MAR in China for 60 Years

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China has a long history in managed aquifer recharge (MAR). The development was divided into 3 stages based on the summary combined with typical MAR projects since 1956, including the first stage applied for industrial energy saving, controlling urban land subsidence and augment agricultural water supply from 1949 to 1978, the second stage for ecological protection and augment of urban water supply from 1979 to 2000 and the third stage for multi-source MAR. In addition, geothermal reinjection and ground source heat pump are also effective use of MAR from 2001 to now(Weiping Wang et al, 2014).

1. The first stage

Groundwater recharge through deep tube wells located the geological conditions of coastal, alluvial, piedmont plain and karst aquifer with cooling water or tap water since 1960s for air-conditioning or heating and controlling land subsidence through Shanghai, Tianjin, Beijing, Shijiazhuang, Xi'an and Nanchang cities etc, characterized by factories being investors, beneficiaries and government being guide. For example, Shanghai city which represents a typical development of MAR for the first stage is located in the Yangtze River Estuary where the deep Quaternary sedimentary covers the area underlying carbonate rock layer, relying entirely on groundwater as urban water supply so resulting in land subsidence with a maximum ground drop depth of 2.63m in 1965. At the same time, five cotton mills in Shanghai carried out injection test with 4 different water sources and recharge techniques of intermittent injection, continuous and intermittent lifting, subsequently observing the groundwater level and land subsidence for many times. the result shows that groundwater recharge through tube well can not only alleviate to increase groundwater level and effectively control land subsidence but solve the problem of pumping groundwater, offering new cold source and heat source for factories with aquifer, that is water was recharged into aquifer in winter while exploited in summer and water was recharged into aquifer in summer while exploited in winter. In 1966, groundwater recharge was done through 134 of deep wells in more than 70 factories of the city at the same time so that average groundwater level raised more than ten meters and ground level up 6mm that meant it is first time to appear phenomenon of ground level rising until it had been fallen several decades(Weiping Wang et al, 2010). Since then, the techniques of groundwater recharge were improved constantly in Shanghai and achieved result showed that the underground water level rising from -10 m to -1.5 m in 1970, the land subsidence being stable at between 0 and 5 mm by 1990 (Yi Liu, 2000), the total amount of groundwater recharge with tap water of 100×10^6 m^3 in Shanghai by 2000, the annual average of groundwater recharge of 20×10^6 m^3 and urban land subsidence being controlled effectively (Shiliang Gong, 2006; Yi Liu, 2000).

In rural area of North China Plain, artificial recharge of groundwater were widely applied through wells, ponds, ditches and basins in order to increase replenishment of the groundwater and ensure the agriculture with bumper harvest and stable production, characterized by farmers putting as free labor, government gave subsidence to these projects and collective economy benefited. For example, the irrigation district of Renmin Shengli Channel in He'nan province adopted a method of combination of well and channel, which use channel water for irrigation and recharge groundwater during the dry seasons, while use well water in contrast. In 1975, the irrigated area reached 300,000 hectare and the water table was maintained at 2m, the saline land area decreased and grain yield increased year after year. Now the module, groundwater recharge through channels diverting surface water and guaranteeing agriculture harvest by pumping groundwater through wells, has been widely applied in larger irrigation districts of diversion Yellow River water in Shandong and He'nan province. The way to be developed, for example, in Huantai county and Yanzhou county of Shandong province and Hebei province, where the water network of all rivers and ditches connection throughout the county were built to retain water by rivers and ditches, infiltrating to recharge groundwater and forming larger groundwater reservoir which played an important role in combating droughts of 1970s. In addition, practical intercepting underflow project in semi-arid and arid region were constructed to alleviate the contradiction between supply and demand of water resources effectively and strengthen the agricultural drought resistance. For instance, Alxa League city of Inner Mongolia has built 70 intercepting underflow projects since 1970s. Among them, the largest one in Alxa Zuoqi resolved tens of thousands of people's drinking water with 90L/s of daily water supply. Intercepting underflow project is an effective measure to exploit and utilize groundwater of river way and valley plain in hilly area (Qinde Sun et al., 2007; Honggu Luo, 1981).

2. The second stage

6 underground reservoirs to prevent salt water intrusion were built to prevent seawater intrusion in Shandong peninsular since 1990s, characterized by mostly government investing and farmers and factories being beneficiary. For example, the Huangshui River Underground Reservoir with total reservoir capacity of 53,59

million m^3, which was composed of a underground cement wall of 5842 m long and 10 m deep combating salt water intrusion and storing groundwater ,6 sluices retaining surface water when flood period 2,518 infiltration wells and 448 infiltration trenches directing flood water into aquifer. What is more, there is a serious water shortage in partial downstream plains. Since 2000, some reservoirs have turned into integrated ecological type instead of flood control and water supply merely. For example, the water in Taihe reservoir in Zibo City of Shandong province in dry seasons is discharged to supply downstream groundwater source by riverbed infiltration.

3. The third stage

Various water sources could be storied in MAR, such as urban stormwater, reclaimed water, foreign water transferred from the other basin such as Yellow River or Yangtze River, which were recovered for drinking water supply or agricultural irrigation, characterized by more experimental pilot project and larger scale of practical projects invested by government. For example, the first urban reclaimed water recharge project in China, Gaobeidian Groundwater Recharge Pilot Project in Beijing, which was completed in 2003 with $200m^3/d$ of design recharge amount composed with combination of a basin and rapid infiltration shaft system(Guichun Yun et al., 2004) that led to the first state standard of *Municipal wastewater reclamation and reuse and the quality of recharging water* *（GB/T19772-2005）*. The pilot project though wetland treatment and basin infiltration with municipal reclaimed was done in Zhengzhou city of Henan province in 2002 and recovered water can be used for fishery, industry and agriculture (Menggui Jin et al., 2009). For another example, a pilot project of karst aquifer recharge with urban treated roof water was established in Jinan in .2011. Continuous monitoring shows that both quality of roofwater and groundwater basically met groundwater quality standard with a recharge amount of $2000m^3$ until 2015(Weiping Wang et al., 2015). In addition, the project of MAR through channel infitration with local surface water released from upstream reservoir and Yellow River water pumped along Yufu River of Jinan, Shandong was implemented to augment groundwater and improve drinking water in 2014, with annual released water quantity of 5,000-7,000 million m3 from 2014 to 2015. There is same project of MAR along Chaobai River with reclaimed water and Yangtze River water was implemented in Beijing(Ji Liang et al., 2013;Fandong Zheng et al.,2015). Furthermore, geothermal reinjection and ground source heat pump are also effective utilization of MAR. In recent years, ground source heat pump (GSHP) technique developed quickly. In 2009, the *Technical code for ground-source heat pump* *system (GB50366-2005)* was issued, which contributed to the development and application of GSHP technology.

There are some typical MAR projects since 1960s in table 1 and symposiums on MAR in table 2 as follows:

Typical Projects on MAR in China since 1960 (Uncompleted statistics)

City/ county/ province	Region	Character	Aquifer	Types	Source water	End use	Date	Operation or not	Volume (m^3/yr)
Huantai	Wuhe River	Practical	Pore	Water spreading of open channel-under tunnel	Runoff in river	Irrigation	1962		
Shanghai	Urban area	Practical	Pore or karst	ASR, ASTR	Cooling water or tap water etc.	Energy saving and preventing land subsidence	1965	Yes	20×10^6
Tianjin									
Beijing									
Shijiazhuang									
Xi'an									
Nanchang									
Huantai	Piedmont plain	Practical	Pore	Water spreading of network of connected channels/diches/ponds	Runoff in the river	Irrigation	1970s		
Yanzhou									
Tengzhou									
Shandong and Henan Province	Yellow River flood plain	Practical	Pore	Water spreading of network of connected channels/diches and irrigation	Yellow River water	Irrigation	1970s	Yes	
Inner Mongolia	Arid and semi-arid area	Practical	Pore	Intercepting dam	Local groundwater runoff	Rural human and livestock drinking water and irrigation	1970s	Yes	2.85×10^6
Shanxi Province									
Hebei Province									
Longkou	Balisha River	Pilot	Pore	Underground dam	Exceed flood water in the river	Agricultural, industrial and drinking water use	1987	Yes	0.6×10^6
Qingdao	Shiren River	Practical					1991	Yes	
Longkou	Huangshui River (Estuary)	Practical					1995	Yes	
Qingdao	Dagu River	Practical					1998	Yes	
Laizhou	Wang River	Practical					1999	Yes	31.9×10^6
Yantai	Dagujia River	Practical					2000	Yes	
Zibo	Zihe River	Practical	Pore and Karst	Recharge release	Local surface water	Drinking and industry water	2000	Yes	

Beijing	Gaobeidian wastewater treatment plant	Pilot	Pore	Combination of well and basin	Reclaimed water	Augment groundwate r	2002		73×10^3
Zhengzhou	Suburban	Pilot	Pore	Wetland, water treatment system and Basin	Reclaimed water	Irrigation	2007		113×10^3
Beijing	Chaobai River	Pilot	Pore	Natural channel	Multiple sources of Yangtze River water and reclaimed water	Drinking water and industry water	2012	Yes	
Jinan	University of Jinan campus	Pilot	Karst	ASTR	Roof water	Drinking water	2008	Yes	700
Linqing	Yellow River flood area	Pilot	Pore	Spreading of open channel-unde rground performed pipe-shaft	Yellow River water	Irrigation	2014	Yes	20×10^3
Jinan	Yufu River	Practical	Pore and Karst	Natural channel	Multiple sources of local surface water and Yellow River	Drinking water and keep springs flowing	2014	Yes	50×10^6

Table 2 Symposiums on MAR in China

Conference	Location	Date	Website
China-Australia Managed Aquifer Recharge (MAR) Training Workshop	University of Jinan, Jinan, China.	October 27-31, 2008	http://china-mar.ujn.edu.cn/
8th International Symposium on Managed Aquifer Recharge - ISMAR8	Tsinghua University, Beijing, China.	October 15-19, 2013.	http://china-mar.ujn.edu.cn/
The Role of Managed Aquifer Recharge in Water Resources Management in China: A Practical Guide for Piloting and Upscaling	Peking University, Beijing, China.	September 7, 2015	http://hydro.pku.edu.cn/

China obtained a great achievement on MAR used for land subsidence control, energy storage, geothermal utilization, prevention of seawater intrusion, augment of urban water supply, agriculture irrigation and alleviation of agricultural disasters etc. However, there are still many problems. It is needed to develop multiple feasible, convenient and economic techniques of MAR fitting to local hydrogeological conditions, prepare guidelines of MAR and management regulations together by establishing demonstration projects, making MAR standardized and the guidelines perfect led by Ministry of Water Resources, Ministry of Environmental Protection and Ministry of Land and Resources jointly.

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