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Assessing the Economic Costs of Water Pollution in the Yangtze River, China

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Abstract
Water pollution of the Yangtze River basin is very serious. Studies have shown that from the upper to the lower river, the water volume decreases and development and pollution increase, especially in trans-boundary areas. The Yangtze Estuary is located at the intersection of Jiangsu Province and Shanghai where the waters flow directly into the East China Sea. The estuary provides drinking water to many people and serves multiple other functions, including agricultural irrigation, tourism, and aquaculture. It plays a pivotal role in the local social and economic development and in people's general wellbeing. Directly or indirectly, the pollution of the aquatic environment in the estuary negatively affects the socio-economic function of the estuary and neighboring areas.

To help policymakers and stakeholders better appreciate the costs of rapid economic development, we examine Chongming County of Shanghai by using James' concentration-loss model and assessing the economic loss in Chongming County from 2005 to 2013 caused by water pollution in the Yangtze Estuary. The most affected function is tourism, while the most harmful pollutant is COD. According to the estimated loss rate, the county has lost almost all of its tourism and potable water function. The inhabitation function also shows severe deterioration.

We conclude that the economic development of the upper river has caused serious economic loss for Chongming County and make five suggestions to remedy this situation. First, the government should streamline management of the estuary environment. Second, to reduce pollution of the river aquatic environment, the government should establish trans-boundary compensation mechanisms. Third, researchers should focus on relevant theories and methodologies of assessing economic loss from water pollution. Fourth, universities should modify their curricula to include more subjects on the environmental research and management so as to train and cultivate high-level professionals. Lastly, administrative departments should work closely with research departments, thus enabling scientific research to affect planning and implementation.

Lea el abstracto en español

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1. INTRODUCTION

As water resources are increasingly exploited, pollution of the aquatic environment in the Yangtze River basin has grown more serious. Areas along the river are densely populated and have highly developed economies. The river suffers from great quantities of pollutants, and the surface water is severely polluted. According to the *China Marine Environment Quality Bulletin*, from 2004 to 2012, the Yangtze River is the East China Sea's greatest source of pollution.

There are many factors leading to the deterioration of the aquatic environment in the Yangtze River basin. Studies have shown that the lack of rigorous organizational mechanisms, a large number of construction projects and the discharge of waste water without treatment both within the boundary and across the boundary are the main factors causing the pollution (Zheng, Shou Ren 2014). In 1998, the Bureau of Water Resources Administration under the Yangtze River Water Resources Commission set up 35 monitoring points at cross-sections along the river. By 2003, the number had grown to 53. From the monitoring results, we can see that the most serious pollution exists at cross-sections (Li Yuan, 1996)

The Yangtze River Estuary is located not only at the end of the lower river, but also at the cross-section of Jiangsu Province and Shanghai. Consequently, this area has the most serious pollution and the greatest impact on the marine environment of the East China Sea. Scholars and administrators are actively exploring solutions to the problem of crossboundary pollution, and the mechanism of crossboundary compensation is considered a relatively effective approach (Zhou Hai Wei and Zang Shen 2013). The design and implementation of such a compensation mechanism is a very complicated systematic project, which involves not only defining responsibilities, but also ecological compensation and crossboundary economic compensation. Crossboundary economic compensation is a key initiative in internalizing the external costs of environmental pollution, which calls for the assessment of crossboundary economic losses in advance (Hou Yu, 2012).

Most of the recent studies on the Yangtze Estuary focus on the environmental change caused by pollutants, the composition of sediment and the change in sediment content, etc. Few researchers have studied crossboundary compensation of economic losses caused by water pollution in the Yangtze Estuary. There is hardly any research on the assessment of economic losses from crossboundary pollution. The mechanism of crossboundary compensation is essential in solving the problem of crossboundary water pollution and eliminating the pernicious influence on the East China Sea marine environment. Still, in order to design an effective crossboundary compensation mechanism, we must assess the economic losses caused by water pollution of the Yangtze Estuary.

Chongming County of Shanghai is located at the center of the Yangtze Estuary and is surrounded by the waters of the lower river. Over the years, it has suffered the most from the pollution of the aquatic environment of the Yangtze Estuary. Therefore, this thesis focuses on the assessment of economic losses suffered by the county as a result of water pollution in the Yangtze Estuary, in order to raise the awareness of authorities, polluters and stakeholders, so that policymakers can create relevant policies and management mechanisms that can be replicated and promoted to improve the quality of the aquatic environment in the Yangtze Estuary and the entire East China Sea.

Literature on the Yangtze Estuary features no more than 5,900 items in the CNKI database. If we search within the above results using the keyword “pollution”, we find only 14 documents related to Yangtze Estuary pollution. In them, researchers focus mainly on the causes of Yangtze Estuary pollution, damage to the environment of the Yangtze Estuary (especially to fish), assessment of eco-environmental risk and so on. We found no assessment of economic loss from water pollution in the Yangtze Estuary.

2. DEFINING THE AREA FOR STUDY

The crosssboundary pollution of the Yangtze River Estuary involves three administrative units of Shanghai city at the lower river: Baoshan District, Pudong New District and Chongming County. Relying on the Yangtze River Estuary resources, these three places have a large population and prosperous local economic development. Baoshan District and Pudong New District have dwellings and businesses along the river, but they also have a considerable number of socio-economic activities far from the river and coast. The social and economic activities are either not directly affected by the waters of the Yangtze River, or the influences are too complex to separate from one another to conduct individual study. Chongming County is made up of three islands located in the middle of the Yangtze River Estuary: Chongming, Chang Xin and Heng Sha, with a total area of 1,411 square kilometers and a population of 688,000 people in

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2012 (Yearbook of Chongming County, 2013). The polluted water from the estuary flows along the coast surrounding the area and into the East China Sea. All of its water resources depend on the waters of the Yangtze River, so it is most seriously affected by the pollution of the Yangtze River. At the same time, over the years the Municipality of Shanghai has been working hard to turn the county into an ecological county, that is, the garden of Shanghai. Furthermore, Chongming County also helps regulate the balance of the ecological system in Shanghai. For the above reasons, we have selected Chongming County as the research object.

2.1 Function Analysis of Yangtze Estuary for Chongming County

The waters of the Yangtze River Estuary serve the following functions in supporting Chongming County:

1) Agricultural irrigation. Every year, the waters of Yangtze River Estuary support tens of thousands of hectares of irrigated land in the county, making it a large agricultural county of Shanghai and an important provider of grains and vegetables. In 2013, the county had an agricultural output value of 6.1 billion yuan, of which 3.14 billion were from farming, 1.04 billion from animal husbandry and 120 million from forestry (data are from agricultural committee of Chongming County);

2) Aquaculture: Supported by the resources of the Yangtze River, Chongming County has always been ideal for producing aquatic products. Chongming crab is renowned at home and abroad. Historically, the Yangtze River Estuary has been the migratory passage of many species. It plays an important role in the county's fishery production. In 2013, the value of fishery output in Chongming County had reached1.62 billion yuan, with 60,740 tons of annual output of aquatic products, of which 43,261 tons are inland aquatic products and 17,479 tons are inshore fishing output. This provides a rich source of animal protein for the city of Shanghai (data are from agricultural committee of Chongming County);

3) Tourism: Over the years, Shanghai has made great efforts to turn Chongming County an ecotourism area, so the county is committed to the development of Dongping National Forest Park, the Dongtan Wetlands and Migratory Birds Protected Area, as well as Sanmin Cultural Village 4A Level Scenic Spots, Pearl Lake, Gao Jia Manor and other major leisure,

agricultural eco-tourism villages. The ecological leisure tourism industry of the county is developing steadily. In 2013, the county received 4,303,000 tourists, generating an operating income of 630,000,000 yuan (Tourism Bureau of Chongming County);

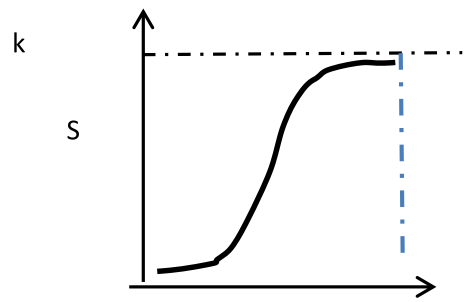
4) Housing: Chongming County is formed by the accumulation of sediment of the Yangtze River. Over the years, due to its relatively advantageous ecological environment and abundant natural resources, the county has attracted many settlers and residents. As housing prices in other districts of Shanghai remain very high, and with the building of the Yangtze River Tunnel Bridge, the high-end residential and villa market has begun to boom;

5) Potable water: Although the people of Shanghai live by the river, they have always obtained potable water from several large reservoirs due to the serious pollution of the Yangtze River Estuary. The Qingcaosha Water Source is located to the north of Changxing Island in the center of the Yangtze River Estuary. With a total area of nearly 70 square kilometers, designed effective capacity of 435 million cubic meters, daily water supply scale of 7.19 million cubic meters and total investment of 17 billion yuan RMB, it provides water to 10 million people and is currently the world's largest river estuary reservoir (data are from Water Affair Bureau of Shanghai City).

We should also highlight that despite the county’s location in the center of the river, the function of recreational swimming cannot be fulfilled, the main reason being that the water at the estuary flows too fast and the water along the bank is generally more than 2 meters deep. Swimming in the river is prohibited for safety reasons, so this function is not taken into consideration.

3. RESEARCH METHODS

Following a comparative analysis of the many methods of assessing economic loss, we have chosen the concentration - loss curve developed by James (1984). According to the curve, when the pollutant concentration is low, the damage to the environment is not significant, but as pollution concentration increases, environmental damage increases dramatically but tapers off after a certain level of pollution at which greater concentrations no longer lead to increases in damage. This trend is often expressed as an S-shape nonlinear equation (Figure 1).



$$\frac{dS_i(C_j)}{dC_j} = b_{ij}\frac{S_i}{k_i}(k_i - S_i)$$

Figure 1. James' concentration-loss curve and equation

In this figure, *C* expresses the concentration of pollutants while *S* expresses economic loss due to those pollutants. Many pollutants affect the economic value of water resources, so when assessing the economic loss due to degrading water resources, the common practice is to calculate the economic losses of water resources from one pollutant, and then calculate the losses from variety of pollutants. If there are *n* kinds of pollutants in an aquatic environment affecting the quality of the environment, the pollution rate from pollutant type *j* is R_j. In order to calculate the pollution rate, we must first establish the differential equation between pollutant concentration and the economic losses of environmental factors.

R_{ij} refers to the ratio between the economic losses caused by the pollutant and functional value K_i under a certain concentration of C_j. It is called the loss rate of the function caused by the pollutant, which can be called pollution loss rate. If *i* represents different functions and *j* represents different pollutants, we obtain the following equation (Figure 2):

$$R_{ij} = \frac{S_i}{k_i} = \frac{1}{1 + a_{ij} * \exp(-b_{ij} * C_j)}$$

Figure 2. Loss rate

In general, the pollution loss rate of the function i caused by pollutant j can be formulated as：

$$R_{ij} = \frac{1}{1 + a_{ij} * \exp(-b_{ij} * C_j)}$$

Figure 3. Loss rate simplified

As a_{ij} and b_{ij} only represent parameters associated with the characteristic of the pollutant and water use function, they cannot be arbitrarily selected and are objective. In addition, given that the toxicity of pollutants does not vary with changes in time or place, once determined, a_{ij} and b_{ij} can be applied to any lake or river.

When there is more than one kind of pollutant in the water, the interactions between them should be subtracted from the simple sum of the comprehensive loss. If the synergic and antagonistic effects between different pollutants are ignored, when there are n kinds of pollutants that are independent from one another and the interactions are subtracted, the comprehensive losses $R_i^{(n)}$ will be as follows:

$$R_i^{(n)} = R_i^{(n-1)} + [1 - R_i^{(n-1)}]R_{in} \quad (2\text{-}4)$$

Figure 4. Comprehensive loss due to independently-acting pollutants with synergic and antagonistic effects ignored

4. DATA COLLECTION

Many annual statistical data used in this study come from the *Shanghai Statistical Yearbook* compiled by the Shanghai Municipal Bureau of Statistics and the *Chongming County Statistical Yearbook*, compiled by Chongming County Bureau of Statistics. Data on the price of water comes from http://www.h2o-china.com/, data related to fisheries, agricultural irrigation area and other relevant data of Chongming through personal communication with the Agricultural Commission of Chongming County.

This research mainly focuses on the economic loss from the pollution of the Yangtze River Estuary, so the data related to the pollution of the Yangtze River Estuary is needed. This data was also obtained through personal communication with the Water Environmental Monitoring Station of the Estuary Station of the Yangtze Water Resources Administration Bureau.

In the assessment of the functional value of housing and tourism, the travel cost method and consumers' willingness-to-pay method are used, respectively, both of which use questionnaires to obtain the needed information. Accordingly, we designed and distributed questionnaires to collect data.

The method of expert investigation is used many times in this study. First of all, this method is used to determine the subjects and the locations of the questionnaire. Secondly, in the design process, some questions were confirmed by expert opinion survey. In addition, valuable information was obtained from experts in Chongming County Tourism Bureau and Sports Bureau concerning the swimming function of the river. Furthermore, when determining the parameters a and b in the loss-concentration curve, we referred to Zhu Qingfa (1996).

5. PRINCIPLES OF ASSESSMENT

5.1 The Principle of Theoretical Support

To accurately and objectively assess the situation, we need relevant theoretical research which can objectively describe the essence and laws of matter as our foundation and support. Theoretical study is the authentic and objective reflection of things and their internal laws, and it is the abstraction of the nature of things. Only with theoretical basis can we reveal the underlying factors of the situation being assessed and the mechanisms of influence. We can design and choose the methods and elements of assessment based on the available information. Assessment without theoretical support is not reliable and may even be incorrect.

5.2 The Availability of Data

A large amount of data on the object of study is needed for any assessment. When objective and sufficient data are unavailable, assessment will be compromised no matter how advanced the methods for conducting it. The assessment will be criticized and may even lose its guiding function in the policy-making process. Therefore, the data needed for the assessment must be available.

5.3 The Principle of Practicability

The assessment methods we choose should be practicable. Sometimes we may have very advanced assessment theories, and in following them we may also choose very good assessment methods. Nonetheless, if such theories and methods cannot be put into practice, we will be unable to conduct effective assessment.

5.4 The Principle of Consistency

In the assessment, we rely on time series data collected over many years. In order to have a dynamic display and objective comparison of the assessment results of the same object over the years, the selection of the time series data must be dynamically consistent; otherwise the assessment results cannot be compared in time series, which would reduce the guiding function of the assessment in practical decision-making.

5.5 The Principle of Optimal Synthesis

Our assessment involves many links, while the links also involve many methods and schemes. In order to ensure the validity of the assessment, under the premise of practicability, we must attempt to select the optimal scheme in every link and to carry out assessment within the optimized synthetic scheme.

6. EMPIRICAL ASSESSMENT OF ECONOMIC LOSS IN CHONGMING COUNTY

6.1 Main Assessment Results

We use different methods to calculate the value of every function in Chongming County. In order to assess the economic loss of Chongming County, we collected data on the concentration of the various pollutants in Yangtze River Estuary and the relevant parameters a_{ij} and *bij*. To calculate the direct loss rate R_{ij} and comprehensive loss rate $R_i^{(n)}$ we first need to calculate the direct loss rate of various pollutants (Rij) and comprehensive loss rate $R_i^{(n)}$ according to formula 4. The results are shown in Table 1 and Table 2 (next page).

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Table 1. Value of Every Function in Chongming $V_{i,}$ (unit: 100 Million yuan)

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013
Value of Fisheries Function	7.25	7.18	7.31	8.82	7.84	7.3	7.74	8.16	8.13
Value of Residential Potable Water	0.665	0.671	0.661	0.656	0.684	0.643	0.908	0.892	1.05
Value of Function	3.94	4.28	5.06	5.6	13.15	21.52	16.18	18.32	21.41
Value of Dwelling Function	2.55	2.59	2.61	2.62	2.75	2.81	2.811	2.808	2.91
Value of the Agricultural Irrigation Function	43.79	44.88	46.18	49.87	50.56	52.78	55.33	58.66	61.05

Table 2. The Result of Loss Rate R_{ij} (unit:%)

Fn	Year	COD	N	Phosphorus	Volatile Phenol	Cd	Pb	Heavy Metals	As
Fishery	2005	0.21	0.0077	0.006431	0.001611	0.00363	0.0001	0.007	0.001017
	2006	0.45	0.00736	0.006431	0.001608	0.00363	0.0001	0.007	0.0010168
	2007	0.49	0.00745	0.006431	0.001608	0.00363	0.0001	0.007	0.001016
	2008	0.56	0.00754	0.006524	0.001608	0.00363	0.0001	0.007	0.0010154
	2009	0.52	0.007096	0.006462	0.001608	0.00363	0.0001	0.007	0.001015
	2010	0.51	0.00753	0.006524	0.001608	0.00363	0.0001	0.007	0.0010156
	2011	0.42	0.00756	0.006524	0.001618	0.00363	0.0001	0.007	0.001015
	2012	0.29	0.0070	0.006524	0.001608	0.00363	0.0001	0.007	0.001014
	2013	0.23	0.0071	0.006524	0.001608	0.00363	0.0001	0.007	0.001014
Fn	**Year**	**COD**	**N**	**Phosphorus**	**Volatile Phenol**	**Cd**	**Pb**	**Heavy Metals**	**As**
Potable Water	2005	0.901	0.0049	0.0036	0.003632	0.001	0.0005	0.006	
	2006	0.990	0.0044	0.0036	0.00363	0.001	0.0005	0.006	
	2007	0.992	0.0045	0.0036	0.00363	0.001	0.0005	0.006	
	2008	0.996	0.0046	0.0031	0.00363	0.001	0.0005	0.006	
	2009	0.994	0.0039	0.0030	0.00363	0.001	0.0005	0.006	
	2010	0.993	0.0046	0.0031	0.00363	0.001	0.0005	0.006	
	2011	0.987	0.0047	0.0031	0.003632	0.001	0.0005	0.006	
	2012	0.954	0.0039	0.0031	0.003632	0.001	0.0005	0.006	
	2013	0.917	0.0040	0.0031	0.003632	0.001	0.0005	0.006	
Fn	**Year**	**COD**	**N**	**Phosphorus**	**Volatile Phenol**	**Cd**	**Pb**	**Heavy Metals**	**As**
Tourism	2005	0.942	0.0032	0.0016					
	2006	0.9952	0.0027	0.0016					
	2007	0.997	0.0028	0.0016					
	2008	0.998	0.00294	0.00157					

	2009	0.9972	0.00226	0.001507					
	2010	0.997	0.00293	0.00157					
	2011	0.994	0.0030	0.00157					
	2012	0.975	0.0022	0.00157					
	2013	0.952	0.0024	0.00157					
Fn	**Year**	**COD**	**N**	**Phosphorus**	**Volatile Phenol**	**Cd**	**Pb**	**Heavy Metals**	**As**
Housing	**2005**	0.7867	0.0049	0.0030					
	2006	0.9659	0.0044	0.0030					
	2007	0.9739	0.0045	0.0030					
	2008	0.9840	0.0046	0.0031					
	2009	0.9778	0.0039	0.003049					
	2010	0.9766	0.0046	0.0031					
	2011	0.9579	0.0047	0.0031					
	2012	0.8831	0.0039	0.0031					
	2013	0.8131	0.0040	0.0031					
Fn	**Year**	**COD**	**N**	**Phosphorus**	**Volatile Phenol**	**Cd**	**Pb**	**Heavy Metals**	**As**
Irrigation	**2005**	0.0167			0.003632	0.00363	0.00366	0.00362	0.009199
	2006	0.0199			0.003628	0.00363	0.00366	0.00362	0.009197
	2007	0.0203			0.003628	0.00363	0.00366	0.00362	0.009187
	2008	0.0212			0.003628	0.00363	0.00366	0.00362	0.009185
	2009	0.0206			0.003628	0.00363	0.00366	0.00362	0.009183
	2010	0.0205			0.003628	0.00363	0.00366	0.00362	0.009187
	2011	0.0195			0.003632	0.00363	0.00366	0.00362	0.009183
	2012	0.0177			0.003628	0.00363	0.00366	0.00362	0.009176
	2013	0.0169			0.003628	0.00363	0.00366	0.00362	0.009176

Table 3. Comprehensive Loss Rate of Various Functions $R_i^{(n}$ (unit:%)

Year	Fishery	Potable Water	Tourism	Housing	Irrigation
2005	0.23	0.90	0.9419	0.7883	0.0398
2006	0.47	0.9899	0.9952	0.9662	0.0429
2007	0.51	0.9926	0.9966	0.9741	0.0434
2008	0.57	0.9958	0.9982	0.9841	0.0442
2009	0.53	0.9939	0.9972	0.9780	0.0437
2010	0.52	0.9935	0.9970	0.9768	0.0436
2011	0.44	0.9870	0.9937	0.9582	0.0426
2012	0.30	0.9552	0.9754	0.8839	0.0408
2013	0.25	0.9186	0.9522	0.8144	0.04

When it comes to calculating the comprehensive loss of various functions caused by various pollutants, the data concerning the value of various functions calculated above (V_i) is multiplied by the comprehensive economic loss rate $R_i^{(n)}$ of various functions caused by various pollutants, allowing us to obtain the comprehensive economic loss of various functions caused by various pollutants, as seen in Table 4 on the next page.

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Table 4. Comprehensive Economic Loss of Various Functions over the Years $V_i*R_i^{(n}$
(Unit: RMB 100m)

Year	Fishery as % of Total	Potable Water as % of Total	Tourism as % of Total	Housing as % of Total	Irrigation as % of Total	Total Economic Loss in Chongming County	Loss as a % of Yearly Econ Growth	Gross Increase Econ Loss in Chongming County
2005	1.69	0.6	3.71	2.01	1.74	9.75	0.1019	95.7
2006	3.37	0.664	4.26	2.5	1.93	12.72	0.1174	108.3
2007	3.7	0.66	5.04	2.54	2.00	13.94	0.1135	122.8
2008	5.05	0.65	5.59	2.58	2.207	16.08	0.1168	137.7
2009	4.14	0.68	13.11	2.69	2.208	22.83	0.1338	170.6
2010	3.80	0.64	21.46	2.74	2.30	30.94	0.1592	194.4
2011	3.4	0.9	16.08	2.69	2.35	25.42	0.11346	224.1
2012	2.48	0.85	17.87	2.48	2.40	26.08	0.1104	236.3
2013	2.01	0.963	20.39	2.37	2.44	28.18	0.1117	252.3
Acc. Econ Loss Over Time	29.64	6.61	107.51	22.61	19.58	185.95		

*Total economic loss is equal to the mathematical expectation of economic loss of the value of every function.

Table 5. Direct Economic Loss Caused by Various Pollutants over Time $V_i{*}R_{ij}$ (Unit: RMB100 million)

Year	COD	N	Phosphorous	Volatile Phenol	Cd	Pb	Hg	As	Total Direct Economic Loss
2005	10.58	0.09	0.06	0.17	0.19	0.16	0.21	0.41	11.88
2006	13.66	0.08	0.06	0.18	0.19	0.17	0.22	0.42	14.97
2007	15.62	0.09	0.06	0.18	0.20	0.17	0.22	0.43	16.97
2008	18.18	0.10	0.08	0.20	0.21	0.18	0.25	0.47	19.68
2009	32.30	0.12	0.09	0.20	0.21	0.19	0.24	0.47	33.83
2010	48.69	0.19	0.12	0.21	0.22	0.19	0.25	0.49	50.36
2011	37.50	0.16	0.10	0.22	0.23	0.20	0.26	0.52	39.19
2012	40.06	0.14	0.11	0.23	0.24	0.22	0.27	0.55	41.82
2013	44.56	0.16	0.14	0.24	0.25	0.22	0.28	0.57	46.43
Total	261.16	1.13	0.84	1.83	1.95	1.71	2.21	4.32	275.13

To clarify, in Table 4, the economic losses of various functions caused by one pollutant are added up, and the result is the total direct economic loss of various functions caused by certain pollutants. The formula it adopts can be seen below in Figure 5. In it, i stands for the types of function, j stands for the types of pollutants, and R_{ij} stands for the economic loss of i kinds of functions caused by j kinds of pollutants. The comprehensive economic loss of various functions in Table 3 covers the comprehensive economic loss indirectly caused by different kinds of pollutants or the interaction of those pollutants. The formula adopts the comprehensive loss rate of formula 2.

$$\sum_{i=1}^{n} V_i R_{ij}$$

Figure 5. Total Direct Economic Loss of Various Functions caused by Certain Pollutants

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6.2 Predictions

In order to determine how losses will rise or fall in the coming years, this study predicts the losses caused by all the different kinds of pollutants, using the horizontal method and the regression analysis method. To enhance the accuracy of the predictions, we take the average of the weighted number of the predictions from the last two methods. Finally, we take the average of the predictions as the rate of economic loss.

Table 6. The Equal-weighted Average of Predicted Economic Loss of Every Function Using Two Assessment Methods (Unit: RMB100 million)

Year	Fishery	Potable Water	Tourism	Housing	Irrigation for Agriculture	Sum
2015	1.50	1.03	28.85	2.79	2.67	36.84
2020	1.17	1.32	64.57	2.09	3.18	70.25
Sum	2.67	2.36	93.42	2.79	5.85	107.08

Table7. The Equal-weighted Average of Predicted Economic Loss Caused by Various Pollutants Using Two Assessment Methods (Unit: RMB100 million)

Year	COD	Nitrogen	Phosphorous	Volatile Phenol	Cadmium	Lead	Heavy Metals	Arsenic	Sum
2015	60.90	0.19	0.16	0.25	0.27	0.24	0.25	0.66	62.92
2020）	119.41	0.27	0.25	0.30	0.32	0.28	0.35	0.73	121.91
Sum	180.30	0.47	0.41	0.56	0.59	0.52	0.60	1.39	184.83

6.3 Empirical Analysis of the Main Assessment Results and Forecasts

6.3.1 Interpretation of Table 2

Table 2 displays the comprehensive economic loss rate of various functions caused by various pollutants, the results being derived using Formula 2. First, let’s examine the potable water and tourism functions, which show the greatest loss rate. The data in the table show that the water in Chongming County has entirely lost the function of potable water. Its loss rate is greater than 90%, absolutely unsuitable for this function. Furthermore, serious pollution has also destroyed the function of tourism, with the loss rate above 90%. Even if tourism resources were developed, the economic benefit would be negligible given the current condition of the water. This represents a major obstacle to Shanghai's strategic plan of transforming Chongming County into an eco-tourism county.

Secondly, in terms of the life and leisure function, as the data in the table show, the pollution of the waters of the Yangtze River Estuary has caused serious economic loss, with the loss rate above 80%. This indicates that the economic benefit of developing real estate on the coast near Chongming County will be low and the real estate industry, featuring houses with a sea-view, will be seriously hampered.

Thirdly, in terms of the economic loss rate of fisheries, the loss rate is mostly between 30% and 50%, which means the current fisheries output roughly represents only half its potential, and about half of its output is lost as a result of environmental damage. This is without taking into account the indirect loss in the form of damage to people's health caused by the poor quality of fisheries. Therefore, such water is absolutely unsuitable for fishery production and culture.

Lastly, in terms of the irrigation function, the loss rate is relatively small and stable, at approximately 4%. This is mainly due to the fact that when the concentration level is low, some pollutants have a positive effect on agricultural production. Nonetheless, this fails to take into account the indirect net loss caused by the decline in the quality of agricultural products as a result of the excessive discharge of various pollutants, as well as the decline in the quality and quantity of agricultural production caused by the sedimentation of pollutants in the soil. Thus, small though the loss rate may be, it is not acceptable and should not be left unchecked.

6.3.2 Interpretation of Table 3

Table 3 shows the comprehensive economic loss of various functions calculated according to the direct loss rate in Table 2 and the value of various functions in Chongming County. The calculation takes into account not only the economic loss rate caused by pollutants, but also the value of various functions. Firstly, considering the total comprehensive economic loss over the years, from 2005 to 2013, the comprehensive economic loss caused by the pollution of the Yangtze River Estuary accounts for more than 10% of the annual economic growth of

Chongming County. If we put the average annual income in Shanghai in the year 2012 at 56,300 yuan, the magnitude of the total economic loss of Chongming County over the years (18.5 billion yuan) represents the average income of 300,000 people combined. If in 2013 the average disposable income is 13,421 yuan for rural residents in Chongming County, as the registered population in the county is 680,000 people, and 390,000 of them are non-rural residents, then the magnitude of the comprehensive economic loss that year would effectively erase the income of the rural population. If in 2012 the per capita living expense of rural residents in Chongming County is 12,000 yuan, then the size of the economic loss caused by the pollution in Yangtze River Estuary represents the combined living costs of about 90% of the county's rural population.

Secondly, in terms of economic loss over time, as seen in Figure 6 (below), from 2005 to 2013 the total economic loss of various functions increases dramatically. Despite a slight drop in 2011 compared with 2010, the general trend is still climbing obviously upward.

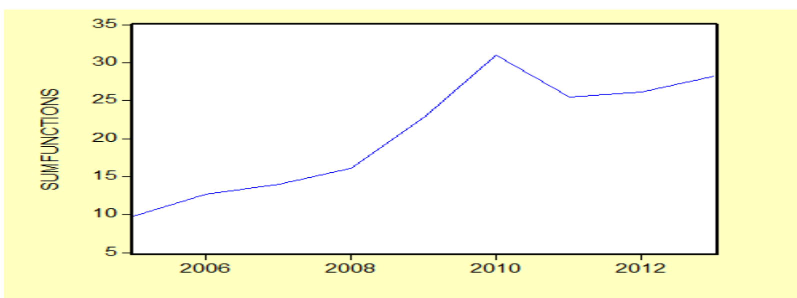

Figure 6. Total economic loss trend of various functions over the years in Chongming County (Unit: RMB100 million)

Thirdly, combining Figure 2 and Table 3, we obtain a picture of the economic loss of various functions. Among the five functions of the water resources of Yangtze River Estuary in Chongming County, the tourism function suffers the greatest economic loss over time, with the lowest rate at 33% in 2006, while from 2009, the loss rate never fell below 57%. From 2005 to 2013, the comprehensive economic loss of tourism exceeds 10.7 billion yuan, equal to half of the county's economic growth during the same period. This is mainly because of the deterioration of the aquatic environment in Chongming County caused by the pollution of the Yangtze River Estuary, which deprives tourists of the environment's leisure values, thus greatly decreasing its potential economic benefit.

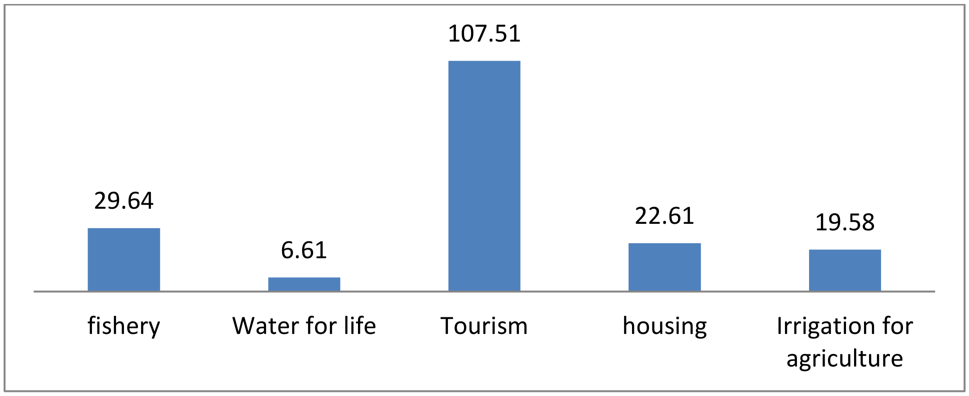

Figure 7. Total economic loss per function from 2005-2013 in Chongming County

（unit: RMB100 million）

In terms of economic loss, following tourism is the fisheries function. The total loss suffered by the fisheries industry is much smaller than that of tourism for the following reasons:

1. The general functional value of fisheries in Chongming County is not very high;
2. Certain concentrations of some organic substances in the Yangtze River Estuary are beneficial to the breeding and development of fish;
3. The current fisheries industry mainly relies on aquatic culture instead of fishing directly in the Yangtze River. The water for aquatic cultures comes from the estuary, but the pollutants in the water have already been sedimented and filtered;
4. The indirect loss in the form of harm to consumers' health caused by the deterioration of fisheries is not considered here.

The economic loss of the life and leisure function ranks third. Because the aquatic environment along the coastal region of Chongming County is damaged, the life and leisure function featuring houses with a sea view is compromised, but far less so than the tourism function. This is mainly because when compared with the city center the population density in Chongming County is low. In the center of the county, there are still large areas of high vegetation coverage, where the environment is more pristine and provides a high value in the life and leisure

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function. Thus, for the residents of Chongming County, the life and leisure function suffers far less from water pollution than the tourism function.

The economic loss suffered by the irrigation function ranks fourth. This stems from the fact that rich nutrients in the polluted Yangtze River Estuary, such as nitrogen and phosphorus, can increase agricultural output to a certain extent. In this sense, irrigation using the polluted water resources has some positive effects on agricultural production. Therefore, the total loss is not so high. On the other hand, the excessive concentration of pollutants in water resources will surely contaminate the soil, crops and underground water, which will inevitably cause a certain degree of economic loss. Nonetheless, in this study, the pollution of soil, crops and underground water, not to mention the indirect harm to people's health and the resulting economic loss, are not taken into consideration.

The economic loss suffered by the function of domestic water ranks last on the list. The magnitude of this loss is the smallest. This is because the population in Chongming County is small and the price of potable water is low, so the total value of the potable water function is not so high. From Table 3 we have learned that the potable water function shows a loss rate of up to 90%, resulting in the use of the Qingcaosha reservoir for Chongming County's potable water needs. The water of the Yangtze River Estuary, however, is completely unable to perform the potable water function.

We should highlight yet another factor in the assessment of economic loss of the five main functions: substitution elasticity. If tourists go to Chongming, they will pay much attention to the pollution of the local aquatic environment, so the influence will be greater. For those who work there, a lack of transportation will cause the substitution elasticity for life and leisure to decrease; thus, the result of the assessment will be relatively small. The same is true with fisheries and agricultural irrigation.

6.3.3 Interpretation of Table 5

Table 5 shows the economic loss caused by various pollutants in the Yangtze River Estuary over time. The last row shows the total value of economic loss from different pollutants from 2005 to 2013. From the total economic loss, we can see that among all pollutants, COD causes the greatest economic loss, accounting for more than 94% of total direct economic loss over the years. It is followed by arsenic pollution, accounting for 2%. Together, the two account for about 96% of the total direct economic loss over the years. Other loss-generating pollutants include lead, cadmium, volatile phenol, nitrogen, and lastly, phosphorus.

The sources of pollution in the Yangtze River Estuary are mainly pesticides, chemical plants and organic fertilizer, which contain large amounts of COD. The higher the concentration of COD in the river, the more serious the organic substance pollution, which results in large amounts of pernicious substances in the water. These substances exert great influence on fisheries, the living environment, tourism, potable water and irrigation. Furthermore, the Yangtze River Estuary is a large tidal estuary with typical tidal banks. In recent decades, with the rapid development of the economy of the Yangtze River Basin, sewage and waste emissions along the river have increased dramatically. The pollutant flux also shows a marked increase, resulting in large amounts of heavy metals such as arsenic being discharged into the river. These pollutants have no direct impact on tourism and living, but with long-term sedimentation, they will have serious effects on people's health via the food chain.

According to the last column, the total economic loss caused by various pollutants has tended sharply upwards over the last decade. This tendency is shown below in Figure 8. In the graph, *sum* refers to the total economic loss caused by various pollutants in the years from 2005 to 2013 (x axis). Despite a slight dip in 2011, the total economic loss caused by various pollutants shows a marked upward tendency. Therefore, reducing the emission of pollutants into Yangtze River Estuary and expediting the regulation and reduction of the COD content in the waters in Chongming County are urgent tasks.

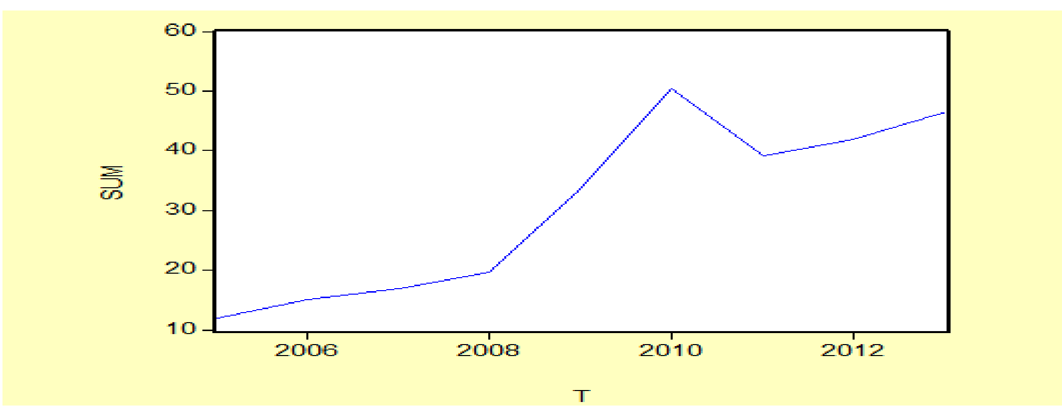

Figure 8. The tendency of change over time of the total economic loss caused by various pollutants

6.3.4 Interpretation of Table 6 and Table 7

From Table 4 and Table 5, we obtain a clear picture of the various pollutants and the economic loss of various functions in the Yangtze River Estuary. The available data tell us that the loss is enormous. Unless we more effectively address this kind of pollution, it could cause even greater economic loss in as little as three to eight years.

According to Table 6, the total economic loss of various functions in 2012 and 2020 will be 10.7 billion yuan, or 60% of the total economic loss from 2005 to 2013. We can estimate the total economic loss of the tourism function in the two years as nearly 90% of the total economic loss from 2005 to 2013.

According to Table 7, the total economic loss in 2015 and 2020 caused by various pollutants will reach 18.5 billion yuan, or roughly 67% of the total economic loss from 2005 to 2013. The economic loss caused by COD increases fastest, with the economic loss of the two years representing 70% of the total economic loss from 2005 to 2013.

6.4 Analysis of Indirect Economic Loss

Due to a lack of data, this study is limited to the consideration of the direct economic loss of functions due to pollution of the Yangtze River Estuary. However, we should bear in mind the fact that in the economic development of a certain area, all the socio-economic activities within the area interact with and influence one another. Together they form an organic whole. Therefore, the economic loss of one function or industry caused by water pollution will inevitably cause inestimable and indirect socio-economic loss to local socio-economic development as a whole.

First of all, the pollution in the Yangtze River Estuary is mainly a result of large amounts of COD. Generally speaking, the higher the concentration of COD in water, the more oxygen it needs, which will then lead to the depletion of the existing oxygen. In the meantime, the level of ammonia and nitrous will also increase, and bacteria and pathogen will breed in large numbers, which will cause aquatic products to become infected. For tourism, the main effect is on scenery, especially when foul-smelling algae thrive in the water. If left untreated, many organic pollutants will deposit at the bottom and exert a lasting toxic influence on the aquatic organisms within a few years. When the aquatic organisms die in large numbers, the eco-system in the river will be destroyed. If people eat the aquatic organisms, they will absorb and accumulate the toxin found in the organisms, which will lead to cancer, deformities and mutation. Thus, deteriorating water quality involves the quality of aquatic products, the quality of crop's, and people's health. Although the damage cannot be quantitatively estimated in the short-term, the harm is great in the long-term.

Secondly, when the environment is destroyed by COD, sometimes even emitting a foul smell, it affects not only the tourism and life and leisure functions, but also the healthy development of service industries such as hotels, catering, business and trade, all of which rely on tourism as a growth engine. The development of these industries directly determines the industrial structural arrangement of Chongming County, that is, whether its focus be on primary industry or tertiary industry. Meanwhile, different industrial structural arrangements determine the efficiency and speed of the region's economic development. From this perspective, we can see that the county suffers enormous economic loss as a result of the pollution of Yangtze River Estuary.

Thirdly, rational industrial structural arrangement will speed up industrial development and people's living standards, which will in turn boost the improvement of soft power and comprehensive power. The pollution of the Yangtze River Estuary hinders the development of tourism, living, catering, hotel industry and cultural exchange, seriously affecting the improvement of the county's soft power and the development of a modern service industry. The damage is inestimably large.

Lastly, the municipal government of Shanghai, while trying to turn Chongming into an eco-tourism island, also hopes to develop a modern, tourism-based service industry by capitalizing on natural and ecological resources.

In summary, the pollution of the Yangtze River Estuary has caused inestimable loss to Chongming County, both directly and indirectly. This loss could represent the wasted potential employment opportunities for residents, employment that could have improved people's standards of living. In order to create a dignified living and working environment for Chongming County and Shanghai as a whole, and to reduce unnecessary economic loss as soon as possible, it is high time that the pollution of the Yangtze River Estuary be controlled.

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7. RECOMMENDATIONS

From the above analysis of economic loss, we can determine that Chongming County suffers very serious economic loss from the pollution of the Yangtze River Estuary, with the total economic loss accounting for more than 10% of annual economic growth. Relevant departments and stakeholders should attribute greater importance to the lasting, substantial economic loss. To this end, targeting the many sources of this loss, we make several suggestions to relevant departments and stakeholders.

7.1 For Government

The Chinese government has passed laws, regulations and systems to deal with the problem of water pollution in the Yangtze River Estuary, but with little success, essentially because the management system is ineffective. First of all, the Yangtze River Water Resources Administration Bureau does not have enough power to prevent local businesses along the river from polluting. Secondly, in the process of crossboundary pollution, it is very difficult to define responsibilities and rights. Furthermore, the Yangtze River Water Resources Administration Bureau has failed to carry out crossboundary administration. Thirdly, there are no strong, dedicated law-enforcement agencies to enforce the laws and regulations.

Faced with this embarrassing situation in the management of water resources in the Yangtze River, the government should, first of all, recognize both the gravity and the primary cause of this loss, that is, the ineffective management of the river. To improve this management mechanism, curb pollution and restore the ecological environment along the Yangtze River, we need to increase the authority and expand the jurisdiction of agencies such as the Yangtze River Water Resources Administration Bureau.

All levels of government should fully recognize the enormous economic loss suffered by all parties due to pollution by businesses and individuals under the government’s jurisdiction: the government itself, people downstream and future generations. They should enhance their moral awareness and sense of responsibility towards the environment and take immediate action to formulate effective mechanisms for managing the aquatic environment along the river, devise and implement relevant policies, systems, laws and regulations. Then, polluters could be punished accordingly and economic loss due to pollution could be appropriately compensated.

There must be laws to follow, and laws must be strictly observed and lawbreakers prosecuted. Only in this way can we restore the ecological environment for the sake of people living along the river.

7.2 For Companies and Residents along the River

The pollution of the Yangtze River is serious and has no easy solution. This is also due to the people's mentality. Pollution involves not only the polluting enterprises and the victims of pollution and economic loss, but also the residents along the river and local government. Businesses lack awareness of their moral duty to preserve the ecological environment for the life and work of others and future generations. As for residents and local government along the river, when presented with the fact that their living and working environment is being polluted and destroyed, they lack the sense of crisis which would drive them to fight against such pollution. They are unaware that this pollution will seriously harm their mental and physical health and cause economic losses, in addition to jeopardizing the survival of future generations. Faced with the degradation of the environment, they are either indifferent or turn a blind eye.

Therefore, we make the following suggestions for polluting businesses:

1. They should weigh the economic benefits against the social and ecological cost, that is whether the profits they gain at the cost of the environment can make up for the economic loss they caused.
2. They should have enough awareness and moral sense to curb their own polluting behavior. If every stakeholder can exercise self-discipline and minimize their polluting behavior, the situation will slowly but surely improve.
3. Every business should invest time and money in cooperating with scientific research institutes in order to develop cost-reducing pollutant-treatment technology and transform it into the standard procedure of industrial production. This will entail upfront costs, but will benefit the whole society.
4. In the production process, every business should publish their daily sewage discharge information; this can serve as an important means of self-supervision and mutual stakeholder supervision.

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Regarding the victims of economic loss, they should be more aware of protecting the environment, have a greater sense of the environmental crisis, environmental cost and economic loss. They should have a clear understanding of the total economic loss and the loss of social welfare caused by others' polluting behavior. They should stand up for their own rights and get organized in monitoring the polluting enterprises.

7.3 For Researchers

When it comes to the perspective of this study, there are several key issues: first, to this day there is still no standard in existing literature for judging assessment results. Therefore, whatever method is used to conduct the assessment, when it comes to the reliability (or lack thereof) of results, there is no answer. Therefore, scholars in relevant field should focus on this issue and conduct relevant research. The second issue concerns the selection of parameters used in the concentration-loss curve. At present, the parameters adopted is the number proved by scholars through experiment, but whether this number can cover all the waters including the marine environment, whether the parameters are constant or will change with the aquatic environment, are all questions that require further study. The third issue concerns the theoretical support of the assessment methods. Among the many research results, there is still no relevant theory obtained from tracking the dynamics of economic loss of certain functions caused by different levels of pollution. This is the difficulty and the core issue in the assessment of economic loss from water pollution. The difficulty lies in the fact that it cannot be tested and repeated, and requires long-term dynamic tracking. In the meantime, research must feature collaboration between economists and environmentalists. It will even require the cooperation of experts in the fields of agriculture, fisheries, water resources, etc. Its importance lies in the fact that it is the foundation of choosing the most scientific and rational assessment method. The fourth issue is about the study of waste water treatment and prevention technology. One of the main reasons many enterprises are not actively and effectively treating their waste water is the cost of treatment. Therefore, scholars should focus on this urgent and important issue. If research can minimize the cost of waste water treatment, it will surely be a tremendous contribution to the progress of human society. The fifth point concerns the relevant laws, mechanisms and policies. Obviously, when dealing with the problem of aquatic environment pollution, the key to crossboundary aquatic environment management lies in the fact that the systems and the mechanisms are not streamlined, which makes it hard to define rights and responsibilities. There are often no pertinent laws to follow, and even when there is one, it is very hard to comprehend. Finally, enforcement is lax, at least partially because there is no corresponding authority to carry out this task. Even if it is carried out, the key to managing crossboundary aquatic environment pollution becomes with what standard is the law to be implemented. Therefore, scholars should step up efforts in the study of relevant standards of compensation, especially the study of crossboundary water pollution, the compensation mechanism, the management mechanism and relevant laws and policies.

7.4 For Education

Institutes of education and learning should set up suitable subjects to adapt to this urgent environment protection demand. As far as China is concerned, the main responsibility of education institutes such as universities is to cultivate practical talents with solid theoretical foundations. Currently, the field of aquatic environments, be it the Yangtze River, inland rivers and lakes, or the ocean and coastal waters, needs a large number of professional technical talent and researchers with expertise in theory to manage the aquatic environment. Relevant universities and other institutes of education should appreciate this enormous demand and try to meet it by adjusting their majors and establishing subjects with both practical value and theoretical guidance. These might include environmental monitoring, environmental statistical analysis, environmental economic analysis, environmental information, environmental law-enforcement supervision, environmental pollution treatment technology, aquatic environment restoration, etc. Doing so would allow them to cultivate high-level professional talent that can meet society’s urgent need.

7.5 For Practitioners

Practitioners should collaborate more closely with research institutes. In China, the practitioners and researchers of aquatic environment management are isolated from one another, yet another significant reason for the failure in preserving and treating the aquatic environment. Practitioners, especially businesses and management departments, rely on the latest results of scientific research to guide practice. For example, they need to know and utilize advanced technology to lower pollution-

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incurred economic costs and decrease the emission of pollutants. Currently, however, they do not actively cooperate with research institutes or share their needs with researchers. As for researchers, they are often busy applying for big projects such as the so-called national 973 and 863 projects. They do not care so much about whether their research results can be synergized with that of practical departments or whether the results can solve real problems. Consequently, we see a separation of theory from practice. The aggregate effect is that practical departments lose confidence in research institutes as they assume that research results cannot guide practice. On the other hand, researchers, cloistered in the ivory tower, do have a complete picture of practical needs. Such mutually asymmetrical information leads to the serious waste of scientific, technological and economic resources. In the meantime, it will also become a huge opportunity cost in the process of environmental pollution and economic development. Therefore, the author suggests that a platform and mechanism for the exchange of information should be established, providing information on practical needs to research institutes, as well as enabling scientific research to play its role in practical application as soon as possible. In the future, this will be the focus of practical departments.

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