Study on the holistic model for water resources system

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Received May 8, 2004

Abstract Based on the Theory of Complex Adaptive System developed recently, a holistic model for water resources system is established at the basin level for analyzing water resources management and allocation of the basin. In this holistic model framework, the subsystems of the water resources system, including hydrologic components, agricultural and industrial production, human living, ecosystem and environment are combined in a dynamic connection with inner variables. According to the characteristics of the holistic model framework, a nesting genetic arithmetic is employed to solve the nonlinear optimal model. The model is applied in the Yellow River basin to analyze the rational amount of diversion water for the West Line of Water Transfer Project form South China to North China and its marginal benefit.

Keywords: water resources, holistic model, complex adaptive system, genetic arithmetic.

DOI: 10.1360/04ez0007

1 Foreword

For the inherent complexity of water resources system, efficient analysis tools are necessary for the rational allocation of water resources and decision-making concerning sustainable development in a river basin. Recently, studies on the competition of water use among different sectors and its macro decision-making are very much emphasized in the field of hydrology. These studies are often carried out by using a holistic model including hydrologic components, agricultural and industrial production, human living, ecosystem and environment.

Up to now there are two known approaches to develop such integrated models: the compartment model approach and the holistic model approach.

Under the compartment approach there is a loose connection between the different components. A notable research effort in integrating economic modeling and complex hydrologic modeling was reported by Noel and Howitt (1982)\cite{1} who incorporated a quadratic economic welfare function (Takayama and Judge, 1964) into a multi-basin conjunctive use model. Lefkoff and Gorelick (1990a)\cite{2} used a mathematical format to...
transform information between the economic model and the hydrologic model. They combined distributed parameter simulation of stream-aquifer interactions, water salinity changes, and empirical agronomic functions into a long-term optimization model to determine annual groundwater pumping, surface water applications, and planting acreage. The authors applied the microeconomic theory of the firm, associated with agronomic functions related to water quantity and quality. Lefkoff and Gorelick (1990b) further extended the model to incorporate a rental market mechanism, considering annual water trading among farmers. Lee and Howitt (1996) used nonlinear regional production models and a hydrology model to analyze the economics of externalities in irrigated agriculture in the Colorado River basin. In China, Chen Zhikai, Weng Wengbin and Wang Hao (1995) imported the macro economy input-output model into water resources system and setup a Macro-Economic Water Resources system. Based on the theory, a multi-objective analysis model system for water resources allocation has been established. Based on it, Wang Zhongjing (1998) defined the conception of water resources carrying capacity for analyzing and evaluating the relationship between water resources and regional economy.

The holistic model for water resources analysis has become an important research field. Under the holistic approach, there is one single unit with both components tightly connected to a consistent model, and an integrated analytical framework is provided. Harding, Sangoyomi, and Payton (1995) used the Colorado River Network Model (CRM) to study the hydrologic impacts of a severe drought in the Colorado River. Booker (1995) extended the basin model reported by Booker and Young (1994) to an integrated hydrologic-economic-institutional optimization model, CRIM—the Colorado River Institutional Model. Henderson and Lord (1995) issued a gaming-type model to simulate potential collective action processes. Ximing Cai (2002) issued a hydrology-agriculture-economy coupling model at the basin level. It is used to analyze the long-term and short-term efficiency of using water in drainage area, and it brought forward new methods in the solutions of nonlinear problems. It has also been applied in Syr Darya drainage area for analyzing the scenes of the sustainable development in the river basin.

The compartment modeling approach is easy to implement for application, but further research is needed to develop more appropriate dynamic connections, through which the economic and hydrologic components can be solved in an interactive way. For the holistic modeling approach, the key issue will be to define the essential relations among different components so that the economic analysis can be realized based on a meaningful physical system.

For building a more scientific and efficient holistic model, the following chief difficulties are identified: