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STAGES AND POTENTIALITY OF WATER RESOURCES DEVELOPMENT IN ARID NORTHWESTERN CHINA①

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ABSTRACT: The processes of water resources exploitation and utilization can be divided into three stages by water resources transformation, and the history, present situation and future trend of water resources development in piedmont areas around high mountains of arid northwestern China. The three stages are: the stage of surface water development (the first stage), the stage of comprehensive development of surface and ground water (the second stage) and the stage of economical development of water resources (the third stage). The three stages link each other and show the law and processes of water resources exploitation and utilization associated with social and technological progress. The economical water policy should run through the three stages. On this point, however, the third stage differs from the others, particularly, refering to irrigated agriculture. The third stage has more progressive significance because it breaks the traditional ideas on water resources development. According to our investigation and calculation, under present conditions of water resources development, the net used water is about $160 \times 10^8 m^3$, accounting for 18% of the total water resources of northwestern China. The water resources have not been fully developed. If the first stage is finished, the exploitable water can be increased by 91%. After the second stage, furthermore, it can be increased by 216%.

KEY WORDS: water resources development, water resources utilization, exploitable water resources, channelizable water resources, northeastern China

Northwestern China is one of the potentially developing economic regions in future due to its bountiful resources such as solar and thermal energy, farmland, minerals and so on. Rare precipitation, however, prevents agricultural development. Most of farmland can't be cultivated without irrigation (Liu, 1980). The irrigated water originates from contemporary glaciers and snow on high mountains which are characterized by extremely cold climate with more pre-

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cipitation. A lot of water flows into piedmont plains and fluvial fans, making river banks and spring areas become a large area of irrigation oases. It is considered that water is primarily restrictive factor for economic development and exploitation of agricultural resources. Therefore, it is very important in theory and practice to deeply study the degree, stages, potentiality of water resources utilization in order to improve economic situations in northwestern China.

By 20-year studies on water resources formation, transformation and changes caused by water resources development for a few case basins of northwestern China which have good economic conditions and high degree of water resources development, it is discovered that irrigated agriculture, economic development and increase of water resources utilization rate are strongly related to water conservancy projects and the level of water resources development. According to the history, present situation and trend of water resources exploitation and utilization in arid northwestern China, water resources development can be divided into three stages: the stage of surface water development, the stage of comprehensive development of surface and ground water and the stage of economical development of water resources. The first and second stages belong to the the period of broadening water sources, aiming at fully developing surface and ground water resources and increasing irrigated areas. The third stage belongs to the period of reducing expenditure of water resources exploitation and increasing utilization rate. In other words, more economic products should be produced by the equivalent water in comparison with the former two stages using advanced technology. The three stages link each other and show the progress of water resources utilization and exploitation with social and technological developments. Economical water policy should run through every stage. However, the policy has special meaning in the third stage during which it breaks the traditional ideas on water resources developments in arid regions.

I. WATER RESOURCES AND SOME CONCEPTS ON ARID LAND

Water resources can be in forms of precipitation, glacier ice, surface water and ground water in arid northwestern China (Tang *et al*., 1992). However, much of precipitation and glacier ice are distributed in mountainous areas. They can not be directly used in industrial and agricultural developments unless they transform into runoff and flow into piedmont plains which are suitable for economic activities due to their bountiful thermal and solar energy, and farmland resources. So, surface and ground water resources and their intertransformations in piedmont plains are discussed below.

1. Surface Water Resources

The amount of surface water out of mountains is about $999.76 \times 10^8 m^3$ in arid northwestern China, of which only the Ertis River of northern Xinjiang is an exterior river and has annual discharge of $119 \times 10^8 m^3$, accounting for 11.9% of the total surface water (Yuan, 1987).

The surface water of Xinjiang is the most bountiful in comparison with the other arid regions of northwestern China. Xinjiang has $883.65 \times 10^8 m^3$ of surface water, accounting for 88.4% of the total surface water. Northern and southern Xinjiang own, respectively, 44.4% and 40.0% of the total Xinjiang surface water. However, there are many international rivers, about $233 \times 10^8 m^3$ outflowing from Xinjiang and $90.8 \times 10^8 m^3$ inflowing into Xinjiang. The net amount of surface water out of Xinjiang is $142.2 \times 10^8 m^3$ and so the actual surface water of Xinjiang is $741.8 \times 10^8 m^3$. Qaidam Basin of Qinghai has about $45.80 \times 10^8 m^3$ of surface water, making up 4.6% of the total surface water in northwestern China. Hexi Corridor of Gansu is $69.96 \times 10^8 m^3$, 7.0% of the total surface water. In summary, the actual surface water is about $857.56 \times 10^8 m^3$ in arid northwestern China (Table 1).

The surface water outflowing mountains can be subdivided into two parts as the following equation:

$$Y = B + R \qquad (1)$$

where $$B = Yc + I + F \quad R = Rs + Rg$$

therefore $$Y = Yc + I + F + Rs + Rg \qquad (2)$$

where Y——surface runoff outflowing mountains;

B——water into water channels;

R——water in rivers of piedmont plains;

I——seepage water by channel system;

Yc——net water used by farmland;

F——seepage water by farmlands;

Rs——water out of balance unit;

Rg——water infiltration from rivers.

2. Ground Water

Ground water in piedmont plains is influenced and controlled by geological texture and natural geographical conditions in arid northwestern China. Most of piedmont plains are large tectonic basins with thick aquifers consisting of the Quaternary sediments and plenty of ground water. Most of the ground water is formed in geological period. A small part of the ground water, natural ground water or substitutable ground water, participate in contemporary water cycle. According to Li Baoxing (1982), the natural ground water in piedmont plains of arid northwestern China is about $350 \times 10^8 m^3$, of which Hexi Corridor of Gansu has $42.5 \times 10^8 m^3$, northern bajada of the Tianshan Mountains $58.4 \times 10^8 m^3$, Tarim Basin $187.5 \times 10^8 m^3$ and Qaidam Basin $30.0 \times 10^8 m^3$, accounting for 13.4%, 18.3%, 58.9% and 9.4% of the total natural ground water, respectively. About 90% of the total natural ground water is transformed from the surface water outflowing from mountains, including seepage water from rivers, water channels and farmlands. Independent ground water includes ground runoff from

Table 1 The stages and potentiality of water resources development in arid northwestern China

Stages of water resources development	Surface water ($\times 10^8 m^3$)	Ground water ($\times 10^8 m^3$)	Total water resources ($\times 10^8 m^3$)	Rates of channelized water ($\times 10^8 m^3$)	Channelizable water ($\times 10^8 m^3$)	Utilization rate of canal system(%)	Utilization rate of farmland water(%)	Exploitable water ($\times 10^8 m^3$)
Status quo	857.6	614.5(35) *	892.6	56	480.3	42	80	161.4
The First	857.6	496.4(35) *	892.6	80	686.1	50	90	308.7
The Second	857.6		892.6	80	686.1	50	90	308.7
		496.4(35) *		50 * *	248.2	90	90	201.0
The Third	857.6	496.4(35) *	892.6		934.3			509.7

* Independent amount; * * Rate of channelized ground water

mountains into piedmont plains in side direction and precipitation seepages. The independent ground water is 35.0 $\times 10^8$ m^3 and occupies 10% of the total natural ground water. However, the present ground water is 614.5 $\times 10^8$ m^3 by water balance calculation (Table 1). The natural ground water of closed inner river basins can be expressed as the following equation:

$$G = Rg + I + F + G_1 + X \tag{3}$$

where G——natural ground water;

G_1——ground runoff from mountains;

X——seepage water from precipitation.

In the view of water resources utilization, the most important term or concept is exploitable ground water (Chen *et al*., 1992).

$$W_o = A - B \cdot \alpha \cdot \eta - E \tag{4}$$

where W_o——exploitable ground water;

A——total water resources;

α——utilization ratio of channel system;

η——utilization ratio of farmland water;

E——evaporation of ground water.

Equation (4) shows the relationship between exploitable ground water and total water resources, level of surface water development and evaporation of ground water. It can be concluded that the exploitable ground water only relies on the evaporation of ground water if the degree of surface water development is stable (Tang, 1992).

3. Total Water Resources, Channelizable Water Resources and Exploitable Water Resources

3.1 *Total water resources*

Total water resources designate to the summary of surface water out of mountains and ground water in piedmont plains minus repeated parts between surface and ground water in terms of calculation, that is,

$$A = Y + G - (Rg + I + F) = Y + (G_1 + X) \tag{5}$$

3.2 *Channelizable and exploitable water*

Channelizable water refers to gross water channelized by various channels and canals, by using all kinds of water conservancy projects and drawing means in a river basin (including rechannelized water). The rechannelized water resulted from transformations between surface and ground water. So, channelizable water can surpass total water resources in a basin. For instance, the total water resources of the Urumqi River catchment in Xinjiang are 6.431 $\times 10^8$ m^3, while the channelizable water is 8.478 $\times 10^8$ m^3 (Qu *et al*., 1991). Additionally, the total water resources of the Shiyang River catchment of Gansu are 16.995 $\times 10^8$ m^3, while the channelizable water is 18.569 $\times 10^8$ m^3 (Chen *et al*., 1992).

Exploitable water designates total net water channelized by the last channels in agriculture and used by industries and municipal supplies. Based on principle of water balance, water resources are always wasted in part by evaporation and other losses in their circulation and dilivery. The exploitable water in a river basin is always less than the total water resources. For ex ample , the exploitable water of the Urumqi River basin is $5.579 \times 10^8 m^3$, accounting for 86.8% of the total water resources . The exploitable water of the Shiyang River basin is $12.875 \times 10^8 m^3$, accounting for 75.7% of the total water resources.

II. STAGES AND POTENTIALITY OF WATER RESOURCES DEVELOPMENT

1. Present Situation of Water Resources Development

It is apparent that the social changes from fishing and hunting to agricultural society are great leap and experienced a long period. It is also well known that development of irrigated agriculture in arid lands originates in utilizing surface water and spring water in the delta of lower parts of rivers or regions easily irrigated. Actually, most of the deltas and regions are still in this stage, though the stage has lasted 2 000 years. With economic and technologic progresses in recent 30 – 40 years, however, the surface water development in arid northwestern China has greatly advanced, and the rates of channelized waters and the utilization ratios of canal systems have been improved, but not in all regions of the northwestern China. The present ratios of channelized surface water are 55%, 80% and 50%, respectively, in Xinjiang, Hexi region of Gansu and Qaidam Basin of Qinghai, with 56% as the average of the entire arid northwestern China. The utilization rates of channel system are 0.42, 0.50 and 0.40, respectively, in Xinjiang, Hexi region of Gansu and Qaidam of Qinghai, with 0.42 as the average of the entire arid northwestern China. The utilization coefficient of farmland water is 0.80 on an average in the arid northwestern China. By calculations using those parameters, the channelized surface water of the northwestern China is $480.3 \times 10^8 m^3$, and the exploited water is only $161.0 \times 10^8 m^3$. The utilization rate of the surface water is only 18.1%, indicating there is great potentiality of surface water development in future.

For increasing utilization rates of water resources and exploitable water, the key water conservancy projects of most regions should focus on constructing reservoirs in mountains to improve channelized surface water, on reducing water seepages of canal system to increase utilization ratios of canal system, and on constructing farmland buildings to increase utilization rates of farmland water.

2. The Stage of Surface Water Development (the First Stage)

A case study on the Urumqi River with catchment and the Shiyang River catchment show that the completation of the first stage is characterized by the ratio of channelized surface water being over 80%, the utilization rate of canal system over 50%, and the utilization rate of farmland water over 90%. After the first stage, the channelized surface water of the arid northwestern China can reach 686.1 $\times 10^8$ m^3, and the exploitable surface water increases to 308.7 $\times 10^8$ m^3, increasing 147.3 $\times 10^8$ m^3 in comparison with present one (Table 1).

Water conservancy projects should be different in different river catchments after the first stage. In the catchments where tectonic conditions facilitate water resources transformations and ground water exploitation, the projects are supposed to concentrate on ground water development. Otherwise, the projects should focus on continuing to improve utilization ratios of surface water development in order to increase the exploitable water resources.

3. The Stage of Comprehensive Development of Surface and Ground Water (the Second Stage)

In the river catchments such as the Shiyang River and the Urumqi River with highly developed economy and large population, as well as the hydrogeological conditions in favor of water resources transformations, the surface water development should be along with the ground water development. In other words, water resources development takes into the stage of comprehensive development of surface and ground waters. In fact, the Urumqi River and the Shiyang River basins have finished the second stage. The exploitable water resources of the second stage are 30% higher than that of the first stage, and the utilization rate increases to 75% −85% (Chen *et al*., 1992; Shi, 1992).

On the basis of water budget, after the first stage, the water infiltration from rivers can be expressed as:

$$Rg = Y \cdot (1 - \beta) \cdot \gamma \qquad (6)$$

$$Rg = 857.6 \times (1 - 0.8) \times 0.85 = 145.8 \times 10^8 \text{ m}^3$$

infiltration from channel system as:

$$I = Y \cdot \beta \cdot (1 - \alpha) \cdot \varepsilon \qquad (7)$$

$$I = 857.6 \times 0.8 \times 0.5 \times 0.9 = 308.7 \times 10^8 \text{ m}^3$$

seepage from farmland as:

$$F = Y \cdot \beta \cdot \alpha \cdot (1 - \varepsilon) \cdot \zeta \qquad (8)$$

$$F = 857.6 \times 0.8 \times 0.5 \times (1 - 0.9) \times 0.2 = 6.9 \times 10^8 \text{ m}^3$$

where β——rate of channelized surface water;

γ——rate of water infiltration from rivers;

ε——rate of water infiltration from canal system;

ζ——rate of water seepage from farmland.

Therefore, the natural ground water will be 496.4 $\times 10^8$ m^3 (Chen *et al*., 1992). If the exploitable rate of natural ground water is 50%, utilization rate of ground water canal system is 0.9, and utilization rate of farmland water is 0.9, the channelizablle ground water of northwestern China will be 248.2 $\times 10^8$ m^3, and the exploitable ground water will be 201.0 $\times 10^8$ m^3. The total exploitable surface and ground water will be 509.7 $\times 10^8$ m^3, increasing 201.0

$\times 10^8$ m^3 and 348.3 $\times 10^8$ m^3, respectively, in comparison with the first stage and the present situation. The unifying utilization rate of the water resources reaches 57.1%, approaching to the highest rate. As a result, the exploitable water can be increased at a high rate when the stage changes from the first to the second (Table 1).

Extensive exploitation of ground water in some river basins like the Urumqi River and the Shiyang River began in the early 1970s. It is proven by practice that this stage is easily accepted by people and lasts 10 to 15 years. It is also proven that water resources development must be strictly programed and managed. Otherwise, it might be overexploited and bring about some environmental problems such as regional decline of ground water levels and water quality, vegetation deteriorations, as well as land desertification. Those changes might not be recovered or adjusted. It is necessary to deeply investigate ground water pathways for its formation and transformation, as well as distribution of wells and exploitation amount in a river basin before its ground water is exploited.

In the basins having finished the second stage, it is not reasonable to increase water resources by improving the utilization ratio of surface water (Qu *et al.*, 1991). The reason is that the exploitable surface water can be increased by improving the utilization ratio of canal system, while the exploitable ground water will be decreased at equilibrium amount due to the transformation and linkage of surface and ground water (Qu *et al.*, 1991). On the other hand, those basins have generally built the system of ground water exploitation, and the reduction of the exploitable ground water may result in some exploitation buildings, such as wells, out of work, and therefore bring about economic loss, environmental and social problems.

4. The Stage of Economical Utilization of Water Resources (the Third Stage)

With economic developments, it is essential to increase supply water in northwestern China. Because the water resources development in some river basins has been in their limitation after the second stage, it is necessary to step in a higher stage, that is, the stage of economical utilization of water resources. The policy of economical utilization of water resources should run through all trades, including industry, municipal system of water supply and agriculture. The agriculture utilizes a large part of water in the northwestern China, occupying 95% of the total water resources. So, there is a great potential to save water in agriculture so long as the agriculture adopts irrigation modernization and other advanced technologies. The economical-water-agriculture will accelerate the economic development of arid northwestern China. If the irrigation quota is reduced from 6 000 m^3/ha to 3 000 m^3/ha, the economic profit of northwestern China will be doubled (Qu, 1988).

III. CONCLUSIONS

(1) On the basis of the history, present situation and future trends of water resources de-

velopment in arid northwestern China, water resources development can be divided into three stages, the stage of surface water development, the stage of comprehensive development of surface and ground water, and the stage of economical development of water resources. The three stages indicate the degree and reasonability of water resources development in arid northwestern China.

(2) The water resources development in most river basins of arid northwestern China is still in the first stage. The exploitable water is only 161.4×10^8 m^3 at present, accounting for 18.1% of the total water resources. It is calculated that after the first stage the exploitable water will increase to 308.7×10^8 m^3, increasing 91.3% in comparison with the present one and accounting for 34.6% of the total water resources. After the second stage, the exploitable water will be 509.7×10^8 m^3, increasing 215.8% in comparison with present one and accounting for 57.1% of the total water resources.

(3) The stages of water resources developments in river basins of the northwestern China are different, along with economic developments. Most of basins are still in the first stage. Only the Shiyang River and the Urumqi River basins have finished the second stage. The basins in different stages in terms of water resources development should focus water conservancy constructions on different projects. For the basins still in the first stage, the key objective is supposed to develop surface water. For the basins in the second stage, the key objective is supposed to develop ground water. After the second stage, the water resources development should change to the economical stage (the third stage) so that economic profit can be increased by using equivalent amount of water resources.

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