, designing, constructing, operating and managing irrigation, drainage, flood control works and rural hydropower. It is also responsible for county and municipal tasks such as constructing and maintaining canals, related irrigation and flood control structures and medium-sized reservoirs (WB, 1997). Figure 26 shows the structure of the most significant bureaus for water management in Shanghai.

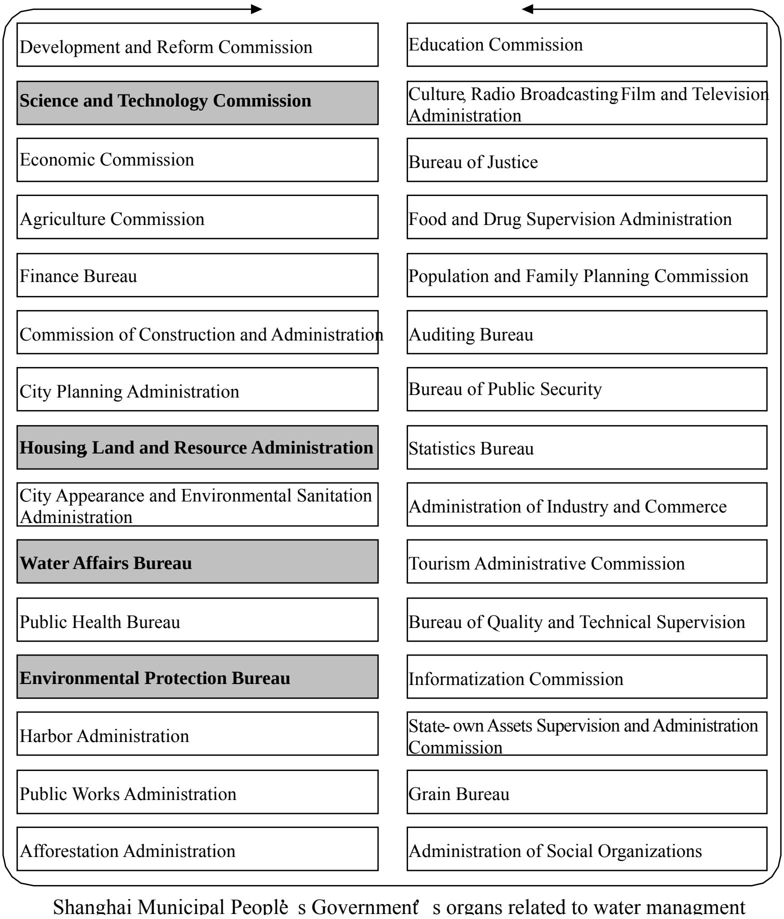

Figure 26: Structure of the water management departments in Shanghai [17]

10 Summary and Recommendations

10.1 Problems and barriers hampering water management

Currently, the shortage of good quality water resources and worsening water pollution of water resources has become an increasingly obvious contradiction that threatens the safety of the water supply. It has posed a serious threat to food security, environmental security and sustainable development.

10.2 Escalating problems in water supply

The escalation of problems is illustrated in the example of Shanghai, where over the past 50 years, water demand has increased rapidly with economic development and population growth. Moreover, the distribution of water consumption distribution across different fields has also changed. Industry remains the major consumer with 69.3% of the total water consumption in Shanghai. In order to meet the increasing demands of population growth and industrial development, water saving becomes essential. Increased water demands require enormous capital investment, improvement of operation and proper management.

10.3 Shortage of good quality water

In Shanghai, the most pressing water issue is not water quantity, but quantity of high quality (class 3+) water. This is because the rainfall in Shanghai is abundant, with 129 rainy days annually an average annual rainfall of about 1,184.4mm. There is an average of 2.415 billion cubic meters of annual local available surface water resources;, Tai Lake has an average of 10.66 billion cubic meters and the the Yangtze River has an average of 933.5 billion cubic meters.

However, the quality of most of this water is low as groundwater aquifers have been contaminated. Most of the Huangpu is below potable water quality the Huangpu's tributaries are toxic in most areas and the rainwater is heavily acidic. The average pH value of precipitation was 4.93 and the occurrence of acid rain was 40% in 2005.

For the assessment of the river water quality, we use the indicator of the Percent of Slight and Non-contaminated River Length to Total Monitoring River Length to illustrate the pollution level of the main rivers. In 2005, 612.9 km of rivers were monitored and only 14.0% were slightly or non-contaminated, 17.7% were classified as Class IV quality , 22.2% were classified as Class V, and 46.1% of the rivers were seriously contaminated or worse than Class V according to the National Surface Water Quality Standard (GB3838-2002). [18]

10.4 Shrinking of river channels

Upstream regulation of the Three Gorges reservoirs made peak floods decrease greatly in the Yangtze River over the past few years, causing most sediment to deposit in the main channel of the river. This, in addition to irrational reclamation of floodplains along the river, caused a shrinking of the channels. Compared with the percentage of water coverage in the 1980s, there has been a decrease of 2.7%. The most seriously affected area would be the city center as the water coverage composes less than 2.5% of the total land area and could increase the possibility of urban flooding due to the decreased capacity of streams and river channels to prevent flooding.

10.5 Insufficient wastewater treatment

Water pollution has caused ecological degradation, declined the water quality of the rivers, lakes and reservoirs, reduced the utility value of water and consequently made the water shortage even more serious. The function of the sewage system is to collect and treat urban sewage in order to improve urban sanitation, promote a good quality of life, prevent basins from being polluted and ensure a high quality water source.

Although, Shanghai has put a lot of effort into increasing the wastewater treatment level, it is still insufficient compared with the rapid economic development. The total wastewater treatment capacity now is about 4.181 million m^3/d, while the total wastewater discharge is 2.173 billion m^3/a and the rate of the treated wastewater is only 70.2%.

10.6 Low efficiency water consumption

The limited high quality water resources have not been efficiently used due to technical, economic and management reasons. The rate of reuse in the industrial sector for the city is about 80.9%, and Daily Household Water Use Per Capita is 331 (liter/d), and water consumption per ten thousand GDP is 125.3 (m^3/10,000Yuan).

10.7 Salt water intrusion and land subsidence

Over the last few decades, groundwater in Shanghai has been overexploited causing saltwater intrusion from the Yangtze River. The Chenhang Reservoir is Shanghai's main water source and is now faced with saltwater intrusion from November to the following April.

Subsidence has been another big problem in the Yangtze Delta with an average velocity of subsidence of about 10.78mm/a year from 1998-2004.

10.8 Social demands and water management

Due to economic development and population increase a lot of water originally available for agriculture is now being used to supply cities and industry. This causes conflicts between towns and counties and production and living needs, all on top of the environment's water needs. It is unclear how many options the different interest groups have for coping with these conflicts.. If actions are taken without clearly defined goals or insufficient planning there is the possibility of decreasing social solidarity and decreasing social justice. Social conventions can break down. It seems that social conventions are broken. Nevertheless, an equal balance between economic, environmental and social needs is almost impossible. Water saving techniques that would be cover all types of users are usually considered too expensive, especially when the price of water charged to the different users does not necessarily reflect the true cost of water.

10.9 Newer technical developments upsetting decision making

Water management today can take advantage of the rapid development of data processing and modelling techniques, remote sensing technology and GIS systems. Extensive background knowledge on hydrologic and bio-chemical processes important for water management have never been applied as widely as today. However, these advantages are being counteracted by factors such as older water managers and administrators who are not keeping pace with the necessary knowledge of the latest techniques. Therefore, decision makers must increasingly rely on modelling results produced by technically qualified (computer) specialists who may have little experience in the realm of water management.

This could lead to a waste of money as well as measures that are in practice less sustainable than they might have appeared in the models.

10.10 Administrative constraints affecting water management

Some problems appeared to be technical but were actually administrative, such as:

- Lost data: New projects, often dealing with issues that have been previously addressed, have to start from zero.
- Lack of, and inappropriate use, of data: Time and space resolution ratio are often not available from standard data sources.
- Coping with Change: The fast growth and changes in urban and rural areas also make it difficult to make appropriate forecasts.

Reliable financial and social data are of equal importance for water management. The different dimensions and conventions in the different sectors make it difficult to use the data in a correct manner. Nevertheless, the major constraint is not technical but organizational and administrative.

Planning and management activities often do not adapt to site specific conditions. A common problem is the simple implementation of technology or procedures that may be inappropriate to the problem at hand. This issue can be solved by an improved resource base, but will also need to include improved training.

Insufficient institutional competence at various government agencies not only hinders alternative and locally adapted solutions, but also acts as a barrier for adequate traditional infrastructure solutions? The artificial subdivision of real-life scenarios into solid categories can make it difficult to cultivate interdisciplinary thinking.

Perhaps the biggest administrative issue is the practice of shifting responsibilities and duties, a phenomenon met in developing and developed countries alike. It implies that when a problem is recognized, all or some parties involved decide that they do not want to become involved in either the problem itself or the removal thereof, especially when high costs may be met or when difficult political hurdles are foreseen. The general attitude in such cases is either to deny responsibility for the recognized problem or to claim that they are not the affected party. What it boils down to is not only the question of who is legally responsible, but also who is prepared to take up the problem and actually make improvements. As long as the parties involved keep shifting responsibilities, no improvement will be made.

10.11 Political and financial constraints affecting water management

Political constraints are often much more significant than technical and administrative ones. One should be aware of the following:

- In the composite process of planning of water resources management, there is often a discrepancy between financial and technical tasks. When selecting a technical solution to a water scarcity, pollution or remediation problem, a purely technical approach disconnected to financial realities, could create unrealistic solutions. Also, the final decision lies with political decision makers, who may have little or no technical and economic background.

- The general organization and management structures frequently are unable to clearly identify the interaction of technical, financial and social problems and find integrated solutions. Decision makers on the political level may find the process of bringing together engineers and environmentalists to resolve their fundamental philosophical differences about how to solve a problem, confusing.
- There is a general tendency to deal ineffectively with risk. Unknown features of the planning process tend to paralyse decision makers, limit the innovative potential and result in stagnant technology and inappropriate solutions. New methods of risk assessment and a public discussion of the risks involved in a particular approach are needed.
- The political pressure under which planning processes must progress, often block an efficient planning procedure.
- In general the planning process tends to be reactive rather than proactive. This tendency unfortunately increases at higher levels of responsibility.. Due to the observations listed above, science, technology, engineering, design, ecological analysis, impact assessment and a range of other factors operate as reactive systems.
- Traditional water resources management has always suffered from the gap between the time (up to ten years) that is required to monitoring and model the existing conditions and processes in specific environments such as river catchments and the short time frame within which individual measures (sometimes less than one year, in case of chemical accidents minutes) must be decided. As a result, often times decisions cannot be checked against longer-term water management objectives and information. This usually results in low efficiency and high costs.

The obstacles mentioned are seldom isolated ones. More commonly they are linked with each other, although connections may not be recognized at first. It is also recognised that the traditional ways of water resource management must be markedly modified in order to cope with these deficiencies along with the continuing increase of water problems in general. It is clear that today’s water problems can only be tackled by efficient and well-experienced water resources management bodies with sufficient political support.

11 Sustainable Water Management Practice in the Future

Sustainable Water Management is management that attempts to maintain water resources for future generations without compromising the natural hydrological recycling or ecosystem integrity. It is the time to improve water management efficiency and actively promote reform of water management in Shanghai. Shanghai’s water management should change from traditional “static water management” to “dynamic water management”, from “experimental water management” to “scientific water management”, from “departmental water management” to “integrated water management”. [19]

The suggested sustainable water management system in Shanghai will change from the traditional "water management by nine dragons" system to "water management by one dragon" system. It means that a local sustainable water management association including the water related government departments should be set up under the direction of a Chief Executive. The association will be in charge of the integrated functioning of flood control, waterlog removal, drought fighting, watershed construction, water supply, drainage, water saving, wastewater treatment and recycling, rain water harvesting, ground water recharge, watercourse renovation, water and soil conservation, water resource protection and so on.

To succeed on its own terms, sustainable water management must act as a tool to promote good environmental governance, ecological protection, social progress, and ethical business practice on the river basin scale. Many communities will continue to struggle with how to practically apply sustainable principles. A set of indicators can act both as a road map to sustainability for local government and as a practical checklist for community activists to track local progress against sustainable principles.

Indicators are the ideal means by which progress towards sustainable development can be measured. However, most indicator initiatives throughout the world have been aimed at state-of-the-environment reporting, with relatively few aimed at developing sectoral indicators. The framework for a sustainable water management indicator system for Shanghai is the first output of an on-going research project in Shanghai. Normally, sustainable indicators can be classified into economic, social, environment and ecological indicators. However, the specific sustainable water management indicator system for Shanghai is based on the integrated natural water cycle, social water cycle and the Pressure-State-Response framework. This integrated indicator system consisting of 4 items, 9 assessment fields with a total of 32 indicators, is selected based on broad scientific investigations and specific local research.

In the future, research will be done on the following:

(1) Consultation on the indicators with experts and local communities.
(2) Quantification of the indicators and specific data collecting.
(3) Comprehensive assessment of the indicator system.
(4) Scenario design and indicator forecast.
(5) Decision support to the government and annual reporting to the public on the indicators.

Overall, sustainable water management is a comprehensive system approach and it should be part of both global thinking and local actions. An indicator system is the core part of complex sustainable water management. Believe it or not, making wise decisions regarding water is our common responsibility.

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Sustainable Water Management
- Chance for Mega Cities?

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Abstract

In 1950 30% of the world's population lived in cities, in 2000 it was 47% and in 2007 more than half of the world's population. Mega cities are considered to have more than ten million inhabitants. Natural growth (the excess of births over deaths), migration from rural to urban areas, and redefinition of administrative boundaries incorporating rural surroundings add to the growth of cities to mega cities. Obviously developing countries presently go through the same processes and harmful activities, as developed countries did in the last century, only at an exponentially larger scale, due to the sheer size of their populations. Thus mega cities need water in quantities, that severely impact local, regional and global water and matter cycles. Water problems of mega cities are not restricted to water scarcity, but efficient distribution, production of waste water and resulting receiving water pollution, both of surface and groundwater, flooding and global change impacts. Effective solutions for water infrastructures only are found by analyzing local water demand and resources conditions. There is no rule, whether it is better to have central or decentralized concepts. However, large-scale central water supply and disposal systems seem less sustainable than smaller autarkic half centralized or decentralized systems. Operation of smaller units also is less vulnerable. But a conventional structure of water authorities also opposes new methods and approaches. A straightforward set of indicators is suggested to evaluate sustainability. Applying these indicators to an urban development it was found that the evaluation results depend on the choice of indicators, physical and time boundaries rather than on data uncertainties. It is agreed, that sustainable water management solutions mainly can be influenced in the preplanning and planning phases, when precise data are not available. In consequence indicator based decision support needs rather uncomplicated methods to evaluate sustainability. It is concluded, that sustainable water management may be the only chance for mega cities in developing countries to survive.

摘要

20世纪50年代，世界上有30％的人口居住在城市，到2000年，这一比例是47％，截至2007年，超过一半的世界人口居住在城市。特大型城市特指居住人口超过1000万的城市。自然增长（自然出生率>死亡率），农村人口向城市地区的迁移，城市行政区域边界的不断延伸包含了更多的原有农村地区，这些因素都进一步加速了普通城市向特大型城市转化的进程。很显然，发展中国家正面临着与上世纪末发达国家所经历过的同样的过程和困境，但是，由于庞大的人口基数使得发展中国家所面临的问题呈指数增长态势。由于特大型城市需要有充足的水量保障，这进一步严重影响了当地的、区域的、全球的水资源循环。特大型城市的水资源问题不仅仅是缺水，还包括不合理的水资源分配，大量废水的产生以及受纳水体（地表水和地下水）的污染，城市洪水和全球变暖。有效地解决水资源问题的方法只能建立在对当地的水资源需求和现状条件的科学分析的基础上。集中式和分散式的水资源管理各有利弊，没有一个固定的标准去判定哪个更优。然而， 大型的集中式供排水系统看上去比小型的半集中式或分散式的供排水系统更为不可持续，且小型装置

的运行更为稳定。然而，传统的水资源管理机构往往反对新方法和新措施的实施。对于水资源管理可持续性的评估，需要有一套简洁明了的指标体系。把这些指标体系用于有效衡量一个城市的发展程度，取决于指标的合理选取，物理和时空边界的确定，数据的不确定性分析。一般来说，在没有精确数据的前提下，可持续水管理的解决方案在预可研和规划阶段会受到较大影响。因此，基于指标体系的决策支持需要相对不复杂的方法来评估水管理的可持续性。综上，可持续水管理是发展中国家特大型城市在未来赖以生存的唯一途径。

1 Introduction

The need for sustainable water management gained recognition after the United Nations Conference on Environment and Development in Rio de Janeiro in 1992, known as “Earth summit”. Ten years later, the World Summit for Sustainable Development in Johannesburg 2002, reiterated the need for sustainable development to relieve the pressures on natural resources. Today in the fast growing cities of China only sustainable water management can stop the escalating water problems.

1.1 Development of mega cities and pressure on resources

Urbanization lately increases rapidly on a global scale, mainly in developing countries. In 1900, less than 14 % of the world’s population was urban, 30% in 1950, 47% in 2000, and today 3.3 billion people, more than half of the world’s population live in cities. In China for example, the number of cities since the 1980s increased from 180 to 666 (Harvey, 2006), because of industrial development. Economics in cities grow much faster than in rural areas, as industries need people and growing industries attract more people all over again. In China in 1952 GDP per capita was 119 Yuan, 275 in 1970, 460 in 1980, 1634 in 1990 and 7078 in 2000 according to the Chinese national statistics bureau. Thus migration from rural to urban areas is accelerating, being the key factor for mega city escalation.

In China and in whole Southeast-Asia, Africa and South America a new phenomenon occurs, namely that many cities grow together and form mega cities, i.e. in the Pearl River Delta between Hong Kong and Guangzhou, in the Jakarta-Surabaya-corridor and Japan’s Tokaido corridor between Tokyo, Nagaya and Osaka (Geiger, 2004). The term mega city conventionally applies to cities with over 10 million people. According to this definition in 1950 New York was the only mega city, while there were five in 1975, 17 in 2001 and today more than 21. However, there is no standard criterion for defining mega cities´ boundaries. For example, Shanghai’s city boundaries include a large population outside the city assets, such as land used for agricultural purposes. Other cities, such as Bangkok, Jakarta, Manila, and Taipei may be twice as large as the official figure; tightly drawn city boundaries omit peri-urban areas just outside the city.

Agenda 21 (Chapter 17.3) noted that more than half of the world’s population lived within 60 km of coasts (United Nations, 1992). It was projected that by 2020 this part would rise to two thirds. Satellite images of the earth by night and computer generated images of population distribution (NSA http://www.earthobservatory.nasa.gov) clearly depict differences with major concentrations along the coasts of the Indian and Asian subcontinents. As economic growth and urbanization are correlated, coastal resources are exploited at particularly unsound rates. This is true for the Asia-Pacific region controlling almost two thirds of the globally vital atmospheric and oceanic phenomena, such as the Asian Monsoon and the El-Nino Southern Oscillation phenomena (Harvey, 2006).

1.2 Urban water problems and limits of urban growth

Although increasing water demand seems of major concern, water problems of mega cities are not restricted to water scarcity, but embrace efficient distribution, production of waste water, surface and groundwater pollution and flooding, all of which again aggravate water scarcity. Developing countries go through same processes and harmful activities, as developed countries did in the past, only at an exponentially larger scale due to the sheer size of their populations and available modern technologies. On top they face global climate change impacts affecting local hydrology. Further, economic development changes water allotment among different users. In Shanghai for instance industrial water consumption in the past 50 years increased from 20% to 69.3% of the total water consumption requiring enormous capital investment, whereby there the most pressing water issue is not quantity, but quality. Groundwater overexploitation in coastal regions and rising sea levels lead to saltwater intrusion, i.e. along the Shandong coastline and in the Yangtze Delta in China.

Another problem for water management in mega cities is that data collection cannot keep pace with the fast growth and changes making appropriate forecasts difficult. Time and space resolutions needed for different planning purposes often are not available from standard data sources. Sometimes data records are not made available or lost and new projects dealing with issues, that have already been addressed previously, have to start from zero. Reliable financial and social data are of equal importance but seldom are linked to water management. The different dimensions and conventions in the different sectors make it difficult to use data of different sources in a correct manner (Geiger, 1995a). Further planning and management activities often are insufficiently adapted to site specific conditions. A common fault is the simple implementation of technologies or procedures that are copied from somewhere else and may be inappropriate to the problem at hand.
Infrastructures, i.e. for water supply and drainage begin to limit the growth of mega cities. Obviously the increasing water problems of mega cities cannot be solved with conventional supply and disposal systems. Related policies and standards developed on past experience fail. Economic based decision making, overcome financial mechanisms, sectorial organization structures and lack of law enforcement exaggerate the technical problems. The mega cities´ problems together with the pressing heritage of the 20th century, that is one billion people not sufficiently supplied with drinking water, two billion people not having adequate sanitation and four billion people polluting water resources, encumber the future.

1.3 Socio-economic implications

Access to public services such as clean water and health services, is closely linked to wealth, whereby in mega cities due to the speed of growth the poor often live in slums not reached by public services. However, access to water is one of the most crucial means to escape from poverty. People usually recognize water shortage and serious water pollution as technical failures, but rarely identify them as the results of mismanagement or as a social problem. Unfortunately in mega cities water management hardly ever is a holistic action of urban growth and economic development policy, associated water demand. Consequently water supply and wastewater collection and storm drainage systems are done by piece meal actions and do not involve all affected administrative institutions, enterprises, public interest groups and general public, as it should be. So many water problems simply are political or administrative.

Due to economic development and population increase in urban areas water needed and originally available for agriculture is now being used to supply cities and industries usually having more political influence due to their economic strength (Geiger, 2005). This causes conflicts between cities and counties, production and living, not even considering environment needs. Action without clear and balanced goals leads to progressing dynamics of the problems. Social justices get lost and social solidarity decreases. It can be observed, that social conventions in rapidly developing cities. An equal balance between economic, environmental and social needs almost never is achieved. Available techniques, i.e. for water saving often are considered to be too expensive, especially, when water prices charged to the users do not meet the true cost of water.
Insufficient competence at various government levels and the artificial subdivision of the holistic reality into different sectors makes it difficult to cultivate interdisciplinary thinking. Maybe the biggest constraint is the shifting of responsibilities and duties, a phenomenon met in developing and developed countries alike (Geiger, 1995a). The question is not only, who is legally responsible, but also who is prepared to take it up. Finally political constraints and corruption often are much more significant than technical and administrative problems. Answers may lay in highlighting local ownership and governance rather than central control and pricing policies (Geiger, 1994).

2 Sustainability and Water Management

Water in times of urban and economic growth usually is considered a commodity rather than part of development. This in history not always has been the case. The increasing water problems helped to understand, that sustainable water management not only forms development but also future life.

2.1 Ancient views on sustainability in water management

Hesiod about 800 BC pointed out the basic connection between water pollution and health of man. At that time it needed 300 years until sanitary measures were installed in Greek cities, although they existed in earlier cultures i.e. in Mesopotamia. Some 2500 years ago Confucius (551 - 497 BC) urged people to use water sparingly to guarantee the continued existence of permanent water use. It also is delivered, that he said”If there were no sustainable rivers, where is the sustainable nation? If there were no sustainable waters, how can we have sustainable civilization? Water, has a long memory”. Lao-tse, his respected teacher said”Rivers, lakes, broad and deep sea, are the cradle of living things”.

Already ancient cities as Miletos practiced integrated water management. It needed creativity to combine art and architecture with social needs using the knowledge on hydrology and technical innovations. This comprehensiveness attracted philosophers to deal with water. Thales of Miletos (624 to 545 BC) first established theories on the water cycle, which later were discussed by Platon (427 to 347 BC). Palissy (1510 to 1590) almost two thousand years later finally added scientific explanations. Descartes in his Rules for the Direction of the Mind 1629 stated “If anyone wishes to search out the truth of all things in earnest, he/she ought not to select one special science, for all the sciences are co joined and interdependent", which today may be considered a scientific insight to sustainability. However, the theory of a continuous water cycle and the obviously ever repeating rainfalls and never drying up springs and rivers left the opinion that water resources are unlimited, an opinion which still is reflected today by high water consumption in regions, where water is scarce. Water became a commodity which everyone uses and disposes without thinking of its origin and its destination.

Maybe for the first time the idea of sustainability was quantified by Carl von Carlowitz (1645 -1714), a German forestry engineer (Carlowitz, 1713). He defined the very simple balance which has to be fulfilled to reach a sustainable status for a given forest unit: “the amount of wood cut in one year should be equal or less the amount of wood growing up in one year”. At last this is a clear definition of what is meant by the expression “carrying capacity of supporting ecosystem”.

2.2 Remarks on today’s understanding of sustainability

Today’s sustainability discussion usually is linked to the World Commission on Environment and Development, which in 1987 defined sustainable development as a “development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs” (Brundtland report, WCED, 1987). Earlier in the 70´s of the last century United Nations (1994) and UNESCO (i.e. 1987 and 1996) through its International Hydrologic Programs (IHP) strongly promoted integrative water management. Dimensions of sustainability then were agreed to be economic, environmental and social. There were, however, different opinions, which dimension should be dominant and if equal by which dimension equity is expressed (Geiger, 1995a).

Figure 1 illustrates different views of sustainability. The circles in Figure 1(a) identify the three dimensions environment, society and economy as being equally important. The interactive system-environment model of Figure 1 (b) refers to the ideas of system theory. It describes that the human-social-system is a part or a sub-system of the ecosphere-system and again the economic-system is a sub-system of the human-social-system. This is correct in a scientific view but does not reflect the typical priorities in practical decision making. There typically the environment is not the biggest and the dominating system but the weakest, as indicated by Figure 1(b). All of these presentations are not helpful, to evaluate sustainability, unless the circles would be given dimensions.

There are different opinions, which dimension should be dominant and if equal by which dimension equity is expressed. To express equity, a monetary currency certainly is not suitable. Environmentalists may have the opinion that the most sensitive dimension of sustainability is the environment being connected strongest to the potential of development for future generations. Thus the World Conservation Union, the United Nations Environment Program and the World Wildlife Fund for Nature defined sustainable development as a development that improves: “the quality of human life while living within the carrying capacity of supporting ecosystems.

According to the Commission of the European Community, the characteristics [criteria] of sustainable development are to maintain the overall quality of life and the continuing access to natural resources as well as to avoid lasting environmental damages. Sustainable water management has to ensure, that todays and future societies can live without compromising the natural hydrological cycle and ecosystem integrity (UNESCO, 1996). In short: “sustainability avoids future regret for decisions made today” (GEIGER, 2004). However, all of these definitions are too general and thus of limited use for decision making in water management, unless precise indicators are formulated.

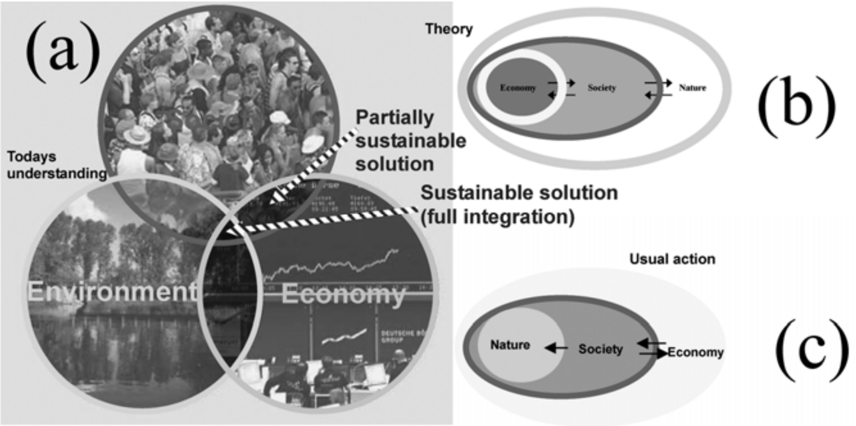

Figure 1: The three dimensions of sustainability (a) according to Munasinge (b) according to Kanatschnig (extracted from Russ, 2000)

2.3 View of sustainability in different development stages and scales

Frequently it is not understood, that sustainability of water systems differs in time and space. A sustainable water concept developed for an individual property may not fit into a sustainable solution on city level. And again a sustainable city concept may not fit into integrated river basin wide water management strategies. Even more sustainable water management must comprise social, cultural and heritage diversities. It must include social, ecological, ethical and not above all economic principals.

The greatest influence on sustainability is given, when the decision for a project is made. For instance one may agree to have Olympic Games, but the decision, that they should be larger than ever before or have architecturally impressive stadiums or superb infrastructure of course determines sustainability level of such games from the very beginning. Of course once such decision is made one still should strive for sustainability during construction and operation, but it is clear, that the greatest chance for sustainability had been missed by the initial decision.

The different components which make water management sustainable do not receive the same priorities at all times. At different stages of societal development different objectives are considered more important. In a pre-industrial society, emphasis is placed on drinking water supply and irrigation. In a industrial society, generation of hydropower and waste disposal and transport are prioritized. Finally, in a post-industrial society, high emphasis is placed on aesthetics and ecology. Figure 2 sketches the interaction of industrialization and the environmental condition. While the existence of changing priorities must be recognized, still lower priority uses cannot be neglected over a long run of time, because of the interdependency of various uses.

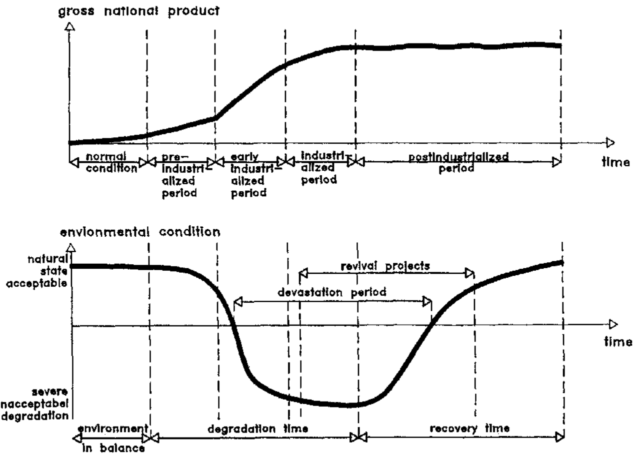

Figure 2: Interaction of industrialization, economics and environmental condition (UNESCO, 1996)

3 Development of Water Management Options

Water management starts with assessing the hydrologic, geological, environmental, socio-economic and other relevant conditions and comparing these conditions with objectives. The objectives may be general, i. e. minimization of flood damage or maximization of amenity value or they may be specified by water laws and regulations, i. e. water quality levels to be achieved or limiting pollution concentrations discharged. While formerly for assessment of existing conditions extensive monitoring and surveying programmes were conducted today surface materials, slope and structures and even surface water quality conditions can be assessed by using satellite data (Bach, 2006). Such an assessment only may take few weeks.

The next step is to arrive at a set of measures to alleviate certain problems. Today there is a pronounced tendency to use all kinds of models for developing water management strategies. However, mostly it is overlooked, that all models have limitations and only can be as good as the input data available. Especially at the beginning of concept development the detailed data to drive models do not exist. Often the quality of planning data not justifies the efforts to do detailed modelling. Therefore in a first instance it is suggested to establish toolboxes of different measures which include their effectiveness as well as implementation and operational costs. Such catalogues may include both technical and non-technical measures. An example for such a toolbox matrix is given in Table 1. From these toolboxes different scenarios can be derived. Finally different scenarios of measure combinations should be compared for their environmental and resource costs.

Defining resource and environmental costs appropriately not only takes economic experience but time. If the problems identified are significant usually it is better to immediately start with implementation of the most effective measures and conduct further detailed investigations later. However, if costs or measures do not find social acceptance politics have to decide whether they want to change their political priorities or lower the objectives.

At present there are no generally and applicable decisions support systems for water management. For individual river catchments, such as the Rhine, Danube or the Elbe river in Germany or the Yellow and Yangtze Rivers in China large research efforts were undertaken.

Table 1: Partikular example for toolbox matrix to deal with water shortage and flooding (Geiger,2004a)

	Purpose/technical objective				
Water management measure	Saving water	Maintaining water balance	Flood control	Control of stream erosion	Storm water pollution control
Water-efficient appliances	P, H, A	P, H, A			
Roof water tanks	P, M, C	P, M, C			
Grey water reuse	P, H, E	P, H, E			
Wastewater reuse	P, H, E	P, H, E			
Green rooftops			P, H, E	P, H, E	
Porous paving			PS, M, A	PS, M, A	
Aerial infiltration			PS, H, C	PS, H, C	
Infiltration swales			PS, H, C	PS, H, C	
Percolation trenches			PS, M, E	PS, M, E	
Aquifer storage & recovery systems	PS, H, E	PS, H, E			
Groundwater recharge facilities		SD, M, E	SD, L, E	SD, L, E	
Erosion & sediment control				D, H, A	D, H, A
Filter strips					SD, H, C
Responsive street layout					SD, H, C
Storm water tanks					SD, H, E
Ponds and wetlands					SD, H, A
Soil filter basins					D, H, E
Landscaping					

location	efficiency	costs
P = Lot level	L= low	E = expensive
S = Subdivision level	M = middle	A = average
D = Division level	H = high	C = low

Solving water problems of mega cities requires typical solutions for each city, each part of it and even for each neighborhood. What functions in one city may be fully inadequate for another location. This calls for decentralization of responsibility and action. It was found, that the larger a city is the more water infrastructures should be subdivided into smaller autarkic half centralized or decentralized systems. Operation of small units also is less vulnerable. It cannot be overlooked, however, that conventional structures of water authorities oppose the introduction of a half or decentralized water system.

Last not least it should be mentioned that water management planning by itself will not solve problems but only helps to identify the most socio-economic comprise to achieve a good status in surface and groundwater. More important it is to implement measures and to enforce laws i. e. controlling industrial or other emissions.

4 Sustainability Assessment and Objectives

For the evaluation of sustainability there is a basic distinction between:

- Strong sustainability: preservation of natural capital cannot be substituted by any other form of capital and a balance must be fulfilled for every case.
- Weak sustainability: depletion of natural capital can be substituted by man-made capital, as long as the sum of both is not decreasing.

This distinction is important for the definition of objectives for sustainability evaluation. Politics today still assumes that one only should meet weak sustainability. Global warming may change this attitude. To solve the severe water problems in mega cities, one should strive for strong sustainability.

4.1 Structure and goals for sustainability evaluation

The first intermediate step for any evaluation is the classification of objectives. To achieve the objectives, criteria (sometimes called index) must be defined, which may comprise of one or several indicators. Figure 3 suggests a thinking structure for the sustainability evaluation. Essential is, to select indicators, that are not overlapping but calculable. Vital is, to merge these indicators in a way that evaluation for sustainability is not distorted. Finally the indicators are calculated for all alternatives and merged to one figure that allows ranking the alternatives.

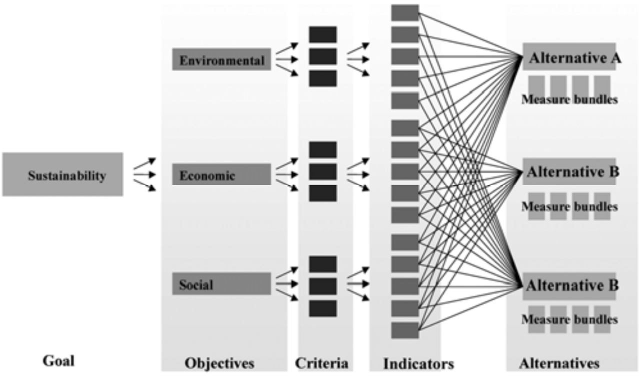

Figure 3: Structure for sustainability evaluation

Although water systems consist of quite similar sub-systems, i.e. freshwater extraction, treatment and distribution, grey water recycling, storm water drainage and wastewater reuse, collection and treatment, due to local hydrologic, geologic, but also socio-cultural and economic conditions in their composition each case should reflect an unique solution (Allon et al.,2004). To find the “best” option for a water concept is a difficult task, as planning horizons and data availability and accuracy in different planning stages vary significantly. Further the interaction of urban water systems with surrounding areas and river basin hydrology make it difficult to identify physical boundaries for evaluations. Even more significant is, in which planning phase the options at hand have to be evaluated. Table 2 relates assessment goals of different planning phases to possible evaluation criteria.

Table 2: Goals of sustainability evaluation in different planning phases

planning phase	assessment goals	evaluation criteria	comments
feasibility study	define requirements i.e. for water supply, storm drainage, waste water reuse, collection and treatment, protection of receiving waters and flood control.	strongly depend on natural and local conditions, interests of stakeholders and political priorities	most money can be saved, environment can be protected best and socio-economic concerns considered most.
pre planning	decide on systems, i.e. for water supply, drainage, waste water treatment, surface or groundwater protection,	strongly depend on natural and local conditions, interests of stakeholders and political priorities.	still money can be saved, environment can be protected and socio-economic concerns considered.
planning	system or protection level largely are firm, only detailed can be optimized.	may address i.e. cost efficiency, society’s acceptance, etc.	economic advances and environmental upgrading maybe marginal.
design	only material choice, etc. may be decided.	criteria may address costs, durability etc.	saving potential is already quite small.
implementation	different construction processes may be sequenced.	construction options can be judged for costs and environmental impacts	Improvements in all respects are marginal
operation	Compare different operational schemes	cost and financial burden for the users	same as in feasibility/ preplanning, but lot less

4.2 Options for sustainability evaluation

There are two basic different approaches to provide decision support for selecting sustainable water management options. The one is, to simulate the (dynamic) processes leading to social, economic and environmental consequences due to different planning, design or operational options. The second is, to make a (static) assessment of system situations in form of water and mass balances or other environmental indicators, as well as social and economic indices. While dynamic simulations require detailed and precise data, static assessments can be done with lumped data. According to Table 2**,** sustainability can be influenced most during initial planning, where detailed data usually not exist, while during design stages more detailed data are available, but sustainability can be influenced least.

Further it should be noted, that the risk of imprecise evaluation results is high, when lumped data are too vague, but even higher, when process modeling is mainly done on the basis of assumptions and literature values. Most reliable answers may be obtained in the pre-planning or planning phase if possible involving hydrologic type of modeling approaches. In consequence**,** this chapter elaborates on indicator based decision support tools. To formulate calculable criteria, which allow for unbiased evaluation of sustainability and functional evaluation methods, however, is a most difficult task.

4.3 Suggestions on reliable indicators

Many indicators have been suggested to achieve environmental, social and economic objectives. To achieve strong sustainability, that is the preservation of natural capital without allowing for substitution by any other form of capital for every case the following two criteria are suggested:

1. Indicator/index of financial burden (socio-economic)
2. Indicators for sustainable groundwater and surface water use (environmental)

Pre-industrial societies usually emphasize drinking water supply and irrigation. In societies undergoing rapid economic development and in industrial societies, generation of electric power, water supply for industry and population, safe drainage and waste disposal are given priorities. In post-industrial societies, as they exist in most European countries high emphasis is placed on aesthetics in urban planning, extensive protection of water resources and ecology. Indicator formula and their objective values for today's needs are suggested in Table 3.

Table 3: Indicator formula and their objective values

indicator/index	formula	objective value
financial burden (social)	$I_{FB} = \frac{CO_{DW} \cdot C_{wm^2} / 1000 \cdot 365}{I_{average}}$ CO_{DW} Water use /day and capita [l/d] C_{wm^2} Unit costs for water [RMB/m³] $I_{average}$ Annual av. income [RMB/year]	If people would be ready to spend about 10% of their income, the objective value is SFB = 0.1. Up to the portion of 10% the costs for water are considered sustainable, whereby a higher portion means an unsustainable financial burden.
ground and surface water use (environmental)	$I_{GW/SW} = \frac{CO_{GW/SW}}{RG_{GW/SW}}$ I_{GW} Indicator for groundwater use I_{SW} Indicator for surface water use CO_{GW} Consumption of groundwater CO_{SW} Consumption of surface water RG_{GW} Regeneration of groundwater RG_{SW} Regeneration of surface water	When the consumption of groundwater is equal to the regeneration of groundwater, extraction and recharge are in balance. This situation may be considered sustainable. Therefore, the objective value for groundwater use is SGW = 1.0. Similarly, the objective value for surface water use is SSW = 1.0.

4.4 Suggestion for practicable evaluation of different alternatives/ scenarios

For ranking indicators/indices of different alternatives/scenarios**,** two methods are recommended, namely the Analytic Hierarchy Process (AHP) and the short bucket theory (SBT).

The **Analytic Hierarchy Process (AHP)** was developed by Thomas L. Saaty (1987) in the early 1970’s for decision structuring and analysis by using matrices and linear algebra for the formalization of a decision process (Merz and Buck 1999: p.46). It allows to structure complex decision problem in a hierarchical order, thus exhibiting the relationship between the decision alternatives, objectives and evaluation criteria. Thus AHP facilitates analysis by transforming a complex evaluation into a hierarchy of smaller more manageable sub-evaluations. A complex dataset is thus decomposed into smaller constituent elements between which pair wise comparison is elicited. AHP is a compensatory decision methodology as alternatives that are deficient with respect to certain objectives can compensate by their performance with respect to other objectives (Merz and Buck, 1999).

To rank the decision alternatives the complex decision situation is structured hierarchically. The top element of the hierarchy represents the overall goal of the decision. The hierarchy decomposes to more specific evaluation attributes such as objectives and manageable decision criteria (sub-objectives) until a level of measurable indicators is met. The final level is constituted by the different alternatives. This hierarchy can consists of as many levels as possible, with each level influencing the paramount level and being influenced by the subordinate level (Merz and Buck, 1999). Thus AHP is applicable method to evaluate sustainability of different water management systems.

The **Short bucket (SBT)** also can be used to calculate the sustainability of different scenarios (Lu Zhibo, 2006). Therefore it is especially useful for environmental impact assessment. According to SBT, the capacity of a wood bucket hoop by wood pieces does not depend on the longest piece or the average piece, but on the shortest piece. If one wants to increase the capacity of the bucket, one must improve the length of the shortest piece. This theory also fits sustainability evaluation. Sustainability of an urban water system is like the wood bucket. It is decided by the lowest indicator value (similar to the wood piece), which constraints sustainable development or which defines the sustainability of a system. This approach for evaluation of sustainability pays more attention to the most deficient factor.

The principles of SBT can be followed in Figure 4. In the process of calculation, one must distinguish positive and negative indicators, because different equations should be adopted according to their attributes. If there is only one indicator in one index, then the equivalent radius is the standardized value of the indicator itself. If there are two indicators in one index, the equivalent radius is equal to the smaller standardized value of the indicator.

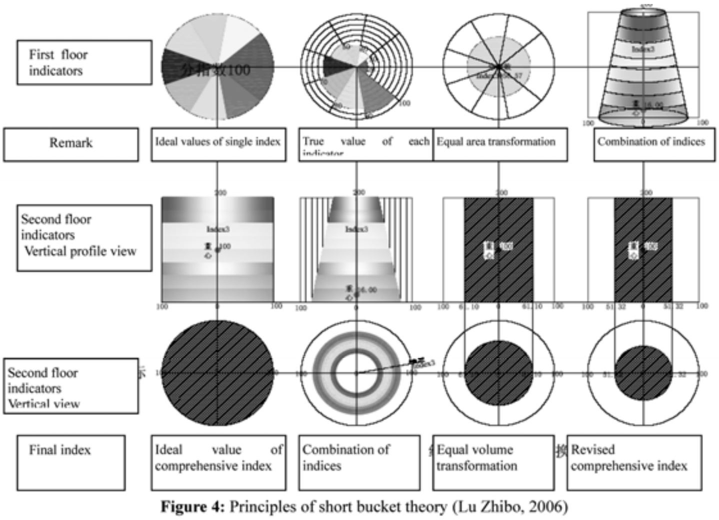

Figure 4: Principles of short bucket theory (Lu Zhibo, 2006)

5 Examples for Old/New Dimensions in Urban Water Mangement

Two examples of integrated urban water management, which aim for sustainability, are presented: the oldest example, known to the author, namely the water supply, matter recycling and storm runoff infiltration system of ancient Mohenjo Daro approx. 2500 BC and a recent one, namely the Flood control and groundwater recharge pilot project in Beijing, which demonstrated different water management options, which later were integrated into the water concept of Olympic Green 2008

5.1 Mohenio Daro：an ancient sustainable solution

The early Harappan civilization developed on the arid plains of the Indus Valley of Pakistan and northwestern India in the middle of the 3rd millennium BC and lasted for about five centuries. The ancient urban dwelling of Mohenjo Daro was a major urban centre of the Harappa Culture. Access to water resources and their maintenance was of vital importance the existence.

Water supply and sewage disposal at Mohenjo-Daro has been extensively studied by M. Jansen (1989 and 1993). The quality and amount of the Mohenjo-Daro data allowed to investigate, why some houses at Mohenjo-Daro had wells and others did not and to quantify which wells within buildings can be interpreted as public and which as private. Even more, Mohenio Daro seemed to have a water concept comprising of rainwater harvesting, waste water reuse and storm and wastewater infiltration after sedimentation. Figure 5 gives some insight into this integrated water concept.

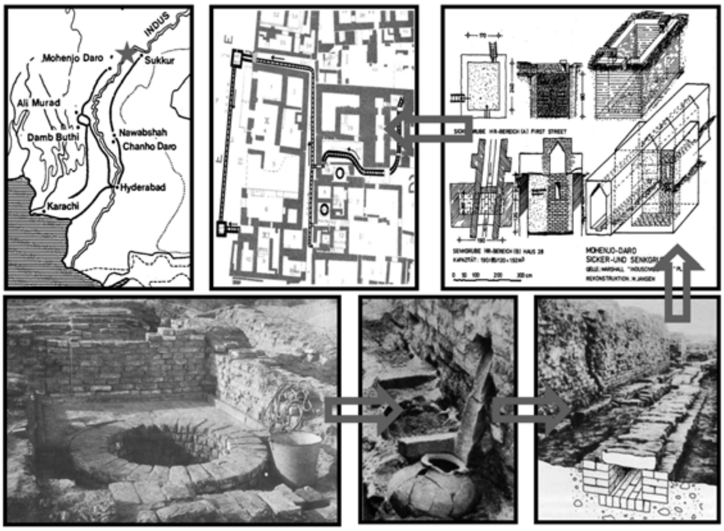

Figure 5: Water supply and drainage concept of Mohenio Daro, approx. 2500 BC (Jansen, 1993)

5.2 Flood control and groundwater recharge - Pilot study in Beijing

Beijing is listed among the world top ten cities suffering from a lack of water resources. The total amount of annual rainfall differs significantly, i.e. from 242 mm in 1869 to 1406 mm in 1959. Unevenly distributed rainfalls, where 80 % of the average annual rainfall of 640 mm appears within three months and urbanization with a high rate of sealed surfaces cause local flooding and reduce groundwater recharge. This in the past decreased groundwater levels in West-Beijing by about 23 meters between 1958 and 1986.

The semi-arid conditions call for integrative storm water management. The technical challenge is that a high degree of flood protection is guaranteed and at the same time groundwater recharge is maximized, which again enhances local water resources. These goals are contradictory, because of the high dynamics of storm runoff and flow limitation necessary for treatment and infiltration to the underground.

In 2000 a four-year joint Chinese-German pilot project with substantial support by The German BMBF and the Chinese MOST was launched to find technical solutions to bridge scarcity and surplus of water as well as demand and availability. The Beijing Water Bureau, mainly through the Beijing Hydraulic Research Institute together with five companies (Dorsch Consult Ingenieurgesellschaft mbH, Munich; GEP Umwelttechnik GmbH, Eitorf; UFT, Bad Mergentheim; WASY GmbH, Berlin; ibb Ingenieurbüro für Bauwesen Professor Burkhardt GmbH & Co, Munich) and two German Universities (Dep. of Urban Water Management, University of Essen and Dep. of Water Quality Control, Technical University Berlin) developed various solutions and outlined different conceptual approaches (Geiger, 2003).

To proof, how sustainable water management options work for Beijing, diverse options were tested in different types of urban development in Beijing. The findings may be transferred to other cities in semiarid regions. Table 4 summarizes the characteristics of the selected demonstration areas.

Table 4 : Characteristics of the selected demonstration areas

Project area	Precondition	Type of change	Future land use	Area in ha
Beijing Institute of Geological Engineering	dense institute and residential	none	residential/ commercial	3
Tianxiu Garden	agricultural	new development	residential	11
Hydraulic Engineering Foundation Works	institute	densification	commercial/ residential	7
Haidian Park	partly agricultural	new development	recreation	38
Beijing Technical School of Water Resources and Hydropower	school/residential	none	residential/school	4
Shuangziyuan	residential	modification	residential	2

On the grounds of the **Beijing Institute of Geological Engineering** in Bali Zhuang detention of surface runoff, followed by different stages of mechanical treatment prior to infiltration into the underground through recharge wells was chosen as drainage component. It was found, that for general applications this concept is not economic. However it was proven, that even under severe space constraints the goal of storm water retention and infiltration may be achieved.

The drainage concept suggested for **Tianxiu Garden** residential area focused on the collection and storage of roof runoff for recharge of evaporation losses in the artificial lake within the area and infiltration of surplus water into the underground. The overflow of this system led into an existing storm sewer, which detained and finally drained street runoff to Qing River. The system was designed for a five-year rainstorm condition.

The components demonstrated in the residential area of Beijing **Hydraulic Engineering Foundation Work** (EFW) include reuse for treated greywater and filtrated rainwater. Greywater from one building is collected in a sump and treated, stored (service water) and reused for toilet flushing. Rainwater from the roofs of two buildings is collected, filtered, stored and additionally used for toilet flushing in another building.

The buildings of the **Beijing Water Conservancy School** accommodate classrooms and laboratories, residential units for the students, administrative and operational units. The school has a long tradition in educating technicians in the fields of water supply, wastewater treatment and drainage systems. Therefore it was decided to install a large variety of water-saving, rainwater harvesting, storm water treatment and groundwater recharge facilities useful also for the practical education and training of students. Roofs were partially connected to a storage tank for rainwater reuse, partially directly connected to a groundwater recharge well in a sandy layer close to surface, partially directly drained to a lawn for aerial infiltration. A playground was covered with pervious asphalt and pervious concrete paving. While surplus water from playgrounds and service streets was collected and treated for groundwater recharge, the water infiltrated and stored in an underground layer was extracted for toilet flushing in times when the rainwater collection storage tank was empty. On the institute grounds also different test facilities were installed in order to compare the infiltration capacities of different pervious pavement types and to test different layouts of first flush devices. The facilities were monitored by students.

In **Haidian Park** the intention was, to demonstrate, how within the park area ponding during severe rainstorms can be avoided. It was feared that due to ponding landscaping and grass would suffer. Furthermore, for safety reasons, a storm runoff treatment structure similar to that of the institute grounds of Geological Engineering Bali Zhuang was used for treatment of the collected surface runoff from streets and parking lots, whereby the parking spaces were covered with concrete lawn turf stones. After treatment this runoff entirely infiltrated to the ground for groundwater recharge.

The water concept in the **Shuangziyuan** residential area included storage and treatment of roof runoff for later use for irrigation. Furthermore, the wastewater from the four apartment blocks and other auxiliary buildings was treated in septic tanks using anaerobic digestion. After treatment, the wastewater is transported into a cistern and used for greenbelt irrigation and car washing.

All water management components investigated proofed to be technically and on the long run also socio-economically effective (Zhang, 2006). Therefore they were considered in the Engineering technical code for rain utilization in building and sub-district, released by the Chinese Ministry of Construction (MOC, 2006) and already incorporated into the water concept of Olympic Green 2008. They generally should be considered in any urban water concept for cities at least in semiarid regions.

6 Conclusion

Urban water systems have to consider social and economic aspects, as already recognized in 1970 by Professor Mc Pherson, one of the first urban hydrologists. Sustainability in water affairs affects society as a whole including its institutions and administration. It is a learning process which begins in schools and continues throughout every ones life, whereby renewal of thinking about water must come from inside, from the user itself. Only today it is understood, that water management is most important to improve poverty and thus social stability. Present management practices cannot meet future water needs in for mega cities.

To minimize failures demonstration projects to test new ideas and approaches must be encouraged endorsing systems analysis and rigorous evaluation of such projects. Pricing incentives must be given that acknowledge full environmental impacts of proposed systems. Pricing policies for drinking and recycled water must be found, that ensure efficient use of these valuable resources, whereby environmental externalities, i.e. the cost of disposal of storm water and treated effluents as well as research funding requirements should be factored into the water price or penalties.

Better integrated planning and water management in urban areas through institutional reforms involving local government, water boards and utilities, and state (government) agencies should be forced, considering self-regulating bodies. Continuing research and education will lead to progressive improvement in costs and efficiency of advanced water concepts. Change of water infrastructures and institutions take time. The key is to invest in small scale infrastructures, especially to solve problems on local scales, but using available technologies to estimate their effects, if applied in general.

It was found, that sustainable water management solutions mainly can be influenced in the preplanning and planning phases, when precise data are not available. In consequence indicator based decision support and rather uncomplicated methods to evaluate sustainability are suggested. It is concluded, that sustainable water management may be the only chance for mega cities in developing countries to survive.

For sustainable water management in mega cities need for action and research is seen for

- quantifying the effects of human activities on environment and society, to forecast consequences of policy options
- linking the time scales of up to ten years for assessing existing conditions by monitoring and modeling processes in river catchments and of short times available for fixing individual measures (sometimes within one year).
- defining calculable indicators for different planning phases, which must be applied whatever the case may be and which could be applied optionally in addition
- developing criteria for the independence of indicators from each other.
- identifying compulsory data accuracies for each indicator in every planning phase
- deriving an unbiased common and non-monetary currency for merging indicators of different sustainability categories
- categorizing available evaluation procedures for their subjectivity and applicability in different planning phases
- establishing practical standards for sustainability assessment and evaluation categorized into minimum and advanced requirements
- investigating the conflicts of sustainability assessment with different and developing unbiased and theoretically sound grounds.

Some related research is underway within the UNESCO chair in Sustainable Water Management program investigating

- Uncertainties of data and their effects on evaluation results (Huo Li, 2007)
- Developing theory and structure for a Hierarchical Decision Support Concept
- Defining necessary catchments' boundaries for sustainability evaluations

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Summary and Conlusions：Building Integrated Water Resources Management in Megacities

Outcome of the ERSEC Workshop on Sustainable Water Management
— Problems and Solutions under Water Scarcity
6 — 8 November 2006, Beijing, P.R. China

1 Introduction

This paper summarizes findings of the “ERSEC Workshop on Sustainable Water Management”, held from 6 to 8 November 2006, Beijing, P.R. China. The conference took place under the general framework of “Ecological Research for Sustaining the Environmental in China (ERSEC)” supported by the German Federal Ministry of Education and Research (BMBF) and implemented by the United Nations Educational Scientific and Cultural Organization (UNESCO) Office Beijing. In response towards the general aim of the ERSEC project to influence the policymaking process in China with ecological considerations, the conference is dedicated towards the promotion and application of scientific research to build better mechanism for integrated water resources management in megacities. It is also expected that the conference could serve to constitute an interactive platform where experts from not only Germany and China, and also other countries, would be able to share and integrate expertise from a multi-disciplinary perspective. A specific focus of this conference is put on groundwater recharging and management in urban areas. The conference received participants of wide spectrum, although most are from Germany and China, the two project host countries. There are also participants from countries with similar experiences and challenge for integrated water resources management including, Australia, Canada, Japan, Jordan, Mongolia, Switzerland, and the United States.

The accelerated development of China has reached tremendous success in the past decades. Nevertheless, it also brought serious environmental challenges, enhancing substantially the pressure to ecological carrying capacity. Such challenge is particularly manifested in regard of water. As one of the most populous countries in the world, the per capita water resources in China is only 2,300 cubic meters, a figure that is only one forth of the world’s average. In addition, the limited water resources are not evenly allocated by time and space with most brought by rainfall concentrated in the summer months. This leaves a bit ironic scenario in China where, at the same time of handling the “thirsty” for water, water-related disasters including storms and floods have to be carefully tackled. Unfortunately, due to inadequate infrastructure and technical level, a large part of the rainfall brought by the storms and floods are not effectively collected. Moreover, water resources are not fully utilized in a sustainable manner, leaving problems including decreasing of groundwater table, land subsidence, seawater intrusion, and serious level of water pollution. The water challenge is even more evident in the rapidly expanding Chinese cities. It is estimated that by 2020 the urbanization rate in China will reach more than 50%, and urban population would reach eight to nine hundred million. However, it is still under question whether ecological carrying capacity, specifically the water resources, could afford such concentration of population.

In light of this, it is necessary to develop sustainable water management in China, and particularly the megacities with large population. It introduces an integrated approach where not only the demand, but also the supply is sophisticatedly tackled. A focus of the conference is thus focused on the management and recharge of groundwater, which is a valuable resource that could serve as an alternative source of water provision for the Chinese cities. Against this general backdrop, efforts of the participating researchers are mainly focuses on the topics of:

1. Sustainable water management for megacities
2. Urban flood management—possibilities for groundwater recharge
3. Treatment of urban waste water for groundwater recharge
4. Institutional framework and management practice for mega cities water supply with special regard to groundwater resources

With subsequent development of China, and the continuous urbanization process accompanied, efforts of the participating researchers surrounding the topic of integrated sustainable water management, with groundwater as a focus, would help provide an important alternative source of water resources for the Chinese cities. In addition the experiences and lessons learned could also serve as reference for other countries going through similar development stages as China.

2 Conference Summary and Statements

The following section is structured according to major topics and points of interests raised and discussed by the participating researchers, organizations and audiences.

Urban water management within integrated water resources management

- An important mode of water management in addition to water management in fields of agricultural water management, and industrial & process management
- On demand side, tackles complex human water drainage and usage patterns with reference towards relevant GIS data
- On supply side, investigate hydrogeological system and set up finite element model
- Conceptualization reached through hydrological models in references to research on the demand side.

Key areas of integrated water resources management

- Policies – setting goals for water use & protection
- Legislative framework – defining rules
- Financing and incentive structures
- Organisational framework
- Institutional capacity building
- Water resources assessment – understanding resources & needs
- Plans for IWRM – combining development options, resource use and human interaction
- Demand management

- Social change instruments – encouraging a water oriented society
- Conflict resolution – ensuring sharing of water
- Regulatory instruments – allocation and water use limits
- Economic instruments – values and prices
- Information management and exchange – improving knowlegde

Necessity of urban groundwater management

- Appropriate groundwater management ensures long-term safety of water supply and minimises human impact
- Tackle possible changes including decline & rise of groundwater table, and water quality deterioration
- Stress on changes of groundwater resources with city evolution
- Avoiding large-scaled land subsidence, disappearance of surface water ponds in urban areas, and the decreased amount f groundwater recharge as well as increasing of urban flood risk

Challenges of urban water management identified

- Declining groundwater tables in Shanghai, Lahore, and many others
- Problematic oversized water infrastructure, water demand derived from old mines refilling competes with demand for human consumption purposes
- Springs, considered as urban cultural heritage are being dried up due to groundwater table declining in Jinan, Shandong province, China
- Excessive exploitation of deeper lying aquifers in Shanghai, China
- In general, groundwater water recharge rate is rising together with the pace of urbanization, nevertheless, the rate for groundwater abstraction is even faster than the recharging rate
- Unplanned, indirect potable reuse
- Political influence, rampant unionism, lobbyism, and theft surrounding the topic of water consumption

Impact of climate change on water

- Research on the impact of climate change on the River Elbe and the Berlin water system.
- Research on the impact of climate change scenarios calculated for AISUWRS case study cities
- Conclusionl: climate change brings increased temperature, and larger differences in seasonal distribution of rainfall, increased intensity of single events, and the decreasing of total rainfall amount

Situation of water management in Beijing

- During the urbanization process, Beijing has incorporated an array of modern concept for urban water management into the urban planning process

- Technical application is ongoing, reclaimed wastewater is now used in Beijing greenbelt gardening and car washing. Total amount for water consumption has been reduced slightly in the urban area while the suburb area is still under water scarcity.
- Besides advanced water saving techniques, relevant economic instruments, policy and legal measures are also being set up in Beijing
- The Olympic Games and venues would become key interventions of integrated water resources management in Beijing
- The Guanting reservoir, one of the two major water sources for Beijing municipality, is now equipped with a system of groundwater collecting model and automatic operations of water supply network. An internet based information monitoring & gathering system is also available
- SAT is applied successfully and economically viable with price level of 2 Yuan/m³

Decision support system

- The application of hierarchical control measures on UWM is currently being applied in Beijing as a case study Use of a multilevel concept, and also the concept of “trade-off” instead of weights, the cybernetic model could also be used to the decision making system
- Optimisation of MCA methods can be applied, and the formulation of an appropriate goal function is also required
- AISUWRS DSS was developed to represent the holistic urban water cycle
- Concept has been applied to scenario analysis in four cities
- Different, internationally applied water index systems for sustainability tested in Shanghai

Technical solutions

- Infiltration of rainwater, river water and the reclaimed waste water
- Series of demonstrative projects set up as sites for technology application, successful demonstration projects for storm water infiltration and rainwater harvesting have been available in Beijing
- Extensive list of storm water recharge techniques: Vegetated Swales, Roof drains + Bio-retention ponds, Vortechs, Pre-fabricated filter units, etc.
- Focus on small storms, larger storms may bypass
- Focusing on natural habitat, for instance, the wetland, even in very cold climates wetlands can provide effective reduction of pollution.

Management of aquifer recharge

- Recharge basins, trenches and wells
- SAT: Intermittent infiltration
- Aquifer storage and recovery, several examples, Bolivar-Virginia water pipeline & ASR site
- Patience is required (only 25 operating sites in 2004 despite long tradition, now a mature technique)
- Both wastewater and storm water can be considered as source for aquifer recharge

Constraints for the reuse of groundwater

- Traces of organic compounds
- Pathogens
- Nitrogen Species, TDS
- Algae-Toxins – surface storage
- Indicators: Pharmaceuticals, EDTA, THM´s, AOI, iodated x-ray contrast media

Implementation barriers

- Technical solutions for most water problems are available, but society does not use them sufficiently
- Groundwater is a hidden resource with invisible effects. Reluctant and hesitate of people to invest resources
- People need to be integrated into the planning of technical solutions: public participation and acceptance

Recommendations to handle the barriers

- Internalize the externalities
- Call for the introduction of a groundwater fee, a rational institutional framework & dialogue with stakeholders
- Make better use of natural, subsoil treatment and storage
- Infiltration of storm water in Jinan is necessary to keep springs running.
- Developers of new housing complexes in Jinan should pay for artificial recharge
- Recharge enhancement can be an effective strategy
- Communities need good technical skills
- MAR alone will not resolve all issues
- Groundwater is a reliable resource as it is continuously present at the place of need
- Careful studies required before full scale implementations
- Urban storm water must be treated if it is to be infiltrated
- Pollutants need to be kept away from where water runoff could get connect with the pollutants
- Institutional reforms linked with the objectives of ecologically sustainable management
- Dilution is no solution to pollution

Possible tools used to tackle the constraints & barriers

- Numerical groundwater models like Feflow can be used to design infiltration ponds but also to assess the regional groundwater situation
- AISUWRS model chain may be used to assess the sustainability of the urban water system
- Hierarchical and cybernetic models are currently developed
- ASRRI-Easy Leacher-PHT3D could be an useful alternative

International outlook

- Water scarcity is a major issue in Pakistan. Hydrogeology has been characterised but more effort is needed to improve the water situation

- In Jordan, water scarcity is most pronounced with ca. 160 m^3/person/a renewable water resources, with the construction of dams and reservoirs in the wadi structures, the surface runoff can be partly redirected to the groundwater
- Institutional framework outlined for Brandenburg, Germany
- Groundwater is a major source of water in Mongolia, total amount of utilization can be small , compared to large-scaled utilization in other places, however, pollution has also been a problem
- A comparison study on sustainable water management was performed between cities including Tianjin, Bandung, Osaka, Colombia, Kundy, Bangkok and Ho Chi Min City

The role of people in integrated water resources management

- Water as an economic good for people
- Overcome Technical Fallacy
- Increase public awareness
- Education > Collaboration > Integration !

Conference general recommendations

- Sustainable management of urban groundwater is possible and should be undertaken.
- Understand the aquifer system, and relevant conceptual model is useful
- Establish holistic water balance as early as possible. Try to include qualitative aspects.
- Make use of rainwater and runoff from impervious surfaces to counter water scarcity.
- Use numerical groundwater models to predict effects of urban water management on groundwater.
- Find and control point contamination sources (e.g. industrial sites, accidental spillages).
- Integrate groundwater management strategies incorporated into the town and urban planning process such as the water sensitive urban design
- Think long term! Embed UWM into IWRM at catchment scale.
- Consider linked surface/groundwater systems
- Source control is important / Keep cities and surface clean in order to save treatment costs for storm water.
- Consider both regulatory and economic instruments for mitigation measures
- Integrate stakeholders into the decision process. Listen to them.
- Perform full environmental impact assessments before implementing a technical solution
- Science can support policymakers by understanding the technical issues, providing information, testing solutions.
- More effort should be directed to organize the available knowledge on an international level.

The three day conference encloses crucial aspects surrounding the topic of integrated water resources management, with focuses on groundwater recharge and management in mega cities. It is expected that, through continuous urbanization in China, topics investigated in the conference could serve as a useful reference for the subsequent planning and policymaking process. In the meantime, it is also trusted that the conference in particular, and the ERSEC project in general, would continue to work as a dynamic forum to exchange and integrate research inspirations that would contribute to the development of China in a sustainable manner.

建立综合的大城市水资源管理

2006年11月6日——8日在中国北京召开的
“可持续的水资源管理：缺水问题及其解决方法”
中国环境可持续发展生态研究项目（ERSEC）国际会议的总结

1 背景

这本摘要概述了2006年11月6日——8日在中国北京召开的“中国环境可持续发展生态研究项目（ERSEC）可持续的水资源管理国际会议”的成果。这次会议是在由德国联邦政府教育研究部资助和联合国教科文组织北京办事处实施的“中国环境可持续发展生态研究项目”（ERSEC）总体框架下举办的。这次会议专注于提升和应用科研成果，为大城市综合的水资源管理建立更好的机制，这也反映了ERSEC项目旨在以生态考量影响中国的决策过程的总体目标。这次会议也为来自中国、德国和世界其他国家的专家提供了一个互动的平台，使他们能够分享和整合多学科的观点。这次会议特别关注城市的地下水回灌和管理问题。尽管多数会议代表来自项目的两个东道国德国和中国，其他国家的代表也广泛参加。比如有来自澳大利亚，加拿大，日本，约旦，蒙古，瑞士和美国的代表，他们的国家在综合的水资源管理方面有相同的经验和挑战。

中国的加速发展在过去几十年中取得了巨大的成功，但也由此带来了严重的环境问题，加深了生态承载能力的压力。水资源面临的挑战尤其突出。作为世界上人口最多的国家，中国的人均水资源占有量只有2300立方米，相当于世界平均水平的四分之一。而且，有限的水资源在时间和空间分布上很不均匀，降雨主要集中在夏季。这就为中国带来了有些矛盾的情形，在解决缺水问题的同时还要解决暴雨、洪水等与水相关的灾害。但是，由于基础设施和技术水平有限，由暴雨和洪水带来的大部分雨水没有得到有效的收集。而且，水资源没有完全按照可持续的方式利用，由此带来了地下水位下降，地面沉降，海水入侵和严重的水污染等问题。水资源的问题在中国迅速扩张的城市中更加显著。估计到2020年中国城市化率将超过50%，城市人口将达到8亿到9亿。然而，生态承载能力，尤其是水资源是否能负担这样的人口密度仍然是个问题。

因此，很有必要在中国，特别是人口众多的大城市发展可持续的水资源管理。在供水和需水中同时引入综合的管理方法是一种先进的解决之道。这次会议的一个重点是地下水回灌和管理，地下水是一种珍贵的资源，在中国的城市可以作为另一种供水的资源。在此大背景下，与会专家的研究成果集中在以下方面：

- 大城市可持续水资源管理
- 城市洪水管理——地下水回灌的可能性
- 为地下水回灌做好城市污水处理

- 大城市供水特别是地下水资源的管理实践和制度框架

随着中国今后的发展及与之相伴的持续城市化过程，与会专家围绕综合的可持续水资源管理，特别是地下水的主题进行研究所得的成果，将帮助中国的城市提供另一种重要的水源。而且，这些经验和教训还可以为世界上其他处在与中国相同发展阶段的国家提供参考。

2 大会纪要

本章中的内容按照大会中所提出问题的顺序及问题的相关讨论进行排列。

综合性水资源管理中的城市水资源管理

- 除农业水资源管理，工业和加工产业水资源管理外的一种重要的水资源管理模式
- 在需水方面，参照相关的地理信息系统提供综合的污水排放和用水模式的解决方案
- 在供水方面，调查水文地质系统，建立有限元模型
- 参照需水方面的研究， 通过水文学模型将其概念化

综合性水资源管理的主要方面

- 政策——设定水资源利用与保护的目标
- 法律构架——制定法规
- 资金和激励机制
- 组织构架
- 制度上的能力建设
- 水资源评估——理解资源与需求
- 综合性水资源管理规划——结合发展选项，资源使用和人的互动
- 需求管理
- 社会变革的工具——鼓励建设节水型社会
- 解决冲突——确保水的共享
- 制度手段——水资源分配和使用的规定
- 经济手段——定价
- 信息管理和交换——提高认识

城市地下水管理的必要性

- 有效的地下水管理能确保供水安全的长期性并最大程度的减少人类的影响
- 应对可能的变化如地下水位的下降和上升及水质退化
- 城市发展带来的地下水资源变化的压力

- 避免大面积的地面沉降、城区地表水池的消失和地下水回灌量的下降以及城市洪水灾害风险的增加

城市水资源管理面临的挑战

- 上海，拉合尔和其他许多城市地下水位的下降
- 特大型水利设施及旧矿回填引起的需水量和人类的用水需求之间的矛盾
- 中国山东省济南市的泉水曾经是城市的文化遗产，却由于地下水位的下降而枯竭
- 中国上海深层含水层的过度开采
- 通常，地下水的回灌率随着城市化的速度而增加，然而，地下水开采率甚至快于回灌率
- 无计划、不直接的饮用水再利用
- 围绕用水产生的政治势力，大规模的联合，游说和偷窃行为

气候变化对水资源的影响

- 气候变化对易北河及柏林水系影响的研究
- “城市水资源系统可持续性评价及提升体系”中案例研究城市的气候变化影响预期模型研究
- 结论：气候变化引起了温度上升，降雨季节分布的更大不均，单次降雨强度的增加以及总降雨量的下降

北京的水资源管理现状

- 在城市化进程中，北京已经将一系列城市水资源管理的现代理念结合进城市规划的过程中
- 技术得到了应用，回收的污水用于北京的城市绿化带灌溉和洗车。城区总的用水量轻微下降，但郊区仍然面临缺水问题。
- 除了先进的节水技术，北京还建立了相应的经济手段和政策、法律措施
- 奥林匹克运动会及场馆将成为北京综合性水资源管理的主要干预方面
- 北京市主要水源地之一的官厅水库装备了地下水收集模型系统和供水网自动运行系统。另外还开通了网上信息监测和搜集系统
- 土壤含水层处理工艺被成功的应用，每立方米 2 元的价格水平在经济上也是可行的

决策支持系统

- 分级控制系统在地下水管理中的应用正在北京作为案例研究
- 使用多级概念，用“流量”代替重量的概念，在决策系统中应用控制论模型
- 要使 MCA 方法得到最佳应用，需要明确指出适当的目标功能
- “城市水资源系统可持续性评价及提升体系”决策支持系统的开发可以呈现完整的城市水文循环

- 这个概念已经在四个城市应用于预期模型分析
- 不同的、国际实用的可持续性水指标体系在上海测试

技术方法

- 雨水、河水和再生水的渗透
- 北京已经开展了一系列为技术应用提供场所的示范项目及成功的雨水渗透和雨水收集示范项目
- 雨水回灌技术的清单：用植被覆盖沼泽， 浮顶油罐的排水系统+生物澄清池，Vortechs 水力离析器，预制过滤装置等等
- 重视小规模的降雨，大规模的降雨可以疏通
- 重视自然栖息地，例如湿地，即使在非常寒冷的气候条件下，湿地也能有效的减少污染

含水层回灌的管理

- 回灌池，回灌渠和回灌井
- 土壤含水层处理工艺：间歇性渗透
- 含水层的储存和恢复，几个例子，玻利瓦尔——维吉尼亚输水管道和含水层的储存和恢复场所
- 需要耐心（尽管有很长时间的惯例，2004 年时只有 25 个运行场所，现在已成为成熟的技术）
- 废水和雨水都可以考虑作为含水层回灌的水源

地下水资源再利用的局限

- 有机物质污染
- 病原体
- 氮氧化物污染
- 有毒藻类
- 指标：碘酸 X 光比较介质，药品，乙二铵四乙酸，重矿物总量，AOI 等技术指标

执行阻碍

- 针对大部分的水问题已经有了技术上的解决方案，但是需要社会的进一步认可。地下水是一种隐蔽的资源，难以引起人们足够的重视和投资
- 需要充分利用公众参与，需要获得公众认可，需要将人的因素纳入到技术方案的规划与实行中

针对阻碍的解决方案

- 将外部效应内部化

- 呼吁征收地下水资源费，建立良性的制度支持及利益相关方的对话模式
- 更好地利用自然资源，促进土壤的处理和养护
- 济南开展的地下水回灌将有利于恢复当地的泉涌现象
- 济南地区新住宅的建设应考虑到地下水回灌因素
- 回灌是地下水资源养护的有效策略
- 社区群众需要好的技术沟通方式
- 地下水资源是一种可靠的资源，因为它总可以在有需要的地方开采使用
- 在大规模开发利用前需要仔细的调研
- 城市雨洪水在回灌之前，需要得到过滤处理
- 应尽量避免污染物与回灌水资源的接触
- 需要得到制度改革的支持，促进可持续生态管理建设
- 稀释不是解决污染问题的方法

可能用于处理阻碍的工具

- 例如 Feflow 一样的地下水资源数据模型，以及过滤池等，但具体技术的应用需要以对当地地下水资源形式的评估为前提
- “城市水资源系统可持续性评价及提升体系”可以应用于评价城市水资源管理体系的可持续性
- 逐级分化管理和控制模型
- ASRRI 简便型过滤器及 PHT3D 可以是很好的选择

地下水资源利用的国际形势

- 水资源缺乏已经成为巴基斯坦的一个主要问题，水文地质学正得到越来越多的人的重视，但是在可持续水资源管理方面， 还需更多的努力
- 在约旦，水资源缺乏已经是一个亟待解决的问题，随着诸如大坝等水利工程的修建，部分截流的水资源可以用来返补地下水
- 德国的布兰登斯堡专门出台了针对城市地下水资源利用的相关政策制度
- 地下水是蒙古的一项重要资源，尽管与其他地方大规模的地下水开采相比，蒙古总的地下水使用量不多，但污染仍然是地下水使用中的一个问题
- 中国南开大学专门针对水资源可持续性管理，和地下水可持续性利用，在天津，大阪，哥伦比亚，曼谷，胡志明市等各国不同地方，开展了相关的比较研究

可持续水资源管理中的人的因素

- 水对所有人来说不仅是自然资源，更是经济产品
- 人需要克服技术错误
- 需要提高公共意识
- 教育 > 合作 >整合 ！

大会特别建议

- 可持续水务管理和可持续地下水资源利用是可行的而且应当得到足够重视
- 需要进一步了解含水层，建立相关模型
- 建立定性考核指标，尽早建立起一套完整全面的水平衡体系
- 收集非渗透性地面的雨水，作为解决水缺乏问题的方案
- 使用地下水资源数据模型，预测城市水资源管理对地下水资源的影响
- 发现并控制点源污染 （例如工厂和事故泄露）
- 将地下水管理方法和策略纳入到城市规划工程中，建立节水型城市规划体系
- 当存长远眼光，在流域层面，将城市水资源管理纳入到综合型可持续水资源管理中
- 考虑地下水地表水资源的联系
- 加强污染源控制，实现城市地区地表生态的清洁，以便进一步节省城市雨洪水的处理成本
- 考虑减少污染的经济成本和制度管理方法
- 将利益相关方充分纳入政策决策过程，倾听各方意见
- 在利用任何一项技术方案之前，进行全面的环境影响评价工作
- 利用科学知识影响政策决策过程，帮助决策者了解技术问题，提供信息，检验解决方案可行性
- 需要更多的将国际层面上的相关知识和研究进行整合和应用

本次大会包含了综合性水资源管理的主要问题，还特别以大城市地下水资源管理为主要关注点。全体与会专家诚挚地希望，本次大会的研究及探讨，能够为中国持续的城市化进程提供有益的帮助，特别是从城市规划和政策制定方面。同时，在总结以往经验的基础上，本次大会及整个中国环境可持续发展生态研究项目，将继续成为中国与国际交流研究成果，整合研究经验的一个有力平台，为中国的可持续发展，作出应有的贡献。

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