Water Resources Management Based on the ET Control Theory

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Abstract

Controlling the total amount of water consumption is one application of the strictest water resources management strategy. In this study, it developed an approach which called the ET control theory to focus on how to reduce the real water consumption (invisible water). The ET control theory is what comparing the target ET with the present ET, if the present ET is more than the target ET; it means that the present consumed water is larger than the permitted. Otherwise, it implies that the water resources are surplus. The acquisition of the present ET has two methods, the calculation method and using the remote sensing ET. The target ET needed to consider the ecological water using of the whole basin, which normally is the average precipitation. The methods about reducing the ET include engineering practices and management practices. The results indicated that using the management practices which include adjusting the planting structure, changing the irrigation system, straw covering and plastic covering, to reduce the agriculture water consumption is the key of the ET control theory.

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1. Introduction

In a river basin, the precipitation is the total water resources. All the water used in the basin, including the life, industry, agriculture, environment, etc, are supplied by the precipitation. The precipitation falling...
on the ground is divided into surface runoff, groundwater recharge and soil water, part of them outflow the basin, the others stay in the basin and constitute the basin ecosystems (natural and artificial) water using which breeds our human civilization. Human beings for its own reproduction and socio-economic development changed the natural ecosystems and the natural distribution of water resources. Particularly in the recent 200 years, with the rapid increasing in populations and devastating economic development, human excessively occupied the water from the natural ecosystem, the behaviour of human leads to the crisis of natural environment and their own water using shortage. Therefore, we must limit human excessive using of water resources, leave enough water to the nature and restore water for the natural ecosystems using. We normally managed the water resources by monitoring the volume of visible-water for a long time. Now, we have to change the concept, and use the $ET$ control theory to control the invisible water, to reduce the water consumption and to achieve the real water saving and the scientific and strict water resources management. The conversion is our new challenge.

2. The concept of $ET$

$ET$ is the abbreviation of evaporation and transpiration, including plant leaf transpiration and evaporation from a variety of surfaces. $ET$ is a process of water moving from the Earth's surface to the atmosphere, also an important component of natural water cycle. In the nature, the water balance equation for a closed basin is expressed as:

$$ P = R + ET + \Delta V $$ \hfill (1)

where $P$—the annual precipitation of the basin,
$R$—the annual runoff (include surface runoff and groundwater runoff) of the basin,
$ET$—the annual evaporation and transpiration of the basin,
$\Delta V$—the annual water storage variations of the basin.

For the annual average, $\Delta V =0$, the water balance equation (1) expressed as:

$$ P = R + ET $$ \hfill (2)

From the equation (2), precipitation ($P$) is the only water resources of region, runoff ($R$) is the available water resources of region, transpiration and evaporation ($ET$) is the only water consumption of region.

3. The concept of the $ET$ control theory

The natural water circle has maintained the balance of the water quantity as the (2) for billions of years. However, with the rapid social and economic development, human water demand is gradually increasing, equation (2) changed, and the annual average water balance equation of the closed basin is expressed as:

$$ P + \Delta W = R + ET $$ \hfill (3)

Where: $\Delta W$——annual volume of over-exploitation of groundwater resources in the basin.

In recent years, the $\Delta W$ is increasing year by year, at the same time $R$ is decreasing gradually. With the $\Delta W$ increasing, the level of groundwater declined; with the $R$ decreasing, the natural and ecological had water crisis in the basin. Many countries had pay attention to these situations, and did a lot of studies for reducing the $\Delta W$ and restoring the $R$. However, the previous studies mainly concentrated in improving the water resources efficiency from the perspective of saving water, but ignored the $ET$ which is the most regional water resources outflow. The $ET$ is real loss of the regional water resources, through controlling and reducing the $ET$, we can decrease the $\Delta W$ and increase the $R$, this is the main point of the $ET$ control theory.
The precipitation is the main source of the regional water resources, the ET is the only consumption. According to the water balance equation (3), it can be seen that under the certain precipitation, to decline the ΔW and increase the R, can only through reducing the ET. First, we have to monitor the present ET which is the base of reducing the ET; second, we have to calculate the target ET—a fixed value which is in accordance with the sustainable development, also is the target of reducing ET. Changing the present ET into the future target ET is our goal, is the center of ET management technology. The specific process is: the present monitored ET whether is in accordance with the goal ET or not. If the monitored ET is more than the target ET, it means that the present consumed water is larger than the permitted consumption, we need to improve the efforts of water saving, and try our best to make the present ET be identical with the target ET, achieve to the balance of supplying and consuming of water. Otherwise, it implies that the available water resources are surplus, we can expand the regional water using.

4. The acquisition of the present ET

There are two methods for the acquisition of the present ET, one is the calculation method, the other is using the remote sensing ET.

4.1. The calculation method

The present ET includes the consumption of life water and industrial water and the water consumption of arable land and non-arable land.

\[ ET_{\text{present}} = ET_{\text{integrated}} \]  

Where: \( ET_{\text{present}} \)—the present ET of the whole basin; 
\( ET_{\text{integrated}} \)—the integrated ET of arable land and non-arable land.

The content of ET includes the ET of Single crop, the average ET of the arable land crops, and the integrated ET of the arable land and non-arable land.

(1) The ET of single crop--ET

The first method--the method of Soil water consumption, which is the classical method.

This method is based on the precipitations and crops irrigations of the project areas, which respectively monitors the soil water content before and after rainfall or irrigation, and obtains the difference between the before and after soil water content of the rainfall or irrigation[1][2]. The equation is followed as:

\[ ET_i = \sum_j (T_{w_j} - T_{s_j}) + (T_s - T_h) \]  

Where: \( ET_i \)—the ET of the single crop \( i \); 
\( T_{w_j}, T_{s_j} \)—the content of soil water before and after the \( j \) rainfall or the \( j \) irrigation; 
\( T_s \)—the content of soil water before seeding; 
\( T_h \)—the moisture of soil water after harvest; 
\( T_{w_j} - T_{s_j} \) is the storage in the soil after rainfall or irrigation, also is the effective precipitation or the effective irrigation, it can be expressed as:

\[ T_{w_j} - T_{s_j} = P_j - D_j \]  

Or

\[ D_j = P_j + T_{w_j} - T_{s_j} \]  

Where: \( P \)—the total precipitation or the total irrigation on the \( j \) times; 
\( D \)—deep seepage(recharging to the groundwater) after the \( j \) rainfall or the \( j \) irrigation. \( \Sigma D_j / \Sigma P_j = \beta \); 
\( \beta \)—the coefficient of rainfall and irrigation water recharge to groundwater.
The second method -- Water balance method, which is the simplified method. The equation is

\[ ET'_i = (P + M)(1 - \beta) + (T_i + T_e) \]  \tag{8}  

Where: \( P, M \) — the precipitations and irrigations during the crop growing period; \( \beta \) — the coefficient of rainfall and irrigation recharge to groundwater, it can be obtained by the extent of groundwater \( \Delta h \) and the specific yield \( \mu \). The equation is expressed as:

\[ \beta = \frac{\mu \Delta h}{P} \]  \tag{9}  

\( \Delta h \) — the extent of groundwater rising;
\( \mu \) — the specific yield.

(2) The average \( ET \) of the arable land — the calculation of \( \overline{ET} \)

The \( \overline{ET} \) can be calculated by using the \( ET_i \), multiplied the \( i \) crop planting areas weighted average for the total arable land areas, the equation is expressed as:

\[ \overline{ET} = \frac{\Sigma F_i}{F} \times \overline{ET}_i = \Sigma f_i \times ET_i \]  \tag{10}  

\( \overline{ET} \) — the average \( ET \) of the arable land crops;
\( F \) — the area of crop \( i \);
\( F \) — the total area of the arable land;
\( f_i \) — the ratio of \( F_i / F \);
\( ET_i \) — the \( ET \) of the \( i \) crop.

(3) The integrated \( ET \) of the arable land and non-arable land — the calculation of \( ET_{\text{integrated}} \)

The integrated \( ET \) is consisted of the \( ET \) of the arable land and \( ET \) the non-arable land. The \( ET \) of the non-arable can be approximately obtained through precipitation minus runoff and groundwater recharge of the rainfall. Usually we take it by multiply the evaporation index. For example, In China Haihe river basin, the \( ET \) of the non-arable land is estimated by 0.6\( ET_i \) [3]. The equation is expressed as:

\[ ET_{\text{integrated}} = \eta ET + (1 - \eta) \times a \times \overline{ET} \]  \tag{11}  

Where: \( \eta \) — the percentage of the arable land area account for the total area;
\( ET \) — the average \( ET \) of the arable land crops;
\( ET_{\text{integrated}} \) — the integrated \( ET \) of the arable land and non-arable land;
\( a \) — a ratio of the the \( ET \) of the non-arable land and the integrated \( ET \) (0.4-0.75)

4.2. Using the remote sensing \( ET \)

Using the remote sensing is a simple way for monitoring \( ET \). Remote sensing \( ET \) is calculated by the energy balance of the solar radiation and ground anti-radiation, which based on the ground heat flux and the amount of light from the remote sensing pictures.

5. The calculation of the target \( ET \)

The target \( ET \) is obtained by equation (3). For the average annual, making the over-exploited of groundwater \( \Delta W \) be zero and \( R \) be constant which considering the ecological water of the whole basin. The target \( ET \) is expressed as:

\[ ET_{\text{target}} = P - R \]  \tag{12}  

6. The comparison of the target \( ET \) and the present \( ET \)

Making the difference between the present \( ET \) and the target \( ET \), that is

\[ \Delta ET = ET_{\text{present}} - ET_{\text{target}} \]  \tag{13}
Through equation (13), it can be seen that $\Delta ET$ is the over-consumption of the water resources in present case, what we must reduce. This reduction amount of water is not the reduction of diverted or pumped water, but the real reduction of water consumption[4].

7. Applications of reducing the real water consumption

The reduction of the real water consumption is the reduction of $ET$ not the diverted water, a part of diverted or pumped water is back to the surface water or groundwater during the water using process, it can be reused by the other water users, the process does not make the reduction of water. Only the management application to reduce the $ET$ is the real reduction of water using [5]. Reducing $ET$ includes the $ET$ reduction of industry, life and agriculture. However, in fact it is difficult to measure the $ET$ of industry and life, so the article only discusses how to reduce the $ET$ of agriculture.

The $ET$ reduction of agriculture may be achieved by the management and engineering measures. Engineering measures are mainly using the water-saving irrigation, including sprinkler irrigation, drip irrigation, micro irrigation, etc [6]. Drip irrigation can reduce the invalid evaporation by maximum, the result of saving water is best, but the investment is large, it can not be promoted on large scale. Management measures mainly include adjusting the planting structure, changing the irrigation system, using the straw covering and plastic covering [7]. These measures can significantly reduce the agricultural evaporation, and do not decrease the farmers’ incomes. So, the management measures are the most important methods for reducing the real water consumption of agriculture.

8. Conclusion

The so-called "$ET$ control theory" is the water resources management based on water consumption controlling, is an inevitable trend to strengthen the water management in a resource shortage areas, is a revolutionary new concept in water resources management. Through the $ET$ management, we can control the total amount of water consumption in a basin, ensure the water resources can be used sustainably. However, there is still a long way to go in the management of using $ET$, which need to be more in-depth study of the following things: first, improving the accuracy of the remote sensing data of $ET$; second, distinguishing the controllable and uncontrollable $ET$; third, determining the target $ET$ in different regions and at different stages.

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