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# System Dynamics Modeling Of Socioeconomic Development Mode Associated With Water Usage In Baiyangdian Lake, Northern China

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## Abstract

With continual increase of environmental pressure from human activities, it has become necessary to study the process of socioeconomic water usage influencing the water quality. Based on the system dynamic model developed before to display the whole related flowing processes and the integrated influencing mechanisms of socioeconomic water usage influencing total phosphorus (TP) and total nitrogen (TN), we set 4 types of different socioeconomic development modes (i.e., type of continual status, type of economic development, type of water quality protection, and type of integrated harmonious development) to dynamically simulate and analyze the impact of socioeconomic and ecological water system on TP and TN. Moreover, it indicated that the type of integrated harmonious development was relatively more conducive to balance the water quality condition and economic development, compared to other three modes. Thus, the research could provide a reference to the water resources planning and management, as well as the eutrophication control.

**Keywords**: System dynamics (SD) model, Socioeconomic water usage, total phosphorus (TP), total nitrogen (TN)

## 1. Introduction

Nowadays, rapid socioeconomic development has brought environmental changes. Socio-economic activities such as wastewater discharge, affect the water quality (Sanches et al., 2011; Kazi et al., 2009). Although we've paid much to manage it, on the whole, water quality deterioration has not been reduced and water resource systems are severely damaged (Rastetter et al., 2013; Josette et al., 2005). Moreover, the contradiction between economic development and water quality protection even becomes sharper recently. According to the water quality report of Statistical Yearbook of China in 2013, some water quality indicators, such as TP and TN, were often in an excessive status. It made the eutrophication situation could not get

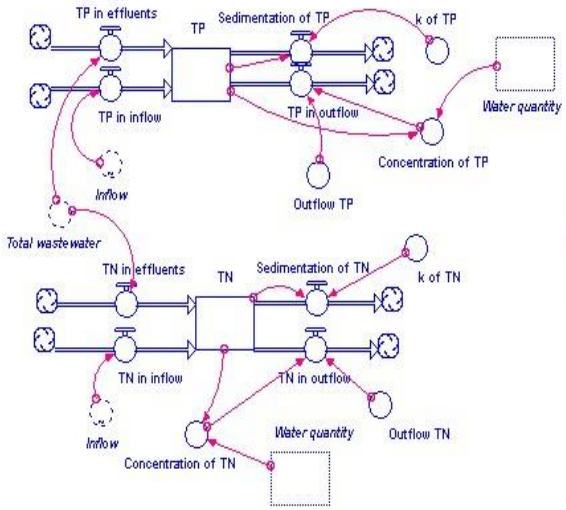
long-term improvement. Hence, both the living health and sustainable economic development would be affected. Therefore, it is necessary to study the process of socio-economic water usage influencing the water quality and to explore an appropriate development mode to balance the contradiction between economic development and water quality protection.

Recently, many scholars have studied the relationship between TN/TP and ecosystem health (Leonilde et al., 2009; Satya et al., 2009; Dogan and Tugrul, 2003) or water balance of supply and demand (Yin and Yang, 2011; Zhu et al., 2004). Besides, many researchers applied system dynamics (SD) models to describe the dynamics of environmental elements involved in water resources system. Fox example, Cheng Qi et al. (2011) built an SD model to estimate municipal water demand. However, most studies focused on pollution treatment in water body; few were sources-oriented from the viewpoint of socioeconomic water usage. Moreover, few studies revealed the internal mechanism and the main influencing factors in the process of socioeconomic water usage producing TN/TP. Based on the SD model proposed by the author before (ZHU et al., 2013) to clarify the internal influencing mechanism, in this paper, we built 4 types of different modes (i.e., type of continual status, type of economic development, type of water quality protection, and type of integrated harmonious development) to achieve the harmonious development between economic improvement and environmental protection.

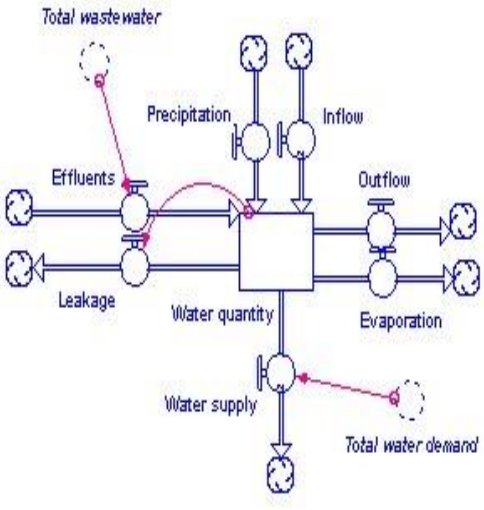
The objectives of this paper are: (i) to dynamically simulate and analyze the whole related processes and the impacts of socioeconomic and ecological water system on TP and TN; (ii) to build the most appropriate mode to balance the water quality condition and economic development.

## 2. Materials and methods

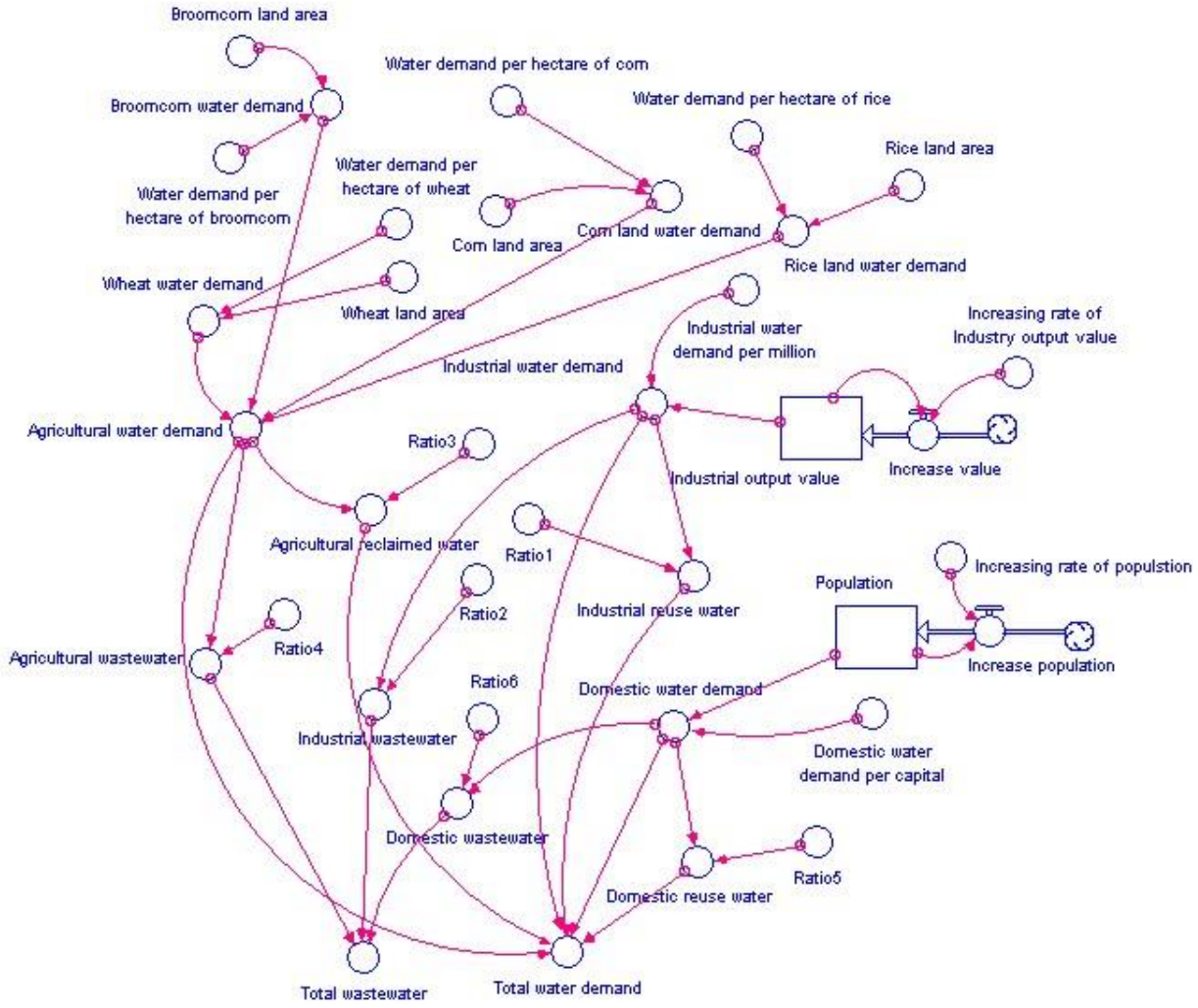
The Baiyangdian Lake (38°43'N to 39°02'N, 115°45'E to 116°07'E), the largest freshwater lake in North China, plays an essential role in not only providing agricultural, industrial, domestic and ecological water sources for its surrounding areas, but maintaining regional ecological security for the Haihe River basin. However, in recent years, the dual pressures both in water shortage and water pollution are more serious in Baiyangdian Lake. Thus, under the sharp conflict, its ecosystem services have been severely affected.




(a) TN and TP




(b)Water quantity




(c) Total wastewater

**Figure 1**. System dynamic model of socioeconomic water influencing TN and TP

System dynamics (SD) models are useful tools that can handle complex problems associated with high-order, nonlinear, and time-varying systems with multiple feedbacks to analyze the driving mechanism and the mutual restraints in changing complex systems. In this paper, based on the proposed model (Fig. 1) before, we built 4 types of different modes (i.e., type of continual status, type of economic development, type of water quality protection, and type of integrated harmonious development) to simulate the different development trends and explore the appropriate mode. And the quantity in the model refers to the total quantity of Baiyangdian Lake, considering all inflow and outflow of the lake, such as the effluents, precipitation, evaporation, etc.

(1) Type of continual status

For this type, assuming the current situation unchanged, we kept the value of all variables and indicators sustaining the current trend. According to the statistics in 2004, we set growth rate of industrial output value per 10 thousand Yuan as 11.34%, growth rate of population as 5.09%, water usage of industrial output value per 10 thousand Yuan as 80.69, reuse rate of industrial water as 40%, and set emission rate of industrial water, agricultural water and domestic water as 44.3%, 12.3% and 17.6 respectively.

(2) Type of economic development

For this type, we made efforts to promote economic development with putting economic development in priority, and devoted more energy and resources to economic development. According to the National Economic and Social Development Statistics Bulletin of Hebei Province, China, Anxin County (where over 85% of Baiyangdian Lake located) had the biggest annual growth rate of 13.3% (2005) in industrial output from 2004 to 2013. Thus, for this mode, we set the industrial output growth rate as 13.3%. Considering that the population growth of Anxin County is between 5.09% to 6.81% from 2004 to 2013, we set the maximum of 6.81% as its population growth. And other parameters remained unchanged.

(3) Type of water quality protection

Contrary to the type of economic development, economy would develop only when achieving rational utilization and protection water resources for this mode; both economic development speed and population growth speed were controlled. And also, we reduced residents living water usage, and improved sewage processing and its reusing rate. According to the National Economic and Social Development Statistics Bulletin of Hebei Province, China, the slowest industrial output average growth from 2004 to 2013 in Anxin County is 11%. Hence, we made it as the industrial output average growth of this type. Besides, we set water usage per 10 thousand Yuan industrial output value dropped from 80.69 $m^3$ to 30 $m^3$, and improved the reuse rate of industrial water from 40% to 80%, remained the population growth rate at 5.09%, and raised the treatment rate of industrial wastewater close to 100%. Namely, direct discharges of industrial wastewater were nearly prohibited by setting its emission rate as 0.01%. Meanwhile, emission rate of agricultural wastewater and domestic wastewater were controlled within 0.5%, and other parameters remained unchanged.

(4) Type of integrated harmonious development

For this type, both economic development and rational exploitation and utilization of water resources were required after comprehensive considering the above 3 types of development trends. We took the average growth rate (12%) of yearly industrial output value from 2004 to 2013 in Anxin County as the growth rate of industrial output value in this type. Then we reduced the water usage of industrial output value per 10 thousand to 50 $m^3$, and the reuse rate of industrial water was set to 80%. Also, emission rates of industrial, agricultural and domestic wastewater were within 0.5%, 1% and 1% respectively. Besides, growth rate of population should not exceed 3%, and other parameters should keep consistent as before.

## 3. Results and discussion

Selecting total wastewater, TN, TP and water quantity as the 4 main variables to compare different modes, and the correspondingly simulation results are shown in Fig. 2 to Fig. 5.

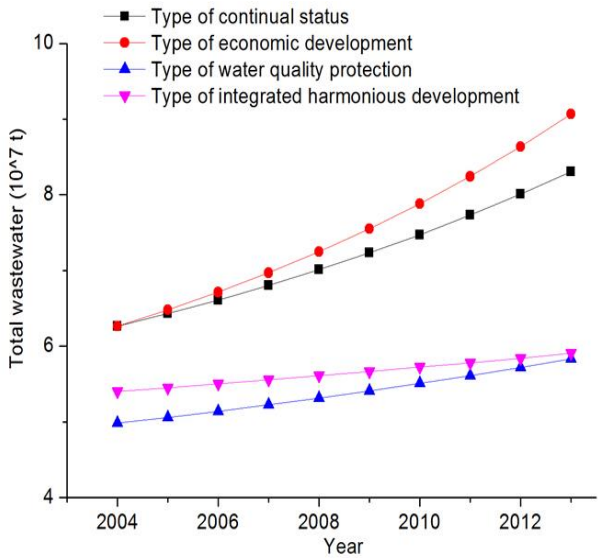



**Figure 2.** Simulation results of total wastewater

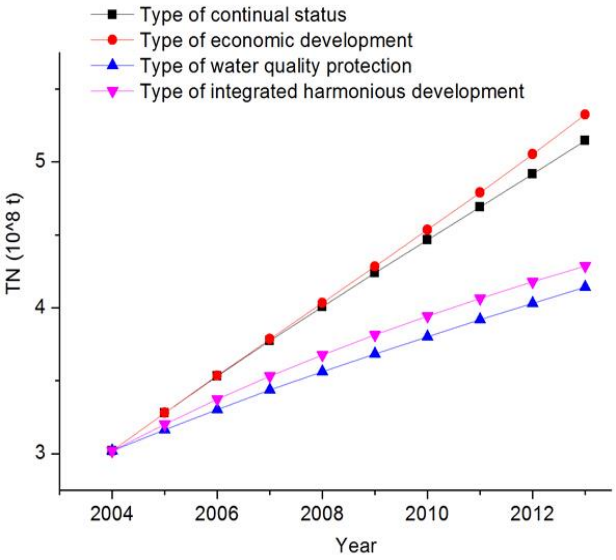



**Figure 3.** Simulation results of TN

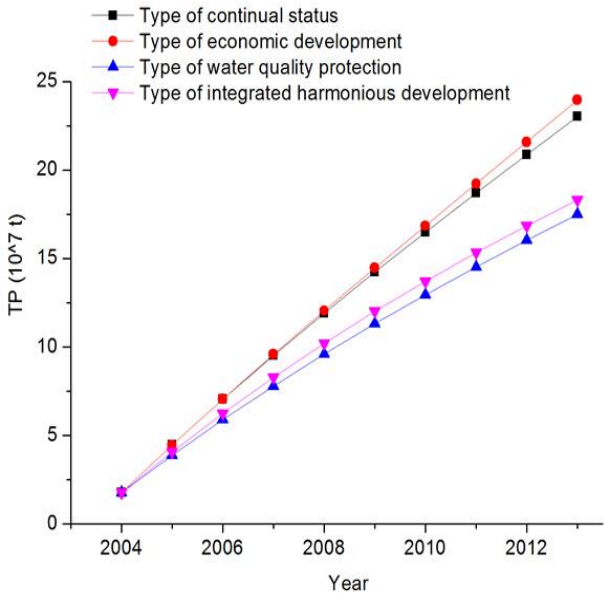



**Figure 4.** Simulation results of TP

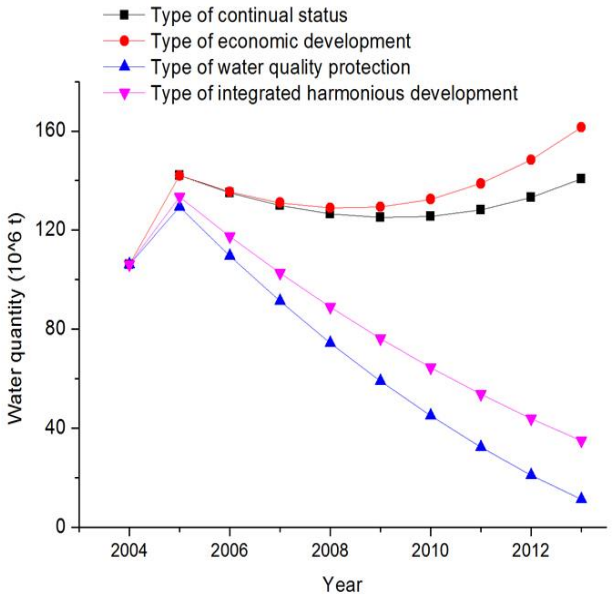



**Figure 5.** Simulation results of water quantity

### 3.1 Type of continual status

From water quantity in Baiyangdian Lake, it strikingly increased from 2004 to 2005, and till

the peak of $1.42*10^8$ t there still was a gradually rising trend. Because, during late 2003 and early 2004, China's Ministry of Water Resources and Hebei province shared fill water project of Yuehe diversion project, diverting 417 millions $m^3$ water from Yuecheng reservoir into Baiyangdian Lake. Therefore, water area in Baiyangdian Lake expanded almost 4 times, and ecological landscape had been greatly improved as well (Shen et al. 2005). However, actually, for the reasons such as absence of rivers into lakes, groundwater overdraft and continuing drought, Baiyangdian Lake has been dry for many years.

Obviously, excluding impact of water transfer project, Baiyangdian Lake itself has very inadequate and scarce water reserves in recent years. In this context, it could be inferred that the reason why water quantity in Baiyangdian Lake has been continued to increase in recent years is mainly caused by increased excessive wastewater into it, rather than increased available water (i.e., precipitation, etc.). Actually, the increasing rate of wastewater discharges is 20.44%, and the rainfall remains stable. Even worse, with excessive wastewater discharged, water quality in Baiyangdian Lake is getting deteriorated, and water eutrophication becomes more pronounced with higher TN and TP concentrations. Under the circumstances, both water scarcity and pollution problems would seriously affect the socio-economic development in Baiyangdian Lake. Thus, rational utilization of water resources and improvement in sewage treatment and recycling would be vital to mitigate the problem. Therefore, the program would be undesirable.

### 3.2 Type of economic development

For type of economic development, growth rate of industrial output value was greater than the other programs. In 2013, industrial output value exceeded 4.7 billion, 100 thousands more than the type of continual status, which indicates further socio-economic development. However, with the increase in industrial output value and population, demand for water resources increased significantly, so well as the wastewater discharges. And the increasing rate of wastewater discharges is 28.07%, which was the fastest speed of all modes. Actually, in 2013, the wastewater discharges, TN and TP were $9.1*10^7$ t, $5.32*10^8$ t and $2.4*10^8$ t respectively, which correspondingly increased by 9.6%, 3.5% and 4.1% compared with type of continual status. According to the Environmental Quality Bulletin of Hebei province (2013), though taking significant ecological regulation effects, water quality in Baiyangdian Lake reached class Ⅴ, which was the worst situation of all seven major river systems in Hebei province (Note: water quality of class Ⅴ represents the heaviest water pollution and could be equivalent to be useless sewage). As to this mode, owing to limited sewage treatment capacity in Baiyangdian Lake, combining with uncontrollable discharges of mass of garbage and wastewater from sanitation and industrial enterprises (paper mill etc.), both water pollution and water shortage situation would be more serious. As a result, Baiyangdian Lake would achieve its economic development at the expense of the environment, thus would be not desirable.

### 3.3 Type of water quality protection

From water quantity in Baiyangdian Lake, it continued to increase significantly. However, different from the above 2 modes, there was a sharp declining trend after peaking. It suggests that the measures had been taken to made wastewater discharges be in control. For this mode, wastewater discharges, contents of TN and TP were respectively $5.83*10^7$ t, $4.14*10^8$ t and $1.74*10^8$ t in 2013, and correspondingly reduced 29.77%, 19.51% and 24.03% compared with type of continual status. Thus both water quality and ecological functions of Baiyangdian Lake would be significantly improved. Meanwhile, for this mode, investments in environmental protection would increase. For example, water consumption per 10 thousand industrial output value decreased to 30 $m^3$, 37.2% of type of continual status, reuse rate of industrial water usage increased to 80%, 2 times of type of continual status, and sewage treatment rate was close to 100%, which making water demand in industrial production declined rapidly.

In addition, for this mode, water quantity of Baiyangdian Lake was close to the minimum ($1.1*10^7$ t) in 2013. To some degree, it indicated the least wastewater into Baiyangdian Lake and the minimum wastewater in total water quantity. Therefore, water quantity of Baiyangdian Lake on this occasion was the most closest to its real water storage, because actually Baiyangdian Lake has been dry for many years. It also reflected that to promote Baiyangdian Lake healthy, a timely water engineering is necessary when controlling pollutants discharges. However, it is worthy to note that for this mode, industrial output value was only 3.2 billion in 2013, which decreased 10.32% compared with the type of continual status. It suggested that though water quality would be protected and remarkably improved for this mode, its water resources could not be fully used with a slow socio-economic development speed.

### 3.4 Type of integrated harmonious development

The type of integrated harmonious development with appropriately controlled economic growth rate and increased input for wastewater treatment and reuse was set to achieve coordinated improvement of both water quality and economic development.

For this mode, population reached about 540 thousands in 2013, 83% of type of continual status, maintaining a certain growth meanwhile would not bring too much load to the environment. Correspondingly, wastewater discharges was controlled effectively. Total wastewater, content of TN and TP was respectively $5.91*10^7$ t, $4.29*10^8$ t and $1.83*10^8$ t in 2013, decreased 28.90%, 16.73% and 20.46% compared with the type of continual status. Both in types of water quality protection and integrated harmonious development, wastewater discharges were controlled appropriately. However, for the latter type, industrial output value reached 4.2 billion, which was 89.1% of type of economic development and 106.09% of type of continual status respectively. It indicates both a fast socio-economic development rate and high treatment

efficiency. Thus, for this mode, with appropriate sewage treatment rate, wastewater reuse rate and water consumption of industrial output value per 10 thousand Yuan, it could be able to achieve stable and sustainable economic growth, and water usage (i.e., industrial, agricultural, domestic, and ecological water usage) could be guaranteed as well. And water balance between water supply and demand would be further achieved with certain water project. Apparently, water resources in the type of integrated harmonious development were rational exploited and utilized. Therefore, the type of integrated harmonious development is the most viable program for Baiyangdian Lake to achieve both water quality protection and economic development.

## 4. Conclusions

With the system dynamic model developed before to display the integrated processes and intrinsic influencing mechanisms of socioeconomic water usage influencing TP and TN, we set 4 types of different modes: type of continual status, type of economic development, type of water quality protection and type of integrated harmonious development to explore an appropriate development mode to achieve both water quality protection and economic development.

For type of continual status, both water scarcity and pollution problems would seriously affect the socio-economic development in Baiyangdian Lake. Thus, it would be vital to strengthen rational utilization of water resources and make improvement in sewage treatment. For type of economic development, Baiyangdian Lake would achieve its economic development at the expense of the environment. Both water pollution and water shortage situation will be more serious with an increase rate of 7.87%, 3.5% and 4.1% of wastewater discharges, TN and TP respectively, compared with type of continual status. And for type of water quality protection, though water quality would be protected and remarkably improved with minimum wastewater, however, its water resources could not be fully used with the least industrial output value. Thus the type of integrated harmonious development could be able to achieve stable and sustainable economic growth and water with a fast socio-economic development rate and high treatment efficiency. Therefore, the type of integrated harmonious development would be the most viable program for Baiyangdian Lake to achieve both water quality protection and economic development.

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