Available online at www.sciencedirect.com
ScienceDirect
Journal of Environmental Sciences 2010, 22(6) 904–907
JOURNAL OF ENVIRONMENTAL SCIENCES
ISSN 1001-0742
CN 11-2629/X
www.jesc.ac.cn

Parameter determination to calculate water environmental capacity in Zhangweinan Canal Sub-basin in China

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Received 02 October 2009; revised 07 January 2010; accepted 09 January 2010

Abstract

Zhangweinan canal sub-basin (ZWN) has the most serious water resource shortage and water pollution problems in north of China. To calculate the water environmental capacity in ZWN, determination methods for design flow rates and degradation coefficients were discussed in this study. Results showed that 90% and 50% hydrological guarantee flow rates were suitable to be the design flow rates for rainy and dry seasons, respectively. Degradation coefficients of COD_{Mn} and NH_3-N were 0.25 day^{-1} and 0.15 day^{-1} for branch streams and 0.5 day^{-1} and 0.25 day^{-1} for mainstreams, respectively in ZWN. With one-dimensional water quality simulation model, water environmental capacities were calculated to be 82,139 tons/yr for COD_{Mn} and 2394 tons/yr for NH_3-N in ZWN.

Key words: degradation coefficient; design flow rate; water environmental capacity; Zhangweinan

DOI: 10.1016/S1001-0742(09)60196-0

Introduction

More and more municipal and industrial wastewater has been discharged with the blooming economy and the quick civilization in China in recent two decades, which has caused serious water pollution problems (Li et al., 2008; Xiang et al., 2010). Water quality at 45% of the 409 monitored sections in the major seven watersheds in China was class IV to V or even worse in 2008 (MEPC, 2009). Therefore, pollution control is becoming an urgent issue and will greatly support the sustainable development of the society and economy (Keller and Cavallaro, 2008).

Pollution gross control is adopted by the environmental protection departments in China in recent years and proved to be an effective way for water environment pollution management. As the base of pollution gross control, calculation of water environmental capacity plays the most important role. Water environmental capacity has the same concept as total maximum daily load (TMDL), which is defined to be the maximum amount of a pollutant that a waterbody can receive and still safely meet water quality standards (Zhang and Liu, 1991; USEPA, 2008). Usually it is difficult to use complex models for water quantity and quality simulation in practice on account of the lack of long-term hydrological and water quality data for most watersheds in China (Yu, 2007). To calculate water environmental capacity based on limited amount of monitored data, simple and proper water quality simulation model is needed. In addition, it is important to investigate different methods for water quality parameter determination when calculating water environmental capacity.

Design flow rate is one of the most important parameters to calculate water environmental capacity. Different methods are often used to determine design flow rates for different rivers. For most rivers in north of China, 90% guarantee flow rate is often zero and environmental capacity can not be calculated in this situation. Therefore, 75% guarantee flow rate, average flow rate in dry season, and long term average flow rate are often used to be the design flow rate (CAEP, 2003). However, long term hydrological data are very limited and confidential in China, therefore, it is still difficult to calculate design flow rate in this way. In many cases, similar rivers are often given the same design flow rates.

In this study, design flow rates of reaches in different functional districts were calculated with different methods and one proper method was selected for water environmental capacity calculation. Different pollutant degradation coefficients were used to calculate water environmental capacity and proper pollutant degradation coefficients were chosen. Finally, appropriate design flow rates and pollutant degradation coefficients were determined and used to calculate water environmental capacity in Zhangweinan canal sub-basin (ZWN).

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1 Methods

1.1 Study area

Zhangweinan canal sub-basin (ZWN) is located in the south of Hai River Basin and it consists of five primary rivers, 13 cities and more than 70 counties. Total area of this sub-basin is 37,700 km^2. It covers part of four provinces including Shanxi, Henan, Hebei, and Shandong and one municipality Tianjin.

ZWN has the most serious water resource shortage and water pollution problems in north of China. The average water resource per capita in this sub-basin is only 240 m^3. Downstream reaches often dry up for more than 100 days each year. The flow rate of many mainstreams is only between 0.03 and 0.5 m^3/sec due to the work of reservoirs and dams at upstreams. Meanwhile, this sub-basin is among the most seriously polluted water sheds in China. Of the major 11 control sections in this sub-basin, 10 have water qualities worse than class V. The primary pollutants include COD_{Mn}, NH_3-N and oils (GEF Hai River Project Office of Zhangweinan Canal Management Agency, 2006).

1.2 Water environmental capacity calculation

In this study, one-dimensional water quality model is chosen to simulate pollutant degradation in the rivers. All the wastewater discharged into one reach is considered to be one point source located at the center of the reach. Then pollutant degradation of this source occurs within half of this reach. Based on the one-dimensional convection equation (Yu et al., 2008), water environmental capacity is calculated using Eq. (1):

$$M = Q_r(C_s - C_0 \exp(\frac{-kL}{u})) \exp(\frac{kL}{2u}) \quad (1)$$

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

In order to determine proper design flow rate Q_r for water environmental capacity calculation, three Q_r calculation methods are investigated as follows:

(1) With the long-term hydrological data, 90% hydrological guarantee flow rate is calculated and set to be the design flow rate. If this value is zero, the smallest monthly flow rate in recent decades will be taken. This is a common method to determine design flow rate when long-term hydrological data are available. If long-term hydrological data are not available, design flow rate will be determined by using experienced values of similar rivers in north China. For example, for branch streams of low flow rate rivers, 0.1 times of the mainstream flux is used to be the design flow rate; for branch streams of high flow rate rivers, 0.25 to 0.5 times of the mainstream flux is used to be the design flow rate.

(2) Since there are many dams in ZWN, the rivers lose most of the nature conditions except in the rainy season. According to the baseline survey data (GEF Hai River Project Office of Zhangweinan Canal Management Agency, 2006), 70% of the annual precipitation happens in the rainy season in ZWN. Therefore, for those functional districts where long-term hydrological data are available, 70% hydrological guarantee flow rate is used as design flow rate (Wang, 2007). For those functional districts where there are no long-term data, 0.1 m^3/sec is used for branch streams of low flow rate rivers and 0.25 to 0.5 times of the mainstream flux is used for branch streams of high flow rate rivers. For headwaters of mainstreams, the design flow rate is determined to be 1.5 times of the design flow rate of mainstreams. The reason for this is the existence of water extraction and ground water infiltration on the way.

(3) Because flow rate is significantly different between in rainy season and in dry season in ZWN, the environmental capacity can be calculated separately for the two periods, rainy season and dry season. According to the water environmental capacity calculation given by the China Academy of Environmental Planning (CAEP, 2004), for rivers in north of China, 50% guarantee flow rate can be considered to calculate the design flow rate for water environmental capacity. Therefore, for the rainy season, 90% hydrological guarantee flow rate is used as design flow rate. For the dry season, 90% hydrological guarantee flow rate for most rivers is zero, 50% guarantee flow rate is set to be design flow rate in dry season. It is a reasonable method to determine design flow rate when flow rate in rainy season and dry season is quite different.

The pollutant degradation coefficients in ZWN are determined according to certain previous studies on degradation coefficients of several rivers in north of China (MWRC, 2002). Experience k_{COD} is set to be 0.25 day^{-1} for branch streams and 0.5 day^{-1} for mainstreams; experience $k_{NH_3\text{-}N}$ is set to be 0.15 day^{-1} for branch streams and 0.25 day^{-1} for mainstreams. With proper design flow rate, 20%, 100% and 200% of the experience degradation coefficients are used to calculate environmental capacities. This variance range is chosen according to the previous study showing that degradation coefficient of COD_{Mn} is generally in the range of 0.05–0.8 day^{-1} (CAEP, 2003).

Design flow velocities are determined in two ways. (1) If the cross section area data are available for a river, level-flux and level-area curves can be plotted. Then design flow velocity can be calculated according to the water level and area at a design flow rate. (2) For data-lack rivers, experience formula provided by Yang Baicheng is used as $u = 0.29Q_r^{0.33}$ (Yang and Li, 2002).

Environmental capacities of COD_{Mn} and NH_3-N calculated with different methods are compared with the environmental capacities reported in the Baseline Investigation Report of Zhangweinan Canal Sub-basin (GEF Hai River Project Office of Zhangweinan Canal Management Agency, 2006). The comparison results are shown in the following part.

2 Results and discussion

2.1 Influence of design flow rate

Design flow rate is calculated with three methods for different reaches in ZWN and the maximum, minimum and average design flow rates are shown in Fig. 1. Figure 1 indicates that the calculated design flow rate is quite different using different methods. At the same time, the design flow rate varies a lot for different rivers in the basin even with the same calculation method. Design flow rate determined by the third method is the highest on average. The average calculated design flow rates are close to or less than 5 m^3/sec, which greatly limit the environmental capacity of this sub-basin.

Environmental capacities of COD_{Mn} and NH_3-N are calculated with different design flow rates and the results are shown in Fig. 2. The environmental capacity reported in the baseline survey report (GEF Hai River Project Office of Zhangweinan Canal Management Agency, 2006) is also shown in Fig. 2. Results illustrate that design flow rate plays an important role in the calculating environmental capacity. For environmental capacity of COD_{Mn}, design flow rate of 90% hydrological guarantee flow rate is the most optimistic way to calculate environmental capacity. The environmental capacity calculated in this way is 2.4 times as large as the capacity reported in the baseline survey report. On the contrary, it is the most conservative way to calculate environmental capacity of NH_3-N, which has the greatest discrepancy from the baseline capacity and is only 64% as large as the baseline capacity. The results calculated with the third method are closest to the baseline values. The environmental capacities of COD_{Mn} and NH_3-N are 1.46 times and 0.93 times as large as the baseline capacities, respectively. The results obtained by the second method are better than that using the first method but worse than that using the third method. Therefore, the third method is chosen to calculate design flow rate for water environmental capacity calculation in ZWN.

2.2 Influence of degradation coefficients

To investigate how degradation coefficients affect the environmental capacities, 20%, 100%, 200% of the experience degradation coefficient values are used as minimum, default, and maximum values. Design flow rate determined with the third method is used.

Figure 3 demonstrates environmental capacities of COD_{Mn} and NH_3-N calculated with different degradation coefficient values. Figure 3 shows that environmental capacities calculated with the experience values are closer to the baseline survey results. Therefore, the default experience value is appropriate to calculate the water environmental capacity of ZWN.

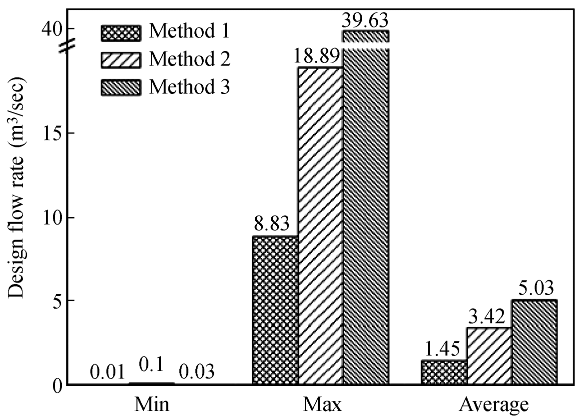

Fig. 1 Results of design flow rates determined with the three methods.

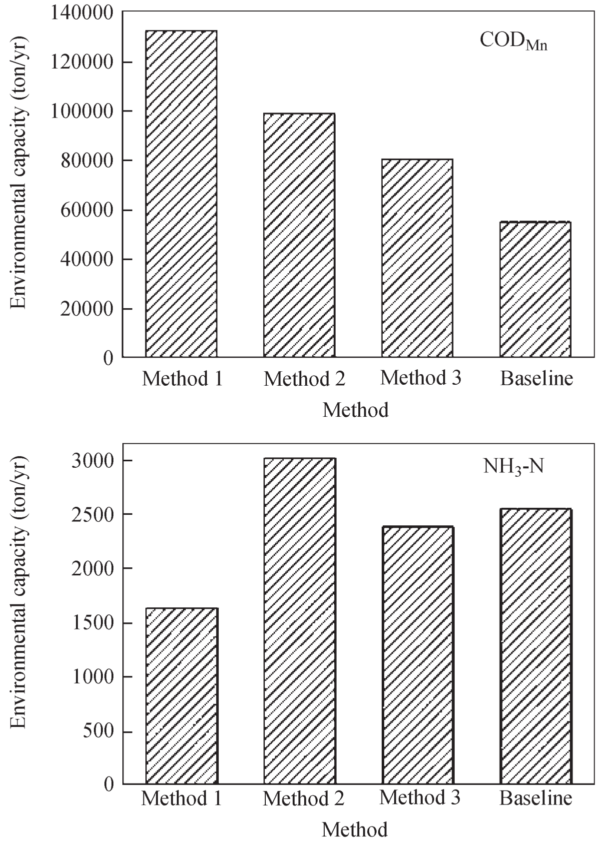

Fig. 2 Environmental capacities calculated with the three methods.

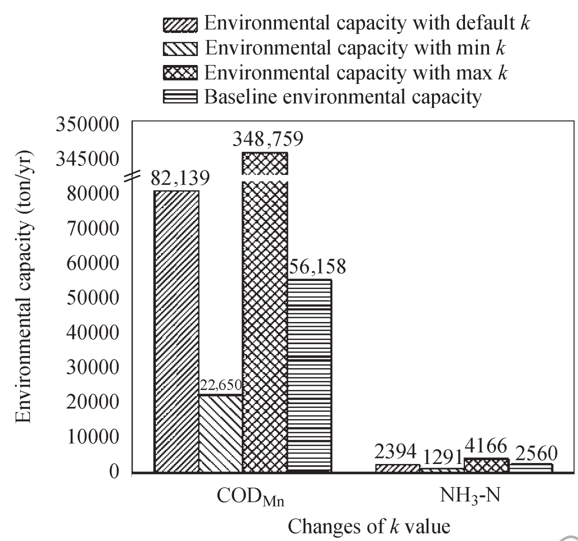

Fig. 3 Environmental capacities calculated with different degradation coefficients.

2.3 Water environmental capacities

According to the study above, the design flow rate determined by the third method and the experience degradation coefficients are appropriate to calculate the water environmental capacity of COD_{Mn} and NH_3-N in ZWN. The calculated water environmental capacities in this basin are 82,139 tons/yr for COD_{Mn} and 2394 tons/yr for NH_3-N, which are 1.46 and 0.94 times as much as the baseline environmental capacities, respectively.

Both design flow rate and degradation coefficient have great influence on water environmental capacity calculation, which is very important for social and economic regional planning. A higher environmental capacity indicates a greater tolerance on pollution input and more room for social and economic development. A balance point is needed between environment and social and economic development and environmental capacity can be a good indicator. Environmental capacity calculation method discussed in this study can be a good reference for other regions.

3 Conclusions

Different methods to calculate design flow rate and degradation coefficient are discussed in this study. For the rainy season and dry season, 90% and 50% hydrological guarantee flow rates are proper to be used as design flow rates respectively. Experience degradation coefficients are good to calculate the environmental capacity of ZWN. The calculated environmental capacities are 82,139 tons/yr for COD_{Mn} and 2394 tons/yr for NH_3-N, respectively.

The method to determine design flow rate by rainy season data and dry season data is suitable for basins with obvious seasonal precipitation difference. For basins without seasonal precipitation difference, which method is best, needs further investigation. Besides, although the experience degradation coefficients are appropriate in this study, more monitoring work on degradation coefficient needs to be done to enhance the accuracy of water environmental capacity calculation. Appropriate environmental capacity determination for basins is quite important for all of the basins in China since all of the basins are overwhelmed by various pollutants. This is the first and most important step for the local government to make decision on regional pollution reduction. The results in this study are of great value for environmental capacity calculations in other basins.

Acknowledgments

This research is supported by the National Basic Research Program (973) of China (No. 2006CB403303), the Grand Special Science and Technology Project on National Water Pollution Management (No. 2008ZX07209-009) and the National Natural Science Foundation for Young Scholars (No. 50809006).

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