Water Consumption in Ningxia Reach of the Yellow River since Integrated Regulation

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\textbf{Abstract}

The annual allocation, inter-annual variation and relation of water diversion and recession are analyzed in Ningxia reach of the Yellow River main stream from 1999 to 2012. Water consumption in Ningxia reach was calculated by water diversion-recession method and water balance method. The average value of water diversion-recession method is 3.264 billion m\textsuperscript{3} and annual variation is relatively steady. The result of water balance method is 3.937 billion m\textsuperscript{3} and annual variation is obvious. It is suggested that strengthen verification of entrances and monitoring of water diversion and recession.

\textbf{Keywords}

Water Consumption, Water Diversion-Recession Method, Water Balance Method, Water Diversion Quantity, Water Recession Quantity, Ningxia Reach, Integrated Water Regulation

\textbf{1. Background and Data}

\textbf{1.1. Background}

The Yellow River water regulation implements double control principles, \textit{i.e.} total water consumption and discharge of control section \cite{1}. Water diversion of the Yellow River main stream in Ningxia reach is mainly from irrigation, industry and urban living water, and water recession mainly related to agricultural irrigation and process structure of industrial water. In recent years, the complexity of water diversion and recession was increased due to the development of agricultural irrigation rule, water-saving transformation, water recession reuse, and construction of industrial base in Yellow River irrigation district. Therefore, scale and proportion of water diversion-recession and water consumption in
Ningxia reach since integrated regulation are needed to analyze for united management and optimal configuration of the Yellow River water resources.

1.2. Basic Data

Integrated water resources regulation of Yellow River began in March 1999 [2], so the year from 1999 to 2012 is selected as study period. Water diversion-recession data are from *monthly report of water diversion project which have license issued by Yellow River Conservancy Commission*. Hydrology data of different time scale in main stream and tributaries of Yellow River are from *Yellow River basin hydrological almanac* [3].

2. Method

2.1. Method of Water Diversion and Recession

For particular river section, water consumption is the difference of water diversion and water recession, based on the calculation of observed water diversion and water recession.

$$W_C = W_D - W_R$$  \hspace{1cm} (1)

where: $W_C$, water consumption; $W_D$, water diversion; $W_R$, water recession.

The accuracy of the method result depends on the accuracy of the data of water diversion and water recession.

2.2. Method of Water Balance

Water balance method is based on the observed data of hydrological station, and evaporation and leakage loss were deducted from the difference of upper and lower section discharge, according to the principle of water balance [4] [5]. The equation is as follows:

$$W_C = (W_U + W_S + W_{UC}) - (W_E + W_L) - W_{L}$$  \hspace{1cm} (2)

where: $W_U$, upper reach inflow; $W_S$, lower reach effluent; $W_S$, controlled water quantity; $W_{UC}$, uncontrolled water quantity; $W_E$, water surface evaporation; $W_L$, section channel leakage; $W_C$, industrial and agricultural water consumption.

According to features of the Yellow River, the interval water consumption of industry and agriculture has its special definition. Water consumption of agricultural irrigation refers to the water which can’t return to the Yellow River due to evaporation and leakage in irrigation process of farmland, grassland, forest and so on. Water consumption of industrial and urban domestic includes user consumption and drainage loss, i.e. the difference of water diversion and waste water into rivers.

Water surface evaporation was calculated by observation data of the representative rainfall and evaporation stations year by year. Evaporating observation data of different evaporating dish are modified according to the coefficient given by *the second national comprehensive planning of water resources*. Water surface area is multiplied by mean width of monthly water surface, according to the
data in *Yellow River basin hydrology almanac*, and distance between upper and lower station. The equation is as follows:

\[
W_E = \left( (E \times a) - P \right) \times A
\]

where: \(W_E\), net evaporation, \(10^8\) m\(^3\); \(E\), mean annual evaporation, mm; \(a\), conversion coefficient of different evaporating dish; \(P\), average rainfall, mm; \(A\), water surface area, km\(^2\).

3. Analysis of Water Diversion and Water Recession

3.1. Entrance Number of Water Diversion-Recession

There are fourteen water diversion entrances in Ningxia Hui Autonomous Region approved by Yellow River Conservancy Commission. Among them, eight for agriculture, three for industry, two for hydropower and one for resident life [6].

In order to reflect the real status of water diversion and recession, remote sensing images of thirty meters resolution in Google earth were applied, and 140 water entrances and the latitude and longitude were identified from Xiaheyan to Shizuishan.

3.2. Analysis of Water Diversion

The Ningxia reach is divided into four parts, i.e. upper Xiaheyan, Xiaheyan–Qingtongxia, Qingtongxia-Shizuishan, and lower Shizuishan. Water diversion of Weining Irrigation Area (WNIA) is the water diversion in Meiliqu and Xiaheyan–Qingtongxia not include Dongganqu. Water diversion of Qingtongxia Irrigation Area (QTXIA) is the water diversion from Qingtongxia~Shizuishan, Dongganqu and lower Shizuishan.

Water diversion in WNIA and QTXIA are mainly occurred in April to August and November, which just related to irrigation season [7]; nearly no water diversion in the other four months from December to March.

The annual water diversion in WNIA is 1.73 billion m\(^3\), which showed slow increasing trend. Among them, it is 1.723 billion m\(^3\) in Xiaheyan–Qingtongxia. The lowest is 1.089 billion m\(^3\) occurred in the year 2003, and the highest is 2.044 billion m\(^3\) occurred in the year 2008.

The annual water diversion in QTXIA is 5.08 billion m\(^3\), which showed slow decreasing trend. Among them, it is 4.467 billion m\(^3\) in Qingtongxia~Shizuishan. The same as WNIA, the lowest is 1.089 billion m\(^3\) and also occurred in the year 2003, the reason is runoff in the main stream of Yellow River is low; the highest is 6896 billion m\(^3\) occurred in the year 1999.

3.3. Analysis of Water Recession

Water recession in Ningxia reach is as follows: no water recession in Meiliqu upper Xiaheyan, water recession in Xiaheyan–Qingtongxia is the same of WNIA and in Qingtongxia~Shizuishan is the same of QTXIA, and no water recession lower Shizuishan.
Water recession in WNIA and QTXIA is mainly occurred in May to August and November, which related to water diversion in irrigation area. Unlike variety of annual water diversion, water recession occurred in the whole year.

The average annual water recession in WNIA is 0.79 billion m$^3$, which showed obvious yearly change. The lowest is 0.627 billion m$^3$ occurred in the year 2009, and the highest is 1.108 billion m$^3$ occurred in the year 2007.

The average annual water recession in QTXIA is 2.752 billion m$^3$, which showed slow decreasing trend. The lowest is 1.923 billion m$^3$ occurred in the year 2003, and the highest is 4.053 billion m$^3$ occurred in the year 1999.

### 3.4. Relationship of Water Diversion and Water Recession

The average ratio of water recession and water diversion in WNIA is 0.46, the maximum is 0.64 and the minimum is 0.35, shown in Figure 1. There is no obvious relationship between water recession and diversion, shown in Figure 2.

The average ratio of water recession and water diversion in QTXIA is 0.54, the maximum is 0.63 and the minimum is 0.46, shown in Figure 3. The relationship between water recession and diversion is very well—larger water diversion larger water recession, shown in Figure 4.

![Figure 1. Ratio of water recession-diversion in WNIA.](image1)

![Figure 2. Relation of water diversion-recession.](image2)
4. Analysis of Water Consumption

4.1. Results of Water Diversion-Recession Method

Water diversion-recession in Ningxia irrigation area controlled better. Seventeen monitoring sites of water diversion and pumping diversion control more than 98% of the total irrigation area water diversion amount. Through various means such as measure, survey, investigation and so on, water recession was controlled over 90% of the whole irrigation area [8] [9].

(1) Water diversion. There is one water diversion entrance locates upper Xiaheyan, six locate in Xiaheyan–Qingtongxia, two locate between Qingtongxia and Shizuishan, three locate lower Shizuishan. The sum of each river channel is the total water diversion.

(2) Water recession. The total water recession includes WNIA, QTXIA and Qingshui River’s water recession [10]. WNIA includes first drainage ditch in Hebei irrigation area, ninth drainage ditch, Beihezigou, Nanhezigou and Hongliugou etc. in Henan irrigation area. QTXIA includes five drainage ditches in Hedong irrigation area, thirteen drainage ditches in Hexi irrigation area, and a
little recession in Taole irrigation area.

(3) Water consumption. The average water consumption in Ningxia reach is 3.264 billion m³. The lowest is 2.161 billion m³ occurred in the year 2003, and the highest is 3.875 billion m³ occurred in the year 2008. Except the year 2003 and 2012, the other annual water consumption is between 3.0 - 3.875 billion m³, shown in Table 1.

4.2. Results of Water Balance

1) Controlled water quantity. There are three tributaries of the Yellow River in Ningxia reach, Qingshui River, Hongliugou and Kushui River. Hydrology station is Quanyanshan, mingshazhou and Guojiaqiao respectively. The observed hydrology data is from 1999 to 2012.

2) Uncontrolled water quantity. Uncontrolled water quantity in Xiaheyan~Qingtongxia was calculated by mean runoff coefficient of Qingshui River and Hongliugou multiply uncontrolled catchment area, and it was calculated by mean runoff coefficient of Kushui River multiply uncontrolled catchment area in Qingtongxia~Shizuishan.

3) Water surface evaporation. It is calculated by observed data of the representative rainfall station and evaporation station year by year.

4) Water consumption. The average water consumption in Ningxia reach is 3.937 billion m³. The lowest is 3.201 billion m³ occurred in the year 2003, and the highest is 5.123 billion m³ occurred in the year 2005, shown in Table 2.

Table 1. Water consumption by water diversion-recession method in 1999-2012 Unit: 10⁸ m³.

| Year | Total Ningxia section | Boundary – Xiaheyan | Xiaheyan – Qingtongxia | Qingtongxia – Shizuishan | Shizuishan – Boundary |
|------|-----------------------|---------------------|------------------------|-------------------------|----------------------|
| 1999 | 36.868                | 6.021               | 7.579                  | 21.881                  | 1.387                |
| 2000 | 35.783                | 5.239               | 7.130                  | 21.850                  | 1.563                |
| 2001 | 32.173                | 4.702               | 8.259                  | 17.102                  | 2.110                |
| 2002 | 30.411                | 4.585               | 9.923                  | 14.339                  | 1.564                |
| 2003 | 21.613                | 2.406               | 5.103                  | 12.030                  | 2.075                |
| 2004 | 33.727                | 4.381               | 8.662                  | 18.385                  | 2.298                |
| 2005 | 35.416                | 4.121               | 9.013                  | 20.151                  | 2.132                |
| 2006 | 35.258                | 4.749               | 9.035                  | 18.241                  | 3.234                |
| 2007 | 31.354                | 4.521               | 5.947                  | 19.570                  | 1.316                |
| 2008 | 38.748                | 4.799               | 12.798                 | 20.058                  | 1.092                |
| 2009 | 36.195                | 4.637               | 11.678                 | 18.324                  | 1.556                |
| 2010 | 30.019                | 4.489               | 12.278                 | 12.718                  | 0.534                |
| 2011 | 31.727                | 5.636               | 11.734                 | 13.815                  | 0.541                |
| 2012 | 27.657                | 4.677               | 11.371                 | 11.175                  | 0.433                |
| Average | 32.639            | 4.640               | 9.322                  | 17.117                  | 1.560                |
Table 2. Water consumption by water balance method in 1999–2012 in Ningxia Reach
Unit: 10^8 m^3.

| Year | Observed runoff in Xiaheyan & Section X | Controlled Uncontrolled Evaporation | Sum | Observed runoff in Shizuishan | Calculated WC |
|------|----------------------------------------|------------------------------------|-----|-----------------------------|--------------|
| 1999 | 268.8                                  | 2.553                              | 1.093 | 0.867                       | 2.779        | 271.6 | 227.6 | 43.98 |
| 2000 | 235.3                                  | 1.877                              | 0.971 | 0.637                       | 2.211        | 237.5 | 204.7 | 32.81 |
| 2001 | 216.0                                  | 2.166                              | 1.023 | 0.735                       | 2.454        | 218.5 | 181.1 | 37.35 |
| 2002 | 218.0                                  | 2.099                              | 1.011 | 0.712                       | 2.398        | 220.4 | 183.9 | 36.50 |
| 2003 | 202.4                                  | 1.751                              | 0.949 | 0.594                       | 2.106        | 204.5 | 172.5 | 32.01 |
| 2004 | 220.0                                  | 2.546                              | 1.092 | 0.864                       | 2.774        | 222.8 | 178.7 | 44.07 |
| 2005 | 271.3                                  | 2.926                              | 1.160 | 0.993                       | 3.093        | 274.4 | 223.2 | 51.23 |
| 2006 | 278.1                                  | 4.058                              | 1.506 | 1.120                       | 4.427        | 282.5 | 233.6 | 48.93 |
| 2007 | 283.3                                  | 1.728                              | 1.254 | 1.140                       | 4.172        | 287.5 | 244.6 | 42.87 |
| 2008 | 263.1                                  | 3.138                              | 1.123 | 1.060                       | 4.201        | 265.8 | 224.8 | 41.00 |
| 2009 | 283.7                                  | 3.238                              | 1.300 | 1.150                       | 3.388        | 287.1 | 241.6 | 45.49 |
| 2010 | 295.0                                  | 3.389                              | 1.240 | 1.190                       | 3.439        | 298.4 | 262.5 | 35.94 |
| 2011 | 277.4                                  | 3.062                              | 1.108 | 1.120                       | 3.050        | 280.5 | 241.2 | 39.25 |
| 2012 | 374.4                                  | 2.231                              | 1.082 | 1.080                       | 2.323        | 376.7 | 356.9 | 19.76 |
| Mean | 263.3                                  | 2.791                              | 1.137 | 0.947                       | 2.945        | 266.3 | 226.9 | 39.37 |

4.3. Comparison of the Two Methods

Through comparison of water consumption calculation results by the two methods, we can see water consumption calculated by water balance method is large than that calculated by water diversion-recession method. The mean water consumption calculated by water balance method is 3.937 billion m^3, while by water diversion-recession method is 3.264 billion m^3, and the difference is 0.673 billion m^3.

5. Conclusions and Suggestions

1) Water diversion in Ningxia reach is mainly occurred in April to August and November, and the mean water diversion in 1999-2012 is 6.81 billion m^3. The mean value in WNIA is 1.73 billion m^3, which showed slowly increasing trend; the mean value in QTXIA is 5.08 billion m^3, which showed slowly decreasing trend.

2) Water recession in Ningxia reach is mainly occurred in May to August and November, and mean water diversion in 1999-2012 is 3.542 billion m^3. The mean value in WNIA is 0.79 billion m^3, which showed obvious yearly change; the mean value in QTXIA is 2.752 billion m^3, which showed slowly decreasing trend.

3) The average ratio of water recession-diversion in WNIA is 0.46, and there is no obvious relationship between water recession-diversion. The mean ratio is
0.54 in QTXIA, and relation between water recession-diversion is very well, larger water diversion larger water recession.

4) The average water consumption by water diversion-recession method from 1999 to 2012 in Ningxia reach is 3.264 billion m³. The inter-annual change is relatively steady. Except the year 2003 and 2012, the other annual water consumption is between 3.0 - 3.875 billion m³.

5) The average water consumption by water balance method from 1999 to 2012 in Ningxia reach is 3.937 billion m³. The inter-annual variation is obvious.

6) It is suggested that strengthen verification of entrances and monitoring of water diversion and recession, in order to further analyze the reason of water consumption difference calculated by two different methods.

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