A waste load allocation method based on unfairness factors and its application in the Zhangweinan Watershed, northern China

Ruzhi Qiu, Yingxia Li, Zhifeng Yang, Chunhui Li, Jingshan Yu and Jianghong Shi

ABSTRACT

A waste load allocation method was developed for industrial wastewater management based on unfairness factors, an industrial allocation factor and pollution reduction discounts. Three unfairness factors were defined to assess the relative efficiencies of energy consumption, pollution discharge and waste treatment costs for different industries. The overall effect of these factors was described by an industrial allocation factor. Based on the values of these factors, industries were classified into three types, after which waste load allocation proportions among different industries were determined using different pollution reduction discounts. This waste load allocation method was then applied in the Zhangweinan Watershed, which is one of the most seriously polluted watersheds in northern China. The results revealed that extractive, mechanical and food industries comprise the type I industries, which had the lowest pollution reduction discounts of 0, 0.25 and 0.5, respectively. The metallurgical industry and other industries were characterized as type II and discounts of 0.5 and 0.6 were given to their primary reductions. Textile, pharmaceutical, oil and pyrogenic, chemical and paper industries were classified as type III industries and had a waste load reduction of more than 80% of the pollution discharge in 2004.

Key words | industrial wastewater, unfairness factor, waste load allocation, Zhangweinan Watershed

INTRODUCTION

Wastewater from industries contributed to 42% of the total discharged wastewater in China in 2008 (Ministry of Environmental Protection 2009) and is one of the major pollution sources in most developing countries. In the Zhangweinan (ZWN) Watershed, which is one of the most seriously polluted regions in China, industrial wastewater accounts for more than 68% of the total wastewater (Zhangweinan Canal Management Agency 2006). According to a report by the Blacksmith Institute and the Green Cross Switzerland in 2008, four of the ten most serious pollution problems around the world were associated with industrial pollution (Zhu 2008). Due to the limited budget for pollution management in most developing countries, determining management priorities for various industries has become a very challenging issue in many watersheds.

Similar to many countries, such as the United States, the water quality objectives for water bodies have been determined by designating functions and setting maximum pollutant concentration criteria in China. Water bodies not meeting these criteria are listed as impaired and management strategies are then developed. After the initial stage control based on maximum pollutant concentrations in the late 1970s, total waste load control became a recognized
factor in some watersheds. The water quality objective for each of the streams and the hydrological information for a watershed can be used to determine the water environmental capacity or total waste load that can be discharged into the watershed without jeopardizing the water quality objectives. The total waste load allowed should be allocated to each province or even each city. This procedure follows the essential idea of the Total Maximum Daily Load (TMDL) control used in the United States (Chadderton et al. 1981; Yassuda et al. 2000).

Many social, economic and environmental factors are involved in total waste load control, which has become more and more complicated due to the economic blooming in China in recent years (Huang & Xia 2001). Although some studies have been conducted to evaluate waste load control methodologies (Rousseau et al. 2005; Cullum et al. 2006; Lee & Chung 2007), the pollutant reduction strategy most commonly used is equal to the percentage reduction for all of the pollution sources in all industries, and does not consider the effects of differences among industries on techniques, output values, energy consumption or scales. Therefore, a scientific and realizable pollution reduction strategy is urgently needed for the water management sector.

In this study, the differences in pollution generation and discharge among different industries were investigated to enhance the effects of environmental management. A waste load allocation method was then developed based on fairness and efficiency. The developed method involved the current waste load proportions in different industries, as well as their economic contributions. An industrial allocation factor was raised to calculate the waste load allocation proportion for different industries. This method was then applied to the ZWN watershed in northern China.

**METHODS**

**Calculation of water environmental capacity**

A one-dimensional water quality model was used to calculate the water environmental capacities in this study. This was because multi-dimensional water quality simulations are often complicated and contain many uncertainties due to the dynamic hydrodynamic conditions of river systems, meteorological processes and a shortage of available monitoring data (Revelli & Ridolfi 2004; Karmakar & Mujumdar 2006; Huang & Qin 2008). The water environmental capacity was calculated using Equation (1), which is as follows, using certain design flow parameters, present water quality conditions and objective water quality conditions:

$$M = Q_r \left[ C_s - C_0 \exp \left( -\frac{kL}{u} \right) \right] \exp \left( \frac{kL}{2u} \right) \tag{1}$$

where $M$ represents the water environmental capacity of a certain pollutant for a reach (g/s); $C_0$ is the objective concentration of the pollutant at the start of the reach according to the water quality goal at this point (mg/L); $C_s$ is the objective concentration of the pollutant at the end of each reach according to the water quality goal at this point (mg/L); $L$ is the length of the reach (m); $Q_r$ is the design flow rate (m$^3$/s); $u$ is the design flow velocity (m/s); $k$ is the degradation coefficient (1/s).

According to the national economic development plan, the indicators of the water waste load for gross control during environmental management of the ZWN are COD and NH$_3$-N (The State Council of the People’s Republic of China 2006); therefore, the water environmental capacities of these two parameters were chosen as examples for application of the waste load allocation method in this study.

**Calculation of unfairness factors and industrial allocation factor**

To quantify the difference in pollution discharge among industries and comprehensively determine the waste load allocation proportions, an industrial allocation factor was calculated for each industry. The unfairness factors of energy consumption, waste load and treatment cost were defined based on the definition of the green contribution coefficient (Lin et al. 2006; Wang et al. 2006) to describe the activities related to pollution in the industrial process. The unfairness factor of energy consumption represents the elements of energy and resources prior to the generation of pollution, while the unfairness factor of the waste load
represents the elements of pollution discharges and the unfairness factor of treatment cost represents the operation cost of the treatment facilities. For each unfairness factor, the profit proportion is incorporated to compare the relative economic contributions. These three unfairness factors are calculated using Equations (2–4), respectively, as described below.

**Unfairness factor of energy consumption**

The unfairness factor of energy consumption is the ratio of energy consumption by industry $j$ among all industries to its profit proportion.

$$U_{e,j} = \frac{C_{e,j}}{P_j} = \frac{c_{e,j}}{\sum_{j=1}^{n} P_j}$$  \hspace{1cm} (2)

where $U_{e,j}$ is the unfairness factor of energy consumption for industry $j$; $C_{e,j}$ is the energy consumption proportion of industry $j$ among all industries; $P_j$ is the profit proportion of industry $j$ among all industries; $c_{e,j}$ is the annual energy consumption of industry $j$ ($10^6$ ton of standard coal) (Zhao & Zhang 2007); $P_j$ is the value of profit of industry $j$ in a year ($10^8$ yuan) (Bureau of Statistics in Shandong, Shanxi, Henan and Hebei, China 2005); $n$ is the total number of all industries.

**Unfairness factor of waste load**

The unfairness factor of the waste load is the ratio of pollution discharge of industry $j$ among all industries for pollutant $i$ to its profit proportion.

$$U_{li,j} = \frac{L_{i,j}}{P_j} = \frac{l_{i,j}}{\sum_{j=1}^{n} P_j}$$  \hspace{1cm} (3)

where $U_{li,j}$ is the unfairness factor of the waste load of pollutant $i$ for industry $j$; $L_{i,j}$ is the waste load proportion of industry $j$ among all industries for pollutant $i$; $l_{i,j}$ is the annual waste load discharge of industry $j$ for pollutant $i$ ton per annum (t/a) (NBS and State EPA 2006).

**Unfairness factor of treatment cost**

The unfairness factor of the treatment cost is the ratio of the proportion of operation cost for treatment facilities of industry $j$ among all industries to its profit proportion.

$$C_j = \frac{O_j}{P_j} = \frac{o_j}{\sum_{j=1}^{n} P_j}$$  \hspace{1cm} (4)

where $C_j$ is the unfairness factor of operation cost for treatment facilities for industry $j$; $O_j$ is the proportion of operation cost of industry $j$ among all industries; $o_j$ is the annual operation cost for treatment facilities of industry $j$ ($10^4$ yuan RMB per year) (NBS and State EPA 2006).

Each unfairness factor represents the relative environmental unfriendliness extent of an industry compared to other industries. The larger these three factors are, the more unfriendly the industries are to the environment and economy. If an unfairness factor is less than 1 for an industry $j$, that industry is relatively friendly to the environment for the aspect represented by that factor.

The industrial allocation factor of each industry is determined by combining these three unfairness factors together as follows:

$$f_{i,j} = \alpha U_{e,j} + \beta U_{li,j} + \lambda C_j, \hspace{1cm} (j = 1, 2, 3, \ldots, n)$$  \hspace{1cm} (5)

where $f_{i,j}$ is the industrial allocation factor for pollutant $i$ in industry $j$; $\alpha$, $\beta$ and $\lambda$ are the weight coefficients of $U_{e,j}$, $U_{li,j}$ and $C_j$, respectively. The most basic situation is considered in this study, with $\alpha = \beta = \lambda = 1$.

**Principles of pollution discharge reduction**

**Primary pollution discharge reduction**

Initially, the water environmental capacity was primarily allocated among all industries based on the industrial allocation factor $f_{i,j}$. Equation (6) was used for this allocation:

$$LR1_{i,j} = \frac{f_{i,j}}{\sum_{j} f_{i,j}} \times (LC_i - EC_i)$$  \hspace{1cm} (6)

where $LR1_{i,j}$ is the primary discharge reduction of pollutant $i$ for industry $j$ (t/a); $LC_i$ is the discharge of pollutant $i$ by all industries (t/a); $EC_i$ is the water environmental capacity of pollutant $i$ (t/a).
The LR$_{1,j}$ values are the basis for the discharge reduction adjustment in the next step. Factors $f_{i,j}$, $U_{e,j}$, $U_{i,j}$, and $C_j$ show the justifiability of industry $j$ to the environment, economy, and society. All industries are then divided into three types according to values of the $f_{i,j}$, $U_{e,j}$, $U_{i,j}$, and $C_j$, and the pollution discharge reduction adjustment method is developed for each type of industry.

### Adjusted pollution discharge reduction

**Type I industry.** If the three unfairness factors $U_{e,j}$, $U_{i,j}$, and $C_j$ are all smaller than 1 and $f_{i,j}$ is smaller than 3 for industry $j$, then industry $j$ is reasonable and efficient in both economic and environmental aspects. Therefore, industry $j$ should be preferentially developed and low reduction discounts from 0 to 0.5 taken as shown in Table 1, where $r_{I,j}$ is the reduction discount that type I industry should use.

After adjustment by the reduction discount $r_{I,j}$, reduction loads for type I industries are calculated by the following equations:

$$LR_{\text{type I}} = r_{I,j} \times LR_{1,j}$$  \hspace{1cm} (7)  

$$LA_{\text{type I}} = LC_{i,j} - r_{I,j} \times LR_{1,j}$$  \hspace{1cm} (8)

where $LR_{\text{type I}}$ is the reduction load of pollutant $i$ from industry $j$, which is a type I industry (t/a); $LA_{\text{type I}}$ is the allowed discharge load of pollutant $i$ from industry $j$, which is a type II industry (t/a); $LC_{i,j}$ is the current discharge load of pollutant $i$ from industry $j$.

**Type II industry.** If the $f_{i,j}$ for industry $j$ is smaller than 3, but one or two unfairness factors are larger than 1, then the industry $j$ is reasonable in general, but inefficient with regards to certain aspects of energy, pollution or wastewater treatment. Therefore, industry $j$ could be developed to some extent, but greater attention should be paid to the inefficient aspects. Additionally, the pollution discharge should be reduced with certain reduction discounts.

After the primary allocation by Equation (6), the reduction loads for type II industries are adjusted by reduction discount $r_{II,j}$ as shown in Table 2. The reduction discount for type II industry is determined according to unfairness factors smaller than 1. If more than one unfairness factor is smaller than 1, then the prior order would be $U_{e,j}$, $U_{i,j}$, and $C_j$.

After being adjusted by the reduction discount $r_{II,j}$, reduction loads for type II industries can be calculated by Equations (9) and (10) as follows:

$$LR_{\text{type II}} = LR_{1,j} \times LR_{1,j}$$  \hspace{1cm} (9)  

$$LA_{\text{type II}} = LC_{i,j} - LR_{1,j} \times LR_{1,j}$$  \hspace{1cm} (10)

where $LR_{\text{type II}}$ is the reduction load of pollutant $i$ from industry $j$, which is type II industry (t/a); $LA_{\text{type II}}$ is the allowed discharge load of pollutant $i$ from industry $j$, which is type II industry (t/a).

Different discounts for reduction are weighted to type I and type II industries which are determined by reference the ideas of previous research by Wei & Ma (2009) on environmental taxes. This is because, according to the results of the unfairness factors, type I industry is fairer than type II industry with respect to environmental and economic aspects. As a result, type I industries should be encouraged over type II industries. Due to larger discount proportions, type I industries attain smaller values of reduction discounts and therefore require a lower reduction in waste than type II industries; therefore, industries could be encouraged to be more fair.

**Type III industry.** If $f_{i,j}$ is larger than 3, then industry $j$ is non-economic and environmentally unfriendly for pollutant $i$, regardless of whether the unfairness factor is smaller or larger than 1. Therefore, more attention should be paid to

### Table 1 | Reduction discounts for type I industry for pollutant $i$

<table>
<thead>
<tr>
<th>Type I industry</th>
<th>$r_{I,j}$</th>
<th>$r_{II,j}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–1.00</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>1.01–1.50</td>
<td>0.25</td>
<td>0.6</td>
</tr>
<tr>
<td>1.51–2.50</td>
<td>0.5</td>
<td>0.7</td>
</tr>
</tbody>
</table>

### Table 2 | Reduction discounts for type II industry for pollutant $i$

<table>
<thead>
<tr>
<th>Type II industry</th>
<th>$r_{II,j}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.30–0.70</td>
<td>0.5</td>
</tr>
<tr>
<td>0.71–1.00</td>
<td>0.6</td>
</tr>
</tbody>
</table>

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industry $j$ during total waste load control. Additionally, the discharge of pollutant $i$ from industry $j$ should be greatly reduced.

When the reduction discount $r_{ij}$ and $r_{II,j}$ for type I and type II industries are used, the reduction loads from type I and II industries are far lower than the primary allocation loads calculated by Equation (6). Type III industry will be responsible for the remaining reduction load as shown in Equation (11):

$$LR_i \sum_{type\, III} = (LC_i - EC_i) - \sum_{j(type\, I-II)} LR_{ij}$$

(11)

$$LA_i \sum_{type\, III} = EC_i - \sum_{j(type\, II)} LA_{ij} - \sum_{j(type\, II)} LA_{ij}$$

(12)

where $LR_i \sum_{type\, III}$ is the total reduction load of pollutant $i$ that should be reduced by type III industries (t/a); $\sum_{type\, III} LA_{ij}$ is the allowed discharge load of pollutant $i$ from type III industries (t/a). This enables the allowed discharge load and reduction load from distinct industry $j$ from type III industries to be calculated using the following equations:

$$LA_{ij} = \frac{1}{f_{ij}} \times \sum_{(type\, III)} LA_{ij}$$

(13)

$$LR_{ij} = LC_{ij} - LA_{ij}$$

(14)

**Watershed characteristics**

The Zhangweinan Watershed (ZWN) is located in north China, and includes five primary rivers, 15 cities and more than 70 counties. Water bodies in this basin have been seriously polluted due to the large amount of industrial and municipal wastewater discharges. Based on the 1,794 km of streams in this watershed, 77% of the river has been seriously polluted and has a water quality worse than class V (the worst class in the standards). The primary pollutants were COD, NH$_3$-N and oils. The total amount of wastewater discharged into this watershed was 828,000,000 tons in 2004, while the total COD and NH$_3$-N discharged into this watershed were 242,000 tons and 17,600 tons, respectively, in 2004 (Zhangweinan Canal Management Agency 2006).

All of the statistics and calculations conducted in this study are based on data collected from 2004. The data describing the waste load from different industries was obtained from a baseline survey report conducted by the Zhangweinan Canal Management Agency 2006. The data describing the energy consumption were from the Yearbook of Chinese Energy 2005–2006 (Zhao & Zhang 2007) and the treatment cost data were obtained from the China Statistical Yearbook on the Environment for 2006 (NBS and State EPA 2006). All of these data are normalized for each industry; therefore, they can be used comprehensively.

**RESULTS AND DISCUSSION**

**Water environmental capacity of the ZWN**

The water environmental capacities of the COD and NH$_3$-N in the ZWN watershed were calculated using Equation (1) in a previous study conducted by Qiu et al. (2009). All rivers in the watershed were divided into reaches. According to the objective water qualities at the start and end of each reach, water environmental capacities of each reach were calculated individually and then summarized together. The parameters used in the basic equation have been explained in the Methods, and all calculations were conducted using Microsoft Excel. The results of the water environmental capacities were 30,411 t/a for COD and 1,433 t/a for NH$_3$-N, respectively.

**Industrial allocation factor of the ZWN**

Based on the classification of national and provincial economic reports, the main industries in the ZWN can be classified as the extractive industry, metallurgical industry, mechanical industry, chemical industry, food industry, thermal and pyroelectric industry, oil and pyrogenic industry, paper industry, pharmaceutical industry and textile industry. These ten industries account for 88% of the profit in this watershed (Zhangweinan Canal Management Agency 2006). The remaining industries are grouped together as other industry. The energy consumption, pollution discharge and pollution treatment costs associated with these industries differ greatly, as shown in Figure 1.

As shown in Figure 1, the COD and NH$_3$-N waste loads per unit of profit were greatest for the paper industry and
The chemical industry. This was due to the large amount of wastewater they discharge, as well as the high concentrations of pollutants they contain. Furthermore, the wastewater treatment cost per unit of profit from the thermal and pyroelectric industry was the highest. The industrial allocation factor $f_{i,j}$ in ZWN determined based on the relative energy consumption, waste load and treatment cost for different industries is shown in Figure 2.

As shown in Figure 2, the values of the industrial allocation factors vary greatly among industries. Specifically, the paper, chemical and oil and pyrogenic industries are the most environmentally unfriendly industries, while the extractive, mechanical and food industries are the most environmentally friendly. In addition, the proportions of the three unfairness factors for different industries vary and each industry has its own most unreasonable aspect reflected by its largest unfairness factor. For example, the most unreasonable aspect of paper industry is its heavy waste pollution; as to chemical industry, the high energy consumption is the most unfair aspect. Finally, approximately half of the industrial allocation factors are greater than 3; therefore, they are classified as type III industries and should take more action to reduce pollution.

Total waste load allocation in the ZWN

The total waste load reduction for COD and NH$_3$-N are the gaps between pollution discharges and water environmental capacities, which are 87 and 92% of the pollution discharges for COD$_{Mn}$ and NH$_3$-N, respectively. Using the unfairness factors and industrial allocation factors calculated above, the total waste load reduction for COD and NH$_3$-N are distributed to different industries as follows described below.

Figure 1 | Energy consumption, waste load of COD and NH$_3$-N, and pollutant treatment cost per unit of profit in the ZWN in 2004 (Me.: Metallurgical; Th. and Py.: Thermal and pyroelectric; Ph.: Pharmaceutical; Oil and Py.: Oil and pyrogenic).

Figure 2 | Industrial allocation factor $f_{i,j}$ for different industries in the ZWN.
For type I industries

Based on the calculated values of the unfairness factors $U_{e,i}$, $U_{l,i}$, and $C_j$ and the industrial allocation factor $f_{ij}$, the extractive, mechanical, and food industries belong to type I industry. The adjusted reduction loads of the industries in $LR_{e,j}$ are shown in Table 3. The three type I industries are responsible for 3,711 and 300 t/a of the reduction loads for COD and NH$_3$-N, respectively, in the ZWN, which accounts for 1.7 and 1.9% of the total waste load reduction.

For type II industries

For the metallurgical and other industries, the industrial allocation factors of COD and NH$_3$-N were smaller than 3, while for the thermal and pyroelectric industry, $f_{NH3-N, Th}$ and $f_{Py}$ is smaller than 3 and $f_{COD, Th}$ and $f_{Py}$ is larger than 3. The adjusted reduction loads $LR_{e,j}$ are shown in Table 4. The type II industries are responsible for 14,303 and 662 t/a of the reduction loads for COD and NH$_3$-N, respectively, in the ZWN, which account for 7 and 4% of the total waste load reduction.

For type III industries

Deducting the adjusted reduction loads of type I and type II industries from the total objective waste load reduction revealed that the remaining allowed waste loads for COD and NH$_3$-N were only 13,874 t/a and 490 t/a, respectively and the remaining reduction loads were 194,053 t/a for COD and 15,204 t/a for NH$_3$-N. Each of these remaining loads will be allocated among type III industries, as shown in Figure 5. The paper industry and chemical industry are responsible for large proportions of the reduction loads, which were 89 and 83% of the total reduction loads for COD and NH$_3$-N, respectively.

Implementation of the allocation method

The purpose of this study was to develop a method of distributing the waste load among different industries, which will be used in environmental management. At this time, this study focused on the optimal environmental conditions. We propose a method for the optimal reduction of wastes, but for different regions or watersheds officers and enterprises can determine specific levels of environmental qualities they wish to attain and then determine which suggested weight reductions they wish to employ based on their own economic, social and environmental conditions. Additionally, a long period of time is required to reach the suggested optimal reduction in waste; therefore, officers and enterprises can develop specific targets for different stages and sections.

As shown in Figure 4, LC represents the current waste load discharge amount, LS represents the stage at which all outlets in the ZWN watershed that discharge wastewater meet the relevant wastewater discharge standards and EC represents the environmental capacity. It is obvious that if one or several stages are inserted between the current stage and the optimal condition, the reduction burden for each stage can be lightened and the target in each stage will become clearer. Additionally, officers and enterprises can develop specific targets for different stages and sections.

The allocated reduction load may be partially achieved by enhancing the technologies employed to product line and wastewater treatment. Taking the paper industry as an example, the common COD concentration of the treated paper wastewater using anaerobic technology is about 100–150 mg/L (Zhang 2008). However, using artificial wetland technology, which has been studied in other

### Table 3 | Adjusted reduction loads for type I industries

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Industry</th>
<th>$r_{ij}$</th>
<th>$LR_{e,j}$ (t/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD$_{Mn}$</td>
<td>Extractive</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Mechanical</td>
<td>0.25</td>
<td>931</td>
</tr>
<tr>
<td></td>
<td>Food</td>
<td>0.5</td>
<td>2,780</td>
</tr>
<tr>
<td>NH$_3$-N</td>
<td>Extractive</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Mechanical</td>
<td>0.25</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>Food</td>
<td>0.5</td>
<td>224</td>
</tr>
</tbody>
</table>

### Table 4 | Adjusted reduction loads for type II industries

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Industry</th>
<th>$r_{ij}$</th>
<th>$LR_{e,j}$ (t/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD$_{Mn}$</td>
<td>Me.</td>
<td>0.5</td>
<td>4827</td>
</tr>
<tr>
<td></td>
<td>Th. and Py.</td>
<td>0.6</td>
<td>6053</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>0.5</td>
<td>3423</td>
</tr>
<tr>
<td>NH$_3$-N</td>
<td>Me.</td>
<td>0.5</td>
<td>387</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>0.5</td>
<td>275</td>
</tr>
</tbody>
</table>
countries since the 1990s, the COD concentration can be reduced to 30 mg/L (Qiao et al. 2003). By using advanced technologies, the pollutant discharge can be greatly reduced.

Conversely, these allocated reduction loads are difficult to achieve if no industrial restructuration is undertaken. According to the Monthly Report of Paper Industry Operation in China, Jan. and Feb. 2008 (State Information Center 2008), large scale paper enterprises account for about 40% of the profits of the entire paper industry. This is because large scale enterprises can produce better quality paper using advanced techniques. Additionally, large scale enterprises can lead to cleaner production lines, advanced wastewater treatment systems and material recycling systems, which will greatly reduce the energy and environmental consumption. However, small scale enterprises do not have these advantages. A similar situation is evident for the chemical industry. Currently, middle scale and small scale enterprises are dominant in paper and chemical industries in China. By restructuring these middle to small scale enterprises into large scale enterprises, efficient and clean production techniques can be promoted and a large amount of pollution reduction can be achieved. This study was based on watershed management; therefore, the tasks for enterprises and relevant stakeholders should be allocated administratively. In addition, encouragement or incentives are necessary to induce enterprises to implement pollution reduction requirements. Accordingly, some
economic or administrative rules can be implemented to promote the competitiveness and reputation of those enterprises that strictly implement reduction plans.

CONCLUSIONS

A waste load allocation method for various industries was developed in this study. Instead of simply allocating the waste load proportionally to the current pollution load contributions, three unfairness factors, $U_{e,j}$, $U_{i,j}$, $C_j$, and an industrial allocation factor, $f_{i,j}$, were proposed. These factors were used to evaluate the energy consumption, pollution discharge, pollution treatment costs and the overall effects of different industries. According to the calculation results of the industrial allocation factor, industries are classified into three types: type I industries should reduce pollution discharge with lower discounts; type II industries should reduce pollution discharge with more discounts; type III industries should be responsible for most of the pollution discharge reductions.

In the ZWN, extractive, mechanical and food industries belong to type I industry and their waste reductions are reduced with low discounts of 0, 0.25 and 0.5, respectively. The metallurgical industry and other industries are categorized as type II industry and discounts of 0.5 and 0.6 are given to their primary reductions. The allocation factors of chemical, oil and pyrogenic, paper, pharmaceutical and textile industries are larger than 3; therefore, they are classified as type III industry. The pollution reduction allocated to type III industries accounts for 80 and 86% of the industrial pollution discharge of COD and NH$_3$-N in 2004.

This waste load allocation method is not only useful in environmental management, but also in other areas, such as the control of non-point sources and for providing comprehensive administrative managements. For example, for non-point source pollution control, the unfairness factors could be defined to represent the toxicity, degradation time of contaminations, and so on. The industrial profit contribution might be replaced by capita GDP of a region or a city. Then the allocation factor could mean the different proportions of reduction load for different type of non-point sources such as pesticides, urban runoff from roofs and road surfaces. In addition, this method can be used for scales ranging from single enterprises to the national level. Therefore, this method is very useful and may be widely applied.

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