Study on evaluation index system for ecological effect of water conservancy projects

N Wei$^{1,3}$, K M Lu$^{2,3}$, J C Xie$^1$ and M K Lin$^1$

$^1$State Key Laboratory of Eco-hydraulics in Northwest Arid Region of China, Xi’an University of Technology, Xi’an 710048, Shaanxi, China
$^2$Powerchina Northwest Engineering Corporation Limited, Xi’an 710065, Shaanxi, China

E-mail: sonardor@126.com (N Wei); lkmgoodman@163.com (K M Lu)

Abstract. With the transformation from traditional water conservancy to ecological water conservancy, functions of water conservancy projects have been changed. In addition to meeting the demand of social economy development, the protection and improvement of eco-environment should be taken into account. As the link between water use for human activities and natural water cycle, it is necessary to research on the ecological effect of water conservancy projects. From the perspective of whether to be affected by human activities, ecological effect is divided into natural ecological effect and social ecological effect, a framework of comprehensive evaluation index system for ecological effect is preliminarily constructed. The concept of ecological effect of water conservancy projects is analysed, and three-level ecological effects of water conservancy projects are presented. The three-level evaluation index system for ecological effect of water conservancy projects is built based on the hydrological regime analysis. The quantitative evaluation can be achieved. The method is applied to evaluate the ecological effect of large-scale water conservancy projects in the Weihe River Basin. The results show that the index system is of high applicability, which provides scientific basis for the quantitative evaluation for ecological effect of water conservancy projects and offers a better support to healthy development of river ecosystems.

1. Introduction

Effect generally refers to a specific scientific phenomenon produced by some motive or reason, which was first put forward in physics. In recent decades, the term “effect” has been used more and more in environmental science, ecology and other disciplines, such as heat island effect, greenhouse effect, and ecological effect. The concept of ecological effect of water conservancy project has been proposed in recent years. The evaluation for ecological effect of water conservancy projects involves many disciplines, such as environmental science, hydrology, ecology, economics, sociology, etc. The influencing factors and mechanisms of ecological effects are relatively complicated. The study on ecological effect of water conservancy projects in different countries is different in breadth and depth. According to the definition of “encyclopedia knowledge”, the ecological effect of water conservancy project refers to the influence of the construction and operation of water conservancy project on the structure and function of river ecosystem. During the last few decades, numerous connotation of ecological effect of water conservancy projects have been introduced [1-4]. In addition, the ecological effect evaluation index and method of water conservancy project are gradually improved [5-7]. With the deep understanding of the ecological impact of water conservancy projects, the ecological effect
evaluation of water conservancy projects transforms from the single factor evaluation to the analysis of ecological effect evaluation index system and model construction [8-10]. A large number of studies abroad analyse the relationship between changes of hydrological elements and ecological effects of water conservancy projects [11-17].

The ecological effect evaluation of water conservancy project involves ecological environment, society and economy, covering many fields, which leads to problems such as weak operability, inadequate applicability and difficulty in quantification. Therefore, based on the theory of ecological effect, this paper establishes the comprehensive evaluation index system of ecological effect, and puts forward a quantitative evaluation index system of ecological effect of water conservancy projects. The method is applied to the large-scale water conservancy projects of Weihe River Basin of Shaanxi Province, which provides scientific basis for the quantitative evaluation for ecological effect of water conservancy projects and offers a better support to healthy development of river ecosystems.

2. Theory of ecological effect evaluation
The original definition of “ecological effect” refers to the phenomenon that is adverse to the evolution of the ecosystem. The ecological effect is divided into two types according to the response results and response reasons. According to the response results, the ecological effect includes ecological positive effect and ecological negative effect. According to the response reasons, ecological effect includes pollution ecological effect and non-pollution ecological effect. With the strengthening of human social activities, the impact of human activities on the eco-environment system is increasing, the retroaction of eco-environment system to human activities is also stronger. It can be said that the source of ecological effect has two aspects, one is the interference of human activities, and the other is the changes of natural environment. Because of these disturbances or changes, the structure and function of ecosystems changes, which leads to the ecological effect. This study divides the ecological effect into natural ecological effect and social ecological effect from the perspective of whether to be affected by human activities. The former refers to the ecological effect caused by the changes of original and pure natural environment. The latter refers to the ecological effect caused by intervention of human activities. This classification further enhances the connotation of the ecological effect and effectively coordinates the contradiction between social-economic development and eco-environment protection, which is beneficial to the organic combination of nature and human interaction.

According to the analysis of the connotation of ecological effect, this paper puts forward the comprehensive evaluation index system of ecological effect based on the scientific, systematic and objective principles, as shown in table 1.

| Classification | Evaluation index |
|----------------|------------------|
| Evaluation of natural ecological effect |          |
| Non-biological evaluation |          |
| Local climate | rainfall, evaporation, temperature, wind speed, humidity, sunlight, etc |
| Hydrology | water level, water yield, sand content, etc |
| Water quality | potassium permanganate index, total nitrogen, total phosphorus, ammonia-nitrogen, volatile phenol, etc |
| Geology and landform | topography, geology, geomorphology, soil, vegetation, etc |
| Biological evaluation |          |
| Terrestrial organism | wild fauna and flora, rare plants and animals, etc |
| Aquatic organism | plankton, phytobenthos, water-living plants, etc |
| Evaluation of social ecological effect |          |
| Evaluation of exploitation of natural resources |          |
| Reclaim land from lakes | aquatic organism, hydrology, etc |
| Overgrazing | vegetation, soil, local climate, etc |
Deforestation, soil erosion, etc
Quantity of discarded water, water quality, soil, aquatic organism, etc
Evaluation of human activities
Water conservancy project construction, local climate, hydrology, water quality, water ecology, etc
Urbanization construction, local climate, soil, vegetation, etc
Construction of industrial zone, local climate, soil, vegetation, etc
Highway construction, vegetation, soil erosion, water quality, etc
Soil and water conservation engineering, local climate, etc
Waterscape construction, local climate, etc

It can be seen that the evaluation of ecological effect covers a wide range of content, which interact with one another. Therefore, in order to avoid the deviation of evaluation result and the difficulty in data collection, narrowing the evaluation scope or avoiding repeated index is usually adopted.

3. Theory of ecological effect of water conservancy projects

3.1. Connotation
The ecological effect of water conservancy projects includes two aspects [1-4]: the ecological restoration effect and the ecological damage effect. The former is the ecological positive effect of water conservancy projects, which means that the construction of water conservancy projects makes a difference in the law of water flow movement, the improvement of the river water quality, the restoration of the river shoal and the formation of the new wetland. The latter is the ecological negative effect of water conservancy projects, which means that the water conservancy projects have adverse effects on the river water ecosystem, such as significant changes in the ecosystem structure, water disruption, production capacity decreased, etc., leading a series of environmental problems. The ecological effect evaluation of water conservancy projects mainly focuses on the ecological negative effect and puts forward the measures and methods to reduce or eliminate the negative effects, such as ecological restoration technology, engineering measures and non-engineering measures, etc. The ultimate goal of ecological effect evaluation of water conservancy projects is to make the ecological system develop in a favourable direction for human being.

3.2. Three-level ecological effect
The evaluation of the ecological effect of hydraulic engineering needs to understand the root of the ecological effect and determine the dominant factors, which can provide reference for the determination of eco-environment protection target and eco-environmental water demand. According to the influence degree of water conservancy projects on the watershed ecosystem, the ecological effect of water conservancy projects can be divided into three levels: primary effect, secondary effect and tertiary effect.

The primary ecological effect mainly reflects the influence of the construction and operation of water conservancy projects on the river hydrological situation. The eigenvalues of the hydrological situation include parameters such as flow rate, frequency, duration, timing of occurrence and rate of change, etc., which are important for the integrity of the ecosystem. The secondary ecological effect is caused by the primary ecological effect. With the changes of the hydrological situation, the physical characteristics and chemical characteristics of the water body changes. Water quality generally includes DO, NH3-N, total phosphorus and other factors, which have important impact on life activities in water. The tertiary effect is the result of the accumulation of the other two. Due to the lag of the ecological effect and the buffer capability of the system itself, the accumulation processes relatively slow.

The three-level ecological effects of water conservancy projects interact with each other. The construction and operation of water conservancy projects is the root of the changes of hydrological
situation. The primary ecological effect is the most direct reflection form of the ecological effect of water conservancy projects, which is the driving force of the other two. The primary effect causes the changes of physical and chemical properties of the water body, which leads to the deterioration of the water environment and drives the secondary ecological effect. The secondary ecological effect affects the diversity and integrity of the water ecosystem, which drives the tertiary ecological effect. The primary ecological effect makes the rhythm of life information carried by the original river disrupted, which directly leads to the change of aquatic life activities and also drives the tertiary ecological effect.

3.3. Evaluation index system
Quantitative evaluation is the focus of ecological effect evaluation of water conservancy projects. Following the principles of integrity, simplicity, strong operability and practicability, the study proposes 10 core indexes and 11 expansion indexes, as shown in table 2.

| Target | Effect’s level | Core indexes | Extended indexes |
|--------|---------------|--------------|------------------|
| Ecological effect of hydraulic engineering | Primary effect | runoff, non-uniformity coefficient of annual runoff, average flow in driest month, days with cutoff | time of occurrence of hydrologic extremes, high-low pulse flow, flood, extreme flow variation, pondage factor, etc. |
| Secondary effect | potassium permanganate index, total nitrogen, total phosphorus, dissolved oxygen | petroleum, NH3-N, volatile phenol, BOD5, COD, heavy metals, etc. |
| Tertiary effect | fish integrity index, species diversity index | |

3.4. Evaluation criterion
The evaluation criterion of ecological effect of water conservancy projects is the basis for determining the impact of ecological effect. Because of the different natural condition and socio-economic background, there is no uniform criterion for ecological effect evaluation, and the following aspects can be referenced:
- National criterion, industry or international criterion, as well as local criterion. For example, “Environmental quality standard for surface water (GB3838-2002)”, “Quality standard for ground water (GB / T14848-93)”, etc.;
- Use the background value as the evaluation criterion;
- Reference to the existing research results at home and abroad;
- Other methods, such as mathematical statistics, expert experience and analogy, and so on.

4. Case analysis
Weihe River Basin is the largest tributary of the Yellow River, with a basin area of 135000 km² and a mainstream of 818 km. Weihe River Basin originates from Niaoshu Mountain in Weiyuan County Gansu province, flowing through Gansu, Ningxia and Shaanxi provinces. The river length in Shaanxi Province is 512 km. By the end of 2015, there were 441 reservoirs in the Weihe River Basin in Shaanxi Province, with a total capacity of 2.179 billion m³, beneficial reservoir capacity of 1.424 billion m³ and the current water supply capacity of 1.285 billion m³. There are 4 large constructed
reservoirs in Weihe basin in Shaanxi Province, including Fengjiashan, Yangmaowan, Shitouhe and Jinpen Reservoir on the tributaries of Weihe River. Due to the excessive development and utilization of water resources, a series of ecological and environmental problems have been triggered. The River is facing the eco-environmental problems such as water shortage, water pollution, soil erosion and river siltation, which seriously restrict the regional sustainable development. The construction of water conservancy projects has an effect on the water quantity, water quality and ecological elements of the river basin. Thus, it is necessary to carry out the ecological effect evaluation of large-scale water conservancy projects.

4.1. Material and method
For the natural ecological effect of the Weihe River Basin in Shaanxi Province, the study gathered data on rainfall, temperature, sunshine, relative humidity, wind speed and evaporation collected from 5 typical weather stations in the basin from 1956 to 2015. For the ecological effect of 4 large reservoirs in the Weihe River Basin in Shaanxi Province, the paper gathered data on measured daily runoff data collected from 5 typical hydrological stations in the mainstream and 4 hydrological stations in the upper reaches of the tributaries of 4 large reservoirs in the basin. The time series analysis method was used to analyse the trend of various indexes.

4.2. Natural ecological effect evaluation
The natural ecological effect were comprehensively evaluated from aspects of rainfall and temperature, sunshine and relative humidity, wind speed and evaporation. The results showed that the annual rainfall for each station presented a decreasing trend, and the annual average temperature and annual minimum temperature showed a slight rising trend, which had an impact on the basin hydrological situation and the background of water resources to a certain extent. The sustained decrease of sunshine hours for each station (except Huaxian Station) was likely to reduce the direct radiation energy on the surface, resulting in the surface potential evaporation reduction. The relative humidity for each station was relatively stable, which indicated that the air drying power changed slightly and had little effect on the surface potential evapotranspiration. The interannual changing trend of wind speed for each site was not obvious, which would not affect the potential evapotranspiration and actual evapotranspiration. The small evaporation (except Huaxian station) showed a decreasing trend, which was consistent with the trend of sunshine hours.

In summary, the natural ecological effect in the Weihe River Basin was generally stable and presented a lightly declining trend. Due to the decrease of rainfall and the temperature rise caused by the greenhouse effect, the stability of the ecosystem was affected. The other indexes had little influence.

4.3. Ecological effect of large-scale water conservancy projects
The evaluation results of primary ecological effect of water conservancy projects: The indexes of the tributary stations in the upstream of the water conservancy projects changed a little, and were basically close to the natural state. Due to the regulating-storing function of upstream water conservancy projects, the indexes of mainstream stations had significant changes. The evaluation results of secondary ecological effect: the water quality of the Weihe River was gradually deteriorated from upstream to downstream. The water quality of tributaries without water conservancy projects was better than that of the mainstream. The main pollution indicators in the basin was NH3-N, BOD5, COD, petroleum, volatile phenol and permanganate index, and so on. The evaluation results of tertiary ecological effect: the fish integrity index of the upstream was higher than that of the downstream, and the fish integrity index of the mainstream was better than that of the tributaries. The macrobenthic species richness was the highest in the middle stream of the Weihe River, and was the lowest in the downstream. In general, the fish integrity and species richness were lower in the basin, and this change was directly or indirectly related to the above-mentioned primary and secondary ecological effects.
5. Conclusion
The main conclusions were as follows: the natural ecological effect in the Weihe River Basin was generally stable and presented a lightly declining trend. Due to the decrease of rainfall and the temperature rise caused by the greenhouse effect, the stability of the ecosystem was affected. The other indexes had little influence. In general, the interference of human activities and socio-economic development were the main reasons for the changes of water resources, water environment and water ecology in the river basin. The construction of water conservancy projects in the basin was the root of variation of hydrological situation. As the most direct reflection of the ecological effect of water conservancy projects, the primary ecological effect was the driving force of the other two.

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