Study on harnessing strategy of brackish water in the Malian River

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Abstract: Located in the inland arid regions of northwest China, Malian River Basin suffers an intensive conflict of supply and demand of water resources. And it encounters an even worse situation because of its brackish water which affects the utilization of the water. The feasibility of desalination of the brackish water is analyzed and then a new harnessing strategy is proposed, based on a longtime monitoring of the water quality of the river as well as a reference to previous treatment schemes. Firstly, the brackish water in non-flood period is supposed to be intercepted by the regulation and storage engineering; second, the brackish water will be desalted; and last, the concentrated water will be disposed in an effective, environment-friendly method. Factors of resources, technology, economy and safety have been taken into account in the new strategy. In this way, the brackish water of upstream could be treated, and the middle and lower reach could be used more efficiently. Analysis of the potential of the new harnessing strategy promises an ultimate solution to the brackish water problem of Malian river, and consequently a good utilization rate of the river basin.

key words- Malian River; brackish water; concentrated water; harnessing strategy; watershed scale

I. INTRODUCTION

Malian River, largest tributary of Jing River in China, originates from gully between Baiyu Mountain in Dingbian County, Shaanxi and Mahuang Mountain in Yanchi County, Ningxia. It locates in the Ordos platform where loess is fractural. The river system is asymmetry for its tributaries are mainly locates in the left bank. The area of the basin is 19100 km^2. The river is 366km long with a gross head of 622m. The river contains two main channels which converge at the south of Qingcheng County. The river then flows through Huanxian, Huachi, Qingcheng and Heshui countybefore it flows into the Jing River in Zhengping of Ningxian. The multi-year average precipitation of Malian River is 449mm, while the upstream region of Hongde station gets only 355.9mm. The average annual evaporation of the three evaporation stations within the basin were 923, 1004 and 1017mm, respectively. Obviously the Malian River basin is an arid region. However Malian River is the largest river in Qingyang City, with an annual runoff of 482 million cubic meters, accounting for 58.78% of the areas' surface water resources [1]. Thus it is extremely valuable to manage the brackish water and improve the utilization efficiency of water resource in such an arid region, in which water resources per capita is the tenth of China's average[2].

Benefited from the development of seawater desalination technology, brackish water has been used as unconventional water resource in many cases, such as new brackish water greenhouse desalination unit powered by geothermal energy in Algeria[3], desalination of brackish river water using Electro dialysis reversal in Barcelona[4], Changhua RO desalination project for high concentration brackish water in China[5]. A desalination plant had been developed in Qingyang City[6]. However, a harnessing strategy based on aimed at the watershed scale has rarely been put forward. Only Xie[2] suggested to build storage dams in the upstream tributaries and main stream, to store and evaporate the brackish water. In this paper, the feasibility of desalination of Malian River is analyzed and a new harnessing strategy is presented, based on a longtime monitoring of the water quality in the river.

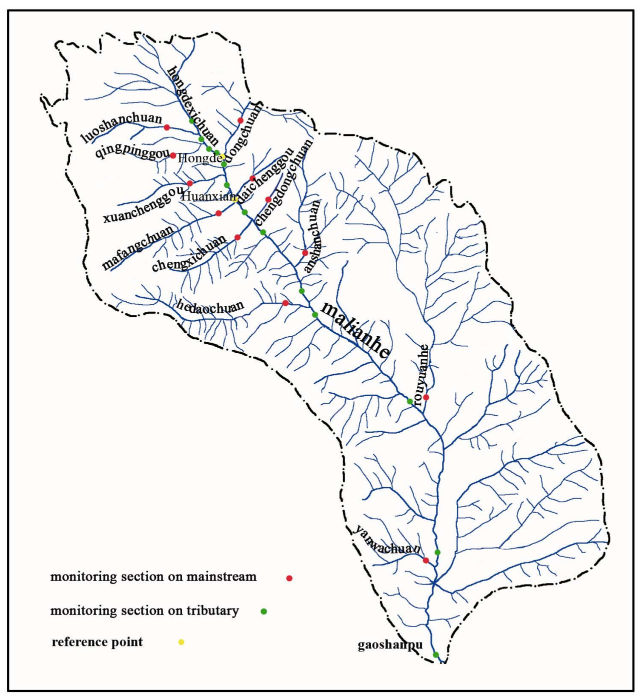

Figure 1 Mapping of Malian River brackish water monitoring sites

Fund: National Natural science Fund for Creative Research Groups - water cycle simulation and control (51021006).

China Institute of Water Resources and Hydropower Research Special research Found – determination of the red control line and establishment of the index system in the water resources exploitation (1224).

978-0-7695-4706-0/12 $26.00 © 2012 IEEE
DOI 10.1109/iCBEB.2012.376

II. QUALITY INVESTIGATION OF BRACKISH WATER

A. Investigation method

The brackish water of Malian River comes mainly from upper reaches, so the key monitor area is the upstream region of Malian River, including tributaries of Hongdexichuan, Hongddongchuan, Luoshachuan, Mafanchuan, Daichenggou, Xuanchenggou and Chengxichuan. To know the progressive mineralization around, several monitoring section was set downstream from Huanxian as well. The monitoring sites layout shows in figure 1. There are 13 monitoring stations in the main stream and 12 in tributaries. The monitoring has been sampled four times at Sep. 2009, Dec. 2009, Mar. 2010 and June 2010 separately. Enhanced monitoring was done in some stations to measure the quality indicators which affect the desalination process.

B. Results of water quality

Table 1 and Table 2 indicate that the TDS of Malian River shows a distinct spatial variation, which is generally at a high level and is hard to be utilized.

Table 1 TDS of Malian River main stream (Unit: mg/L)

Monitoring sites	Max	Min	Ave
Up of Luoshanchuan intersection	12.13×10^3	9.80×10^3	10.98×10^3
Down of Luoshanchuan intersection	10.71×10^3	9.44×10^3	10.08×10^3
Down of Qingpinggou intersection	9.88×10^3	7.94×10^3	8.64×10^3
Xichuan Bridge	9.60×10^3	7.36×10^3	8.71×10^3
Dongchuan Hydrometric Station	9.43×10^3	6.04×10^3	8.14×10^3
Up of Daichenggou intersection	9.20×10^3	6.27×10^3	7.86×10^3
Up of Chengdongchuan intersection	8.94×10^3	5.42×10^3	6.73×10^3
Down of Chengxichuan intersection	8.42×10^3	4.28×10^3	5.98×10^3
Up of Hedaochuan intersection	6.55×10^3	2.90×10^3	4.20×10^3
Down of Hedaochuan intersection	4.13×10^3	1.75×10^3	2.92×10^3
Qingcheng Bridge	2.99×10^3	2.08×10^3	2.54×10^3
Up of Yanwachuan intersection	2.33×10^3	1.41×10^3	1.90×10^3
Gaoshanpu	2.43×10^3	0.51×10^3	1.54×10^3

Table 2 TDS of Malian river tributary (Unit: mg/L)

Monitoring sites	Max	Min	Ave
Luoshanchuan	12.07×10^3	9.69×10^3	10.52×10^3
Qingpinggou	7.47×10^3	5.21×10^3	5.95×10^3
Hongdedongchuan	9.25×10^3	5.95×10^3	7.49×10^3
Xuanchenggou	7.46×10^3	4.52×10^3	5.63×10^3
Daichenggou	6.03×10^3	3.04×10^3	4.08×10^3
Mafangchuan	5.11×10^3	2.68×10^3	3.46×10^3
Chengdongchuan	4.86×10^3	2.03×10^3	3.13×10^3
Chengxichuan	3.99×10^3	2.09×10^3	2.71×10^3
Anshanchuan	2.32×10^3	1.21×10^3	1.64×10^3
Hedaochuan	1.76×10^3	0.51×10^3	1.23×10^3
Rouyuanhe	1.60×10^3	0.66×10^3	1.03×10^3

The TDS of the tributaries shows a downward trend from north to south. Tributaries upstream from Hongde are mineralized at the highest level, with Luoshanchuan of 10518mg/L, Hongdedongchuan of 7.49×10^3mg/L, Qingpinggou 5.95×10^3mg/L separately. Between Hongde and Huanxian is moderate mineralized, with the TDS degree in $3.00\sim5.00\times10^3$mg/L in the tributaries. Reaches downstream of Huanxian, the degree of all tributaries is below 3.0×10^3mg/L, remarkably lower than upper reaches.

Because of the tributaries, the TDS of main stream also shows a downward trend from upstream to downstream. Upstream from Hongde can't be utilized by human and domestic animals at a high level of 10.98×10^3mg/L in the stream intersection of Luoshanchuan, and 8.71×10^3mg/L in the Xichuan Bridge. To intersection of Chengxichuan, the TDS declines to 5.98×10^3mg/L. The downstream can be utilized for irrigation through some process, with Hedaochuan of 2.92×10^3mg/L and Gaoshanpu of 1.54×10^3mg/L.

III. GENERAL IDEA

According to the monitoring results of Malian River water quality, the TDS of the brackish water mainly comes from the upper reaches, because the TDS level of upper reaches is obviously higher than lower reaches. So interception of upper reaches flow should drastically decrease the TDS level of the middle and lower. The key area to be managed is the upper reaches from Huanxian, in which TDS of the tributaries change significantly. As the TDS of the water mostly comes from groundwater [2], flood can dilute the brackish water adequately, the interception only need to be implemented towards non-flood brackish water.

So the general harnessing scheme should be focused on the upper reaches, by desalinating the brackish water in a reasonable way and disposing the concentrated water in an effective, environment-friendly pattern, the upper reaches brackish water is utilized, the middle and lower reaches can be used more easily, and the Malian River can be utilized as a whole.

IV. KEY TECHNOLOGY

Xie[2] argued that the Malian River could only be 'partially utilized' rather than 'fully used', which result from the limits of the desalination in this basin. The limits derived from the desalination cost and the treatment of concentrated water which are thus the focus to be discussed below.

A. Brackish water desalination

Analysis of desalination technology feasibility：

Brackish water desalination is not a big problem, for there are many optional methods [7-15]. Based on the established idea, the TDS of brackish water to be intercepted is about 6.77×10^3mg/L. Compare to the raw water quality of Canghua desalination project(Table 3), we are at the same level, and can obtain desalinated water with RO.

Technology feasibility not only requires desalinated water, but also need process running efficiently as long as possible. The quality of Malian River is a little better than Canghua's to run RO, except the sulfate (Table 3). And, there are many pretreatment methods to remove sulfate, such as ion exchange, adding quicklime et al. So, it may run as well as Canghua desalination project did. In order to confirm the result, we did a lab-test, the recovery can achieve to 85%, and a pilot test is running, which treatment capacity is $20m^3/h$. It can be verified, desalination based on RO in Malian River is technically feasible.

Table 3 Water quality comparison between Malian River and Changhua desalination project

Test item	Water quality of Canghua desalination project	Potential water taking of Malian River	
		Water quality	Compare result
TDS（g/L）	12.89×10^3	6.77×10^3	low
turbidity（NTU）	5	4	low
conductivity（μs/cm）	21.27×10^3	7.85×10^3	low
total hardness（mg/L）	3.32×10^3	3.38×10^3	not far-off
bicarbonate（mg/L）	637.66	110.45	low
carbonates（mg/L）	0	9.67	not far-off
sulphate（mg/L）	1.34×10^3	2.31×10^3	high
chlorides（mg/L）	6.63×10^3	2.21×10^3	low
Ca（mg/L）	270.54	282.5	not far-off
Na（mg/L）	3.66×10^3	1.13×10^3	low
Mg（mg/L）	644.48	607.5	low
Fe（mg/L）	200	＜0.03	low
Mn（mg/L）	0	＜0.001	same
Ba（mg/L）	0.26	0.125	low

Analysis of economic feasibility:

Investment cost is estimated in accordance with industry regulations and revised by local conditions. The RO desalination plants investment costs is about 420 million Yuan. Because the project is very beneficial for the Qingyang's economic development, the local government said that there would be a discount in electricity price for this project. We should point that, the electricity cost is calculated in two ways, one is in accordance with 0.50 Yuan/kwh, and the other is 0.20 Yuan/kwh as a discounted price before network. Other basis of cost calculation is as follow: The designed production capacity is 59500 t/d, the designed unit product power consumption of main motor and auxiliary is 3.0kwh and 0.3kwh respectively, 36 persons will be working in the plant, the average annual wage for one person is 25,000 Yuan, the depreciation period is 15 years, membrane life is 5 years, maintenance fee is 1.5% of the investment costs, management fee is 20% of the total salaries.

According to the basis above, the estimated depreciation charges, chemical agent cost, replacement charge of membrane, wages and welfare, overhaul expense and maintenance check cost, and management cost is 1.29, 0.47, 0.32, 0.04, 0.29, 0.01 Yuan/t respectively. The electricity cost is 1.65 or 0.66 Yuan/t, depends on whether there is subsidy on electricity price. The water making cost is 4.07or 3.08 Yuan/t according to the electricity price.

According to the classified water price in Qingyang City, the water price of domestic, administration institutions, commercial and capital construction is 3.20, 5.50, 7.50 Yuan/m^3, respectively. Water producing cost of the desalination is lower than the selling price of all the other terminals except domestic water. If electricity price is subsided, the cost will be cheaper than the price of domestic water. So it can be judged that, in Qingyang City, desalination based on RO is economically feasible.

B. Concentrated water treatment

According to local conditions, there are three options to choose to treat concentrated water.

1. One choice is discharging concentrated water into polls to cultivate marine products. The waste water of marine aquaculture is disposed by natural evaporation.

According to the research results of the Chinese Academy of Fishery Sciences, diversified aquaculture mode in the brackish water is feasible by transplanting and habituation of aquaculture species, also with improving and control of water quality. More than twenty aquaculture species can be cultured industrially, such as shrimp, acipenserBaeri, jifu tilapia, ortunustrituberculatus and so on.

According the designed treatment capacity and the results of lab test, 3.3 million m^3 concentrated brackish water have to be evaporated. It means that depending on the precipitation and evaporation level in Qingyang City, at least $6km^2$ water area is needed for water balance. Based on geological survey of Malian River Basin, Chengzhanggou can be used as the concentrated brackish water aquaculture site. The drainage area of Chengzhanggou is $15km^2$ approximately, the length of the main ditch is about 5km, and the ditch width is about 150m.The trench is flat and conducive to evaporation.

2. In addition to natural evaporation, forced evaporation by power or heat can be used to treat concentrated water. This study is a partner of water resources integrated plan in Qingyang City. In the plan, desalinated water is supplied to construct thermal power plant. Combination of forced and natural evaporation may be another solution.

Large amounts of steam are produced during the process of power plants. Excess steam can be reused as heat source for forced evaporation. High quality water from forced evaporation can be added to boiler directly, while the remaining concentrated liquid is discharged into evaporation ponds to crystallize solid. The solid can be used as deicer salt in winter.

There are many advantages in this method, such as thermal pollution reuse, waste utilization and land saving. But the proportion of forced and natural evaporation has to be adjust by the amounts of excess steam.

3. Another choice is well reinjection, when there is a right mining area in hydrogeological where concentered water can be rejected into mining well. If not, we can re-inject wastewater into a newly dug deep well.

This method is cheap, easy, land free, and pollution free, which can be described as the best solution. However, the program needs a certain number of abandoned mining areas for disposing after several years of mining. Also the re-injection requires detailed hydrogeological exploration data.

In summary, at least three choices can be used to treat concentered water. Treatment for concentrated water is not the restriction to improve the water quality in Malian River. It is also feasible to treat concentrated water in Qingyang City.

V. EFFECT ANALYSIS

Table 4 shows the changes of TDS and runoff in different development degree of brackish water. We can see that, the TDS of middle and lower reach water will reduce along with the increase of the development degree of brackish water.

If the upstream brackish water is intercepted completely, the TDS of the junction under the Malian River and Chengxichuan will decline from 5.17×10^3 to 1.91×10^3mg/L, and those of Qingcheng and Gaoshanpu would decline from 2.39×10^3 and 1.25×10^3mg/L to 0.68×10^3 and0.51×10^3mg/L, respectively.

In this project, 19.55 million tons of high quality water can be produced each year to alleviate the water shortage situation in Qingyang City greatly, that is of great significance for the promotion of resource exploitation, as well as support to the regional economic and social development.

Table 4 Changes of TDS and runoff in different development degree of brackish water

Site	Development degree	TDS（mg/L）	Runoff（m^3）
Up of Daichenggou intersection	0%	7.41×10^3	23.96×10^6
	25%	7.41×10^3	17.97×10^6
	50%	7.41×10^3	11.98×10^6
	75%	7.41×10^3	5.99×10^6
	100%	0	0
Down of Chengxichuan intersection	0%	5.17×10^3	40.47×10^6
	25%	4.78×10^3	34.48×10^6
	50%	4.22×10^3	28.49×10^6
	75%	3.38×10^3	22.50×10^6
	100%	1.92×10^3	16.51×10^6
Qingcheng Bridge	0%	2.39×10^3	94.64×10^6
	25%	2.05×10^3	88.65×10^6
	50%	1.66×10^3	82.66×10^6
	75%	1.21×10^3	76.67×10^6
	100%	0.68×10^3	70.68×10^6
Gaoshanpu	0%	1.25×10^3	223.54×10^6
	25%	1.08×10^3	217.55×10^6
	50%	0.9×10^3	211.56×10^6
	75%	0.71×10^3	205.57×10^6
	100%	0.51×10^3	199.58×10^6

ACKNOWLEDGEMENTS

This research was supported by National Natural science Fund for Creative Research Groups - water cycle simulation and control (51021006), and China Institute of Water Resources and Hydropower Research Special Research Found–determination of the red control line and establishment of the index system in the exploitation of water resources (1224). The authors would like to very grateful to the Qingyang Municipal Government, Water Conservancy Bureau, Environmental Protection Agency, National Development and Reform Commission of Qingyang City for their substantial support and help.

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