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Agricultural economic loss calculation caused by the different protection levels of river ecological basic flow

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Abstract: Many agricultural water uses crowd the river ecology of the river water, thus leading to irreversible habitat damage. This paper presents an agricultural economic loss calculation model that is based on river ecological basic flow (REBF) protection by introducing a typical crop water requirement coefficient. First, the water balance equation is used according to a set of REBF protection values to compute the agricultural water shortage that results in the REBF. Second, the agricultural water shortage that results in REBF protection and a typical crop water requirement coefficient are used to determine the food production generated by REBF protection. Finally, the loss of food production and the food market prices are used to determine the agricultural economic loss caused by the different protection levels of REBF. A case study of the Weihe River in China is conducted. The calculation model is used to compute the agricultural economic loss on the basis of REBF protection in the Baoji section of the Weihe River, and the change law of the agricultural economic loss that results in different levels of the REBF is discussed. In addition, changes in the canal water use coefficient and the crop structure that affect agricultural economic loss are analyzed. Results show that the spatial and temporal variations in the runoff affect the changes in time and space of the agricultural economic loss. The higher the REBF protection level, the higher the agricultural economic loss. In addition, agricultural economic loss can provide a quantitative basis for reasonable REBF protection. The size of agricultural economic loss helps the government sector in decision-making on REBF protection.

Keywords: REBF; protection levels; agricultural economic loss; Baoji section of the Weihe River

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Introduction

Over the past decades, the controversial and conflict-laden water resource allocation issue has challenged decision makers due to the pressure from the rising demand for freshwater that is associated with various factors, such as population growth, economic development, food security, environmental concern, and climate change (Li et al., 2014). High economic and demographic growth rates have led to the rapidly increasing demand for water for industrial and commercial uses (James et al., 2013). The agricultural water sector has the highest water usage. According to Calzadilla et al. (2010), approximately 70% of natural water resources are diverted annually from global river systems to supply agricultural irrigation, and the agriculture industry uses the largest amount of water; for instance, agricultural production accounts for ≥ 80% of global water consumption; furthermore, 90% of the human consumptive water footprint comes from agricultural products (Hoekstra and Mekonnen, 2012). Agriculture is the largest water consumer in Northern China, accounting for 74.4% of the total water use in 2008 (MWR, 2008). However, with reduced water resources, the continuous agricultural demand for water has led to decreases or shortages in the water available for meeting the eco-environmental water demand around the world, especially in arid and semi-arid regions (Valipour et al., 2015; Valipour, 2015).

The basic function of the river ecological environment should be maintained. the river channel should keep the relative volume of flow to prevent atrophy, depletion, and loss of channel function, that is, water flow, which is a basic condition for maintaining the river ecological environment function (Huang, 2013). The relative volume of flow is the river ecological basic flow (REBF) (Mu et al., 2015). After many years of research, as many as 207 relatively mature calculation methods that are based on the REBF calculation model have been developed (Tharme, 2003). Meanwhile, new methods have been proposed and can be roughly classified into four categories: hydrology, hydraulics, habitat simulation method, and overall analysis (Sang et al., 2006; Acreman and Dunbar, 2004). The REBF cannot bring direct benefits to agriculture or generate agricultural economic losses. Consequently, people do not focus on the REBF, thereby resulting in discontinuous flow and river atrophy. With the shrinkage of rivers and the deterioration of the environment, people have begun to realize the value of the REBF. Meanwhile, many scholars have analyzed and calculated the REBF value, such as Xu Meimei (2016) and Li Huaien (2016). Researchers have begun studying the measures and technologies for safeguarding the REBF, such as Lin

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Qicai (2010), Zhu Lei (2013), and Zhou Yang (2012). However, they have not calculated the economic loss that is based on the REBF and cannot provide a quantitative basis for the reasonable protection level of the REBF.

Calculating the agricultural loss can solve the conflict between the Department of Agricultural Water and the REBF protection in addition to providing a quantitative basis for the reasonable protection level of the REBF. Qureshi (2007) studied the agricultural opportunity costs of ecological water use in the management of water resources in the Murray basin of Australia. By constructing a stochastic dynamic process model that considers the influence of many factors, Jones (2007) analyzed the economic loss generated by transferring agricultural irrigation water to ecological water use. Sisto (2010) calculated the agricultural loss compensation standard that results from the ecological water requirement in the Northern Chihuahua desert in the downstream of the Rio Conchos basin. Malano and Davidson (2009) proposed a balance analysis framework for the agricultural and ecological water use in Krishna Valley in India and the Murray–Darling Valley of Australia and used the residual method to compute the agriculture economic loss that results from water shortage.

This study aims to establish a method for calculating the agricultural economic loss and a compensation standard model that is based on REBF protection and analyze and calculate the agricultural economic loss and the amount of compensation that are based on the REBF using the Baoji section of the Weihe River as an example. To achieve these objectives, the following were performed. (1) The water balance method was used to calculate the water shortage that was based on the different protection levels of the REBFs. (2) The crop water requirement coefficient and water deficit were introduced into the calculation of agricultural production loss. (3) The changes in market prices and the agricultural production loss were combined to compute the agricultural economic loss and the compensation. Developing this study on the agricultural economic loss that is based on the REBF protection in arid and semi-arid northwest area can help in the protection decision-making on the REBF in water-deficient areas, thereby possibly resulting in practical significance and broad application prospects in the scientific management of limited water resources during drought periods (Li et al., 2015).

1 Methodology

1.1 Agricultural water shortage based on the different protection rates of the REBF

1.1.1 REBF protection rate

The REBF protection rate is the ratio of the days that the runoff can meet the REBF to the total number of days in one year. The calculation formula can be expressed as follows:

$$P_i = \frac{n_i}{N_i} \times 100\% , \qquad (1)$$

where P_i is the protection rate of the REBF, %; N is the number of days the runoff can meet the REBF in ith year, days; and N_i is the total number of days in the ith year (365 or 366 days).

1.1.2 Agricultural water shortage based on the REBF protection

Assuming that the water usage of the other sectors remains the same, the agricultural water sector is selected to protect the ecological river base flow. Protecting the REBF is bound to restrict agricultural water use. Thus, the agricultural ecological water deficit based on REBF protection is combined with the water balance equation as follows:

$$W_L = W_G - W_Q = W_G - (W_R + W_P - W_I - W_D - W_A + or - W_T) , \qquad (1)$$

where W_L is the agricultural water deficit based on the REBF protection, a hundred million m^3; W_G is the REBF value, a hundred million m^3; and W_Q is the measured runoff, a hundred million m^3;W_R is runoff,a hundred million m^3;W_P is precipitation,a hundred million m^3;W_D is the amount of domestic water used, a hundred million m^3;W_I is the amount of industrial water used, a hundred million m^3;W_T is the amount of water transferred outside or inside the watershed, a hundred million m^3;.

The calculation results are classified into two situations. (1) If the difference between the two values is greater than zero, then the REBF is insufficient, and this result is the agricultural water shortage based on REBF protection. Meanwhile, we can protect the REBF from the diversion of the Department of Agricultural Water. (2) If the difference between the two is less than 0, then the REBF can meet the runoff. We do not need to protect the REBF and reduce agricultural water consumption.

1.2 Agricultural economic loss based on the REBF

1.2.1 Crop water requirement coefficient

The crop water requirement coefficient has two main definitions: (1) the ratio of evapotranspiration water to dry matter quality or harvest production throughout the growth period and (2) the ratio of the evapotranspiration to evaporation from the water surface throughout the growth period. On the basis of Definitions (1) and (2), this article

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can calculate the crop water requirement coefficient as follows:

$$K_C = \frac{ET}{E_O} or K_C = \frac{ET}{M}, \qquad (2)$$

where K_C is the crop water requirement coefficient, m^3/kg; ET is the crop water requirement throughout the crop growth period, mm; E_0 is the water surface evaporation, mm; and M is the harvest or dry matter production, kg.

1.2.2 Crop yield loss

Crop yield loss is the ratio of agricultural water shortage based on REBF protection to the crop water requirement coefficient and expressed as follows:

$$Q_L = \frac{W_L}{K_C}, \qquad (4)$$

where Q_L is the agricultural production loss based on REBF protection, kg; and K_C is the crop water requirement coefficient, m^3/kg.

1.2.3 Agricultural loss based on REBF protection

The agricultural loss based on REBF protection is the product of the food production loss based on the abovementioned policy.

$$Y_{EC} = Q_L \times P_C, \qquad (5)$$

where Y_{EC} is the agricultural economic loss based on REBF protection, one hundred million yuan; and P_C is the current price of the corresponding crops, yuan/kg.

1.2.4 Unilateral agricultural water loss

Unilateral agricultural loss is the rates of agricultural economic loss and total shortage water.

$$y_w = \frac{Y_{EC}}{w}, \qquad (6)$$

where y_w is the unilateral agricultural water loss, yuan/m^3; and w is the agricultural water shortage based on the REBF, m^3.

2 Case analysis

2.1 Study area

The Guanzhong section of the Weihe River basin is in the middle of Shaanxi province. The east longitude and north latitude of the Guanzhong section of the Weihe River basin are 106°30'–110°30' and 33°30'–35°40', respectively. The Baoji section of Weihe River (Lin Jia Cun–Chang Xing bridge) has a total length of 224 km and is in the middle and lower reaches of Weihe River (Fig. 1). The Baojixia irrigation district, whose latitude and longitude are 34.350 and 107.90, respectively, is in western Guanzhong. This district has a total control area of 2355 km^2 and has two diversion hubs, namely, the Lin Jincun and Wei Jiabao hydrological stations. The Baojixia Yuanshang and Baojixia Yuanxia irrigation districts are formed. The Baojixia YuanShang irrigation district obtains water from the Linjiacun hydrological station. The irrigation district measures 12.8 million hm^2. The annual average water diversion is 6.08 hundred million m^3. The Baojixia YuanShang irrigation district mainly includes Jintai, Xianyang, Baoji, Qishan, Yangling, Wugong, Qianxian, Jingyang, Qindou, WeiCheng, and Gaoling (Fig. 1).

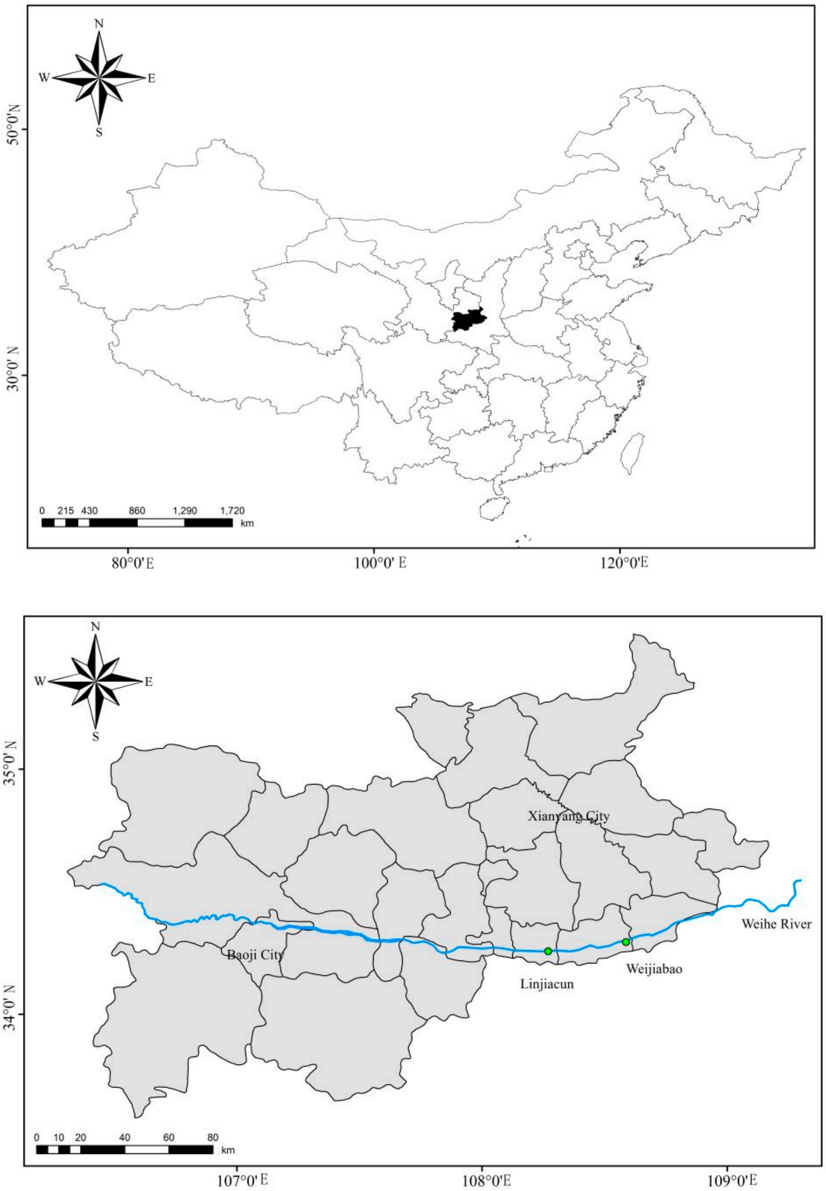

Fig.1.Location of the Weihe river in China and The Baojixia Yuanshang irrigation districts

2.2 Problem analysis in the study area

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Xu Zongxue (2016) analyzed and calculated the basic flows that can protect the fish and purify the water in the Baoji section of the Weihe River channel, and their values were 1.1 and 2 m^3/s, respectively. Furthermore, by combining the different methods and the practical situation of the Baoji section of the Weihe River channel, the study provided the REBF security recommended value of 4 m^3/s. However, for many years, the basic function of the REBF has been difficult to meet, especially in different dry season. Furthermore, the relatively few years of REBF are difficult to protect.

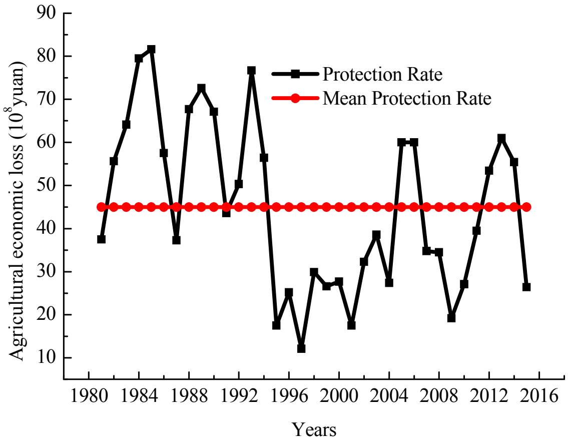

Fig. 2. REBF protection rates from 1981 to 2015.

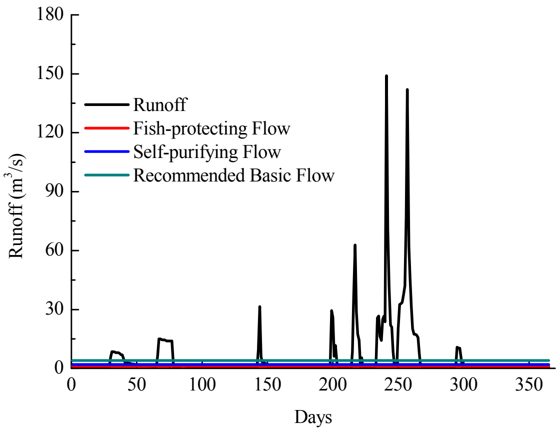

Fig. 3. Daily runoff in Linjiacun (three) station and the recommended basic flow.

When the REBF protection value is 4 m^3/s (Xu, 2016), the daily runoff in Linjiacun (three) station cannot fully meet the REBF, and its mean protection rate is only 49%. On a large scale, the trend of the protection rates based on the REBF is likely to decrease (Figure 1). In 1997, the basic flow that could protect the fish and purify the water often could not be satisfied, and the recommended base flow was difficult to meet. Irreversible damage was produced, the ecological environment deteriorated, and the basic function of the REBF was difficult to fulfill because the basic flow that maintains the basic function was difficult to protect. These are also the main problems in the Baoji section of the Weihe River.

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2.3 Data source

The data mainly come from “People's Republic of China hydrological yearbook”, “shaanxi statistical yearbook”, and “water statistical yearbook of shaanxi”.

2.4 Program setting

2.4.1 Selection of typical year

Through the analysis of the frequency of the runoff data from 1980 to 2015 in Lin Jiacun (three), this study selected 2011, 2010, 2009, and 1997 as the median water, dry, extra dry, and extreme low flow years, respectively (Table 1). This study investigated the agricultural loss on the basis of the four typical years.

2.4.2 Setting of protection level and order

The protection level refers to that within each year and the interannual one. The interannual ecological base flow protection values are 4, 6, and 8 m3/s (Xu et al., 2016). The protection rates within the year are 40%, 50%, 75%, 90%, 95%, and 100%. The protection order of the REBF is from A to Z.

2.4.4 Selection of typical crops

The advantage crop in the Baojixia YuanShang irrigation district is winter wheat in late October to early June, whereas that in late June to early October is summer corn. Therefore, this study selected winter wheat and summer corn as the typical crops.

2.4.5 Calculation principle of the water shortage based on the REBF and economic loss

Formula (2) was used to calculate the water shortage that is based on the REBF protection. The period of water shortage could be divided into two typical crops, and the agricultural loss was calculated.

Table 1. Water shortage days of the REBF protection target.

Protection rates (%)	Typical years	Protection days	Water shortage days					
			40%	50%	75%	90%	95%	100%
39.50	2011	144	2	39	131	176	201	222
27.10	2010	99	47	84	176	221	246	267
19.20	2009	70	76	113	205	250	275	296
12.21	1997	45	101	138	230	275	300	321

3 Calculation results

3.1 Agricultural water shortage based on REBF protection

Formula (2) was combined with the REBF protection value to calculate the agricultural water shortage on the basis of the different protection rates of the REBF (Table 2).

Table 2. Agricultural water shortage based on the different protection rates.

Years	Agricultural water shortage (10^8 m^3)					
	40%	50%	75%	90%	95%	100%
2011	0.006	0.110	0.386	0.517	0.576	0.620
2010	0.131	0.231	0.491	0.610	0.683	0.730
2009	0.165	0.269	0.521	0.644	0.716	0.802
1997	0.335	0.453	0.742	0.838	0.921	1.032

3.2 Crop water requirement coefficient

According to the surface water evaporation throughout the growth period of winter wheat in Baoji and Xianyang and the corresponding period of winter wheat water requirement, the winter wheat crop water requirement coefficients were computed (Table 2).

Table 3. Crop water requirement coefficients of winter wheat and summer corn.

Years	Winter wheat (m^3/kg)	Summer corn (m^3/kg)
2011	0.82	1.14
2010	0.86	1.13
2009	0.88	1.15
1997	0.84	1.29

3.3 Agricultural loss based on the REBF protection

The price of winter wheat is 2.1 yuan/kg, and the price of summer corn is 1.7 yuan/kg. Water shortage and type (4, 5) were used to compute the agricultural loss (Table 4).

Table 4. Agricultural economic loss based on the different protection rates of the REBF.

Years	Agricultural economic loss (10^8 yuan)					
	40%	50%	75%	90%	95%	100%
2011	0.02	0.28	0.99	1.25	1.34	1.44
2010	0.32	0.56	1.20	1.38	1.55	1.67
2009	0.39	0.64	1.06	1.33	1.51	1.71
1997	0.84	1.12	1.51	1.75	1.96	2.24

4 Result and Discussion

4.1 Analysis of agricultural economic loss calculation model of REBF

The main functions of this article are: 1) The calculation model of agricultural economic loss caused by REBF protection mainly provide a quantitative basis for the REBF protection. When we known that the agricultural economic loss caused by the REBF protection, we can provide a target that protect the REBF protection. That's the only way to do it, we can reduce the agricultural loss, and it will not affect the protection of REBF. 2) At the same time, by calculating REBF value, combined with the agricultural economic loss caused by REBF protection, we can analyze and calculate the reasonable level of REBF protection by using the principle of maximizing benefit.3) Moreover, we compare the economic loss caused by other REBF protection measures to the agricultural economic loss caused by the REBF protection, and adopt economic means to determine the final reasonable protection measures of REBF.

The main advantages of this article is: At the present stage, REBF protection in the section of Weihe river still in the safeguard measures and technical support (Lin and Li,2010.Zhu et al.,2013,Zhou et al.,2012, Gao et al.,2013). And we cannot make quantitative research that agricultural economic loss caused by the REBF protection. Meanwhile, the government departments have adopted different protection level of the REBF to to prevent the river, water environment destruction, but it is aimless to do protect the REBF and they will spend a large amount of money. By computing the agricultural economic loss caused by REBF protection, we have a clear basis for REBF to follow.

The main shortcomings of this article are: Calculating the agricultural economic loss was mainly considering the change of water, and the natural disasters of different disasters do not consider, therefore, the agricultural economic loss caused by the REBF protection may have some deviation, and then the final result may have some deviation; and the usage of water sector in river is more than agricultural water departments, however, this paper does not calculate the other water use department’ s economic loss caused by REBF protection.

Scope of application: The area where the REBF is difficult to be guaranteed due to the large volume of agricultural diversion, especially in some areas due to the large volume of water diversion, leading to the river breaking and shrinking. And the ecological base flow of the river can also be extended to the water requirement of the river environment.

4.2 Analysis of the differentiation in the spatial and temporal changes in agricultural loss and trend

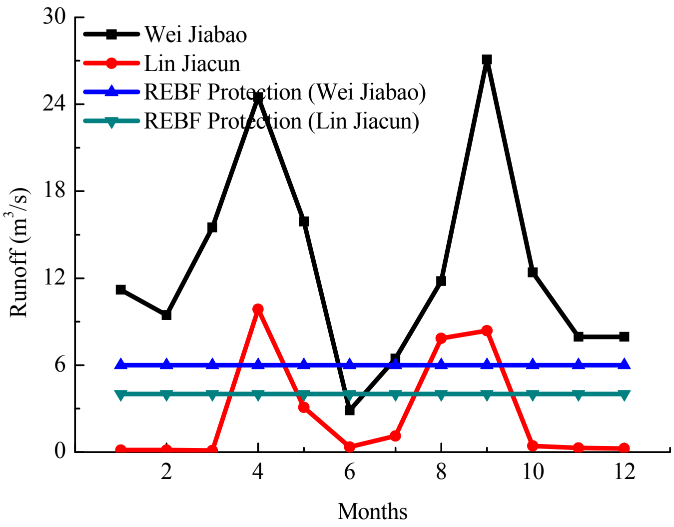

Fig. 4. Annual variations in runoff in Lin Jiacun and Wei Jiabao hydrological stations.

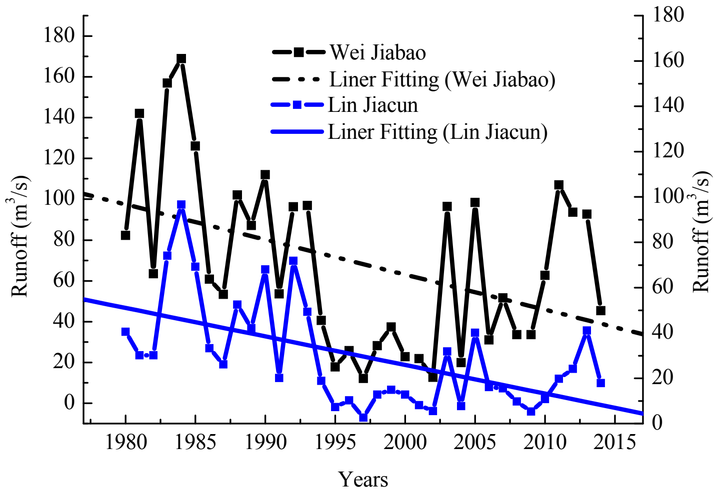

Fig. 5. Interannual variations in runoff in Lin Jiacun and Wei Jiabao hydrological stations.

Through an analysis of the temporal and spatial variations in the agricultural economic loss based on REBF protection, we can uncover the change rule of the loss. Therefore, analyzing the space and time changes and change trend of the economic loss that is based on REBF protection has a guiding significance for the reasonable protection level of the REBF. The change in agricultural economic loss based on the REBF has significant characteristics, such as timeliness, regionality, and uncertainty. Timeliness and regionality are mainly reflected by the big difference in various periods and regions of the agricultural loss that is based on REBF protection. In terms of uncertainty, the change trend of the agricultural loss is not noticeable and relatively vague.

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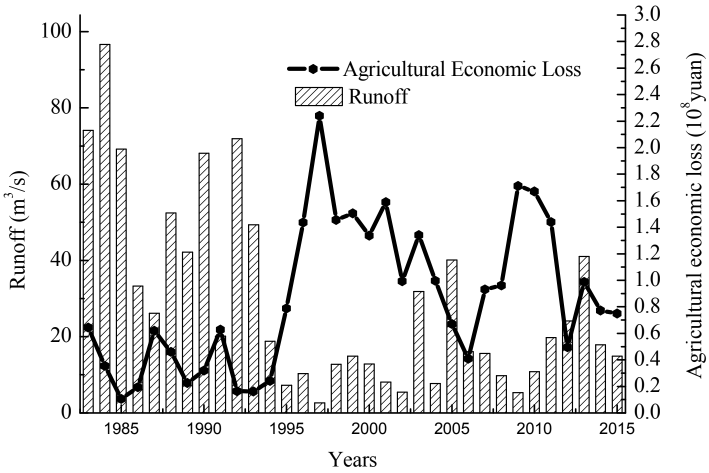

Fig. 6. Relation curve between the runoff and the agricultural economic loss.

Therefore, agricultural economic loss based on REBF protection has regional characteristics. The changes in agricultural economic loss are based on the changes in runoff. The differences in runoff in the Lin Jiacun and Weijiabao sections of Weihe River are relatively big (Figs. 4 and 5); the runoff of the former can meet the REBF protection target, which cannot produce agricultural economic loss. Protecting the REBF is difficult with the latter amount, and the agricultural economic loss is higher.

In the long run, the agricultural economic loss based on REBF protection tends to rise gradually, but the local variations display a local drop (Fig. 6). The runoff is the basis for computing the agricultural loss that is based on REBF protection, and the time change process of the runoff directly affects the time change of the agricultural economic loss (Fig. 6). Fig. 5 shows that the runoff tends to drop in the long term and shows an upward trend in local areas.

4.3 Analysis of the influence of the different protection levels and orders on the agricultural economic loss

Analyzing the agricultural economic loss that is based on the different protection levels in the typical years can provide a quantitative basis for the management of the REBF. In addition, REBF protection will not happen overnight as it is a long process. Therefore, a timely analysis of the economic loss in the different stages of REBF protection is indispensable. Furthermore, the different protection levels of the REBF have varying ecological effects and can protect various REBF functions.

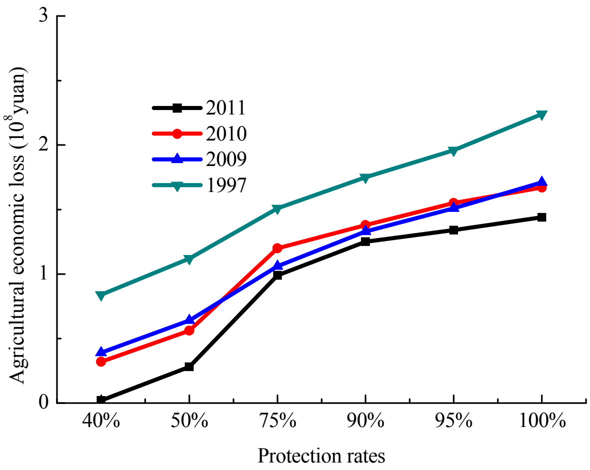

Fig. 7. Agricultural economic loss based on the different protection rates.

The agricultural economic loss based on the different protection levels of the REBF maintains a certain gap (Fig. 7). The agricultural economic loss decreases as the runoff decreases. Meanwhile, in the typical years, the higher the REBF protection rates, the larger the agricultural economic loss that is based on REBF protection. Thus, when protecting different REBF functions, we can choose various protection goals according to the agricultural economic loss that is based on the functional recovery of the REBF.

The agricultural economic loss is caused by the different protection levels of REBF in different typical years had different variations with the different protection rates of REBF variation, the agricultural economic loss with different guarantee rate curve respectively in water level years and dry years, dry years and dry years are:

$$Y = 1.5744 \times Ln(X) + 1.4256, R^2=0.9972; \quad (7)$$

$$Y=2.2016 \times X-0.5379, \ R^2=0.992; \quad (8)$$

$$Y=1.645 \times X^{1.5015}, \ R^2=0.9889; \quad (9)$$

$$Y=2.2016 \times X^{0.9632}, \ R^2=0.9773。 \quad (10)$$

The correlation coefficients were 0.9972, 0.992, 0.9889 and 0.9773 respectively, and the degree of fitting was higher. Therefore, by analyzing the frequency of water volume from a river and the extent of the year's protection in a certain year, we can use the formula that from (7) to (10) to calculate the agricultural economic loss caused by the REBF protection.

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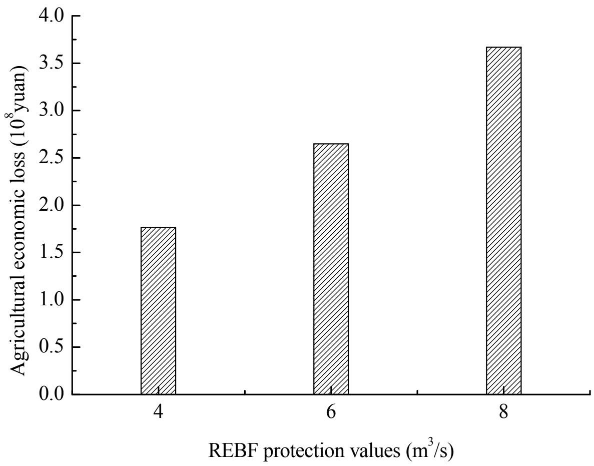

Fig. 8. Agricultural loss based on the different protection levels of the REBF.

The different protection levels of the REBF produce not only different agricultural economic losses but also benefits for the ecological function value of the REBF. Through the calculated value of the REBF, we developed three-REBF values of 4, 6, and 8 m^3/s. The different protection values of the REBF need varying amounts of water to meet the REBF. The higher the protection level, the larger the agricultural economic loss. The agricultural economic loss based on the different protection levels of the REBF is shown in Fig. 8.

The protection order can provide an effective protection solution for the implementation of the REBF, whereas the different protection orders of the REBF will produce various amounts of agricultural economic losses and give rise to the eco-effectiveness ecological utility. For example, the choice of REBF in different periods can have beneficial effects on fish migration, egg-laying, and water self-purification function. Fig. 9 shows that the agricultural economic loss whose protection orders are arranged from large to small is the largest and that whose protection orders are arranged from small to large is the smallest.

In conclusion, combining the annual protection level and the different protection orders and rates of years, flexible REBF protection can be accomplished as required by different functions and times. Finally, the REBF function performs well.

4.5 Analyzing and comparing the calculation results

We can use two kinds of methods, namely, the water rights trading mode and the agricultural ecological compensation, to deal with the agricultural economic loss that is based on REBF protection. The water right trading price and the agricultural compensation standard unilaterally show the water agricultural ecological economic loss that is based on REBF protection.

Calculating the agricultural economic loss caused by the different protection levels of the REBF can elucidate the advantages and disadvantages of the levels and provide a quantitative basis that the government and relevant basin management departments can use to develop a solution for REBF protection. The agricultural loss compensation based on the REBF can not only protect the interests of the agricultural water sector but also meet the REBF, thereby improving the role of ecological water and thus highlighting the ecological function of the water resource.

The agricultural economic loss based on REBF protection is not yet determined. Thus, the nature of the agricultural economic loss that is caused by the REBF protection was the REBF value in this study. Formula (6) was used to obtain the unilateral agricultural water loss (REBF) value, which was 2.46 yuan/m^3.

Huang Wenjing (2013) used a fuzzy mathematical method to calculate the unilateral REBF value of different hydrological stations in the Guanzhong section of the Weihe River (Table 8). Therefore, the calculation results are relatively reasonable.

Table 8. Unilateral ecological base flow value in the Guanzhong section of the Weihe River [1].

Hydrological station	Unilateral ecological base flow value (yuan/m^3)
Lin Tong	2.011
Wei Jiabao	3.006
Xian Yang	3.302
Hua Xian	2.105

5 Conclusions

In this study, a calculation model of the agricultural economic loss based on REBF protection was presented. The method first safeguards the REBF and uses the calculation model to determine the agricultural economic loss that is based on the different protection levels of the REBF. The main conclusions are as follows. (1) The analysis of the rationality of the calculation results showed that the computation method for agricultural ecological economic loss used in this study is feasible. (2) The spatial and temporal variation characteristics of agricultural economic loss based on REBF protection are influenced by time and space variations in the runoff changes and are negatively correlated with differences in the runoff. (3) The higher the REBF protection level is, the higher the agricultural economic loss. The different REBF protection orders may also affect the agricultural economic loss. (4) Using two kinds of methods, namely, the water rights trading mode and the agricultural ecological compensation, to deal with the agricultural economic loss that is based on REBF protection.

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