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Quantitative calculation model of dilution ratio based on reaching standard of water function zone

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Abstract. Dilution ratio is an important indicator of water quality assessment, and it’s difficult to calculate quantitatively. This paper proposed quantitative calculation model of dilution ratio based on the permissible pollution bearing capacity model of water function zone. The model contains three parameters of concentration. Particularly, the 1-D model has three river characteristics parameters in addition. Applications of the model are based on the national standard of wastewater discharge concentration and reaching standard concentration. The results show the inverse correlation between the dilution ratio and the $C_p$ and $C_0$, and the positive correlation with $C_s$. The quantitative maximum control standard of dilution ratio is 12.50% by 0-D model and 22.96% by 1-D model. Moreover, we propose to choose the minimum parameter and find the invalid pollution bearing capacity.

1 Introduction

Dilution ratio (ratio of waste water to runoff) can be used for evaluating water quality, calculating the local water resources sustainable capacity, evaluating the sustainable development of the region, etc [1][2].

However, determination on the reasonable value of the ratio is difficult, particularly, integrated quantity-quality assessment of available water resources in water function zone. The reason is that different water quantity, quality, pollutant capacity, concentration, and reaching standard, etc comprehensively influenced the dilution ratio [3]. Qiang Huang [1] improves the dilution-ratio calculation method and its way for successful application. Their results could be better convinced if they constructed unified model based on water function zone.

Water function zone is the basis for water resources development and protection. The “Code of practice for computation on permissible pollution bearing capacity of water bodies” was based on reaching standard of water function zone [4].

This paper we preliminarily focus on the quantitative calculation model of dilution ratio based on reaching standard of permissible pollution bearing capacity of water function zone.

2 Models

In this paper, the dilution ratio model is generally designed by the identity of following equation at the pollution discharge section.
\[ M = C_p Q_p \]  
\[ \text{Where, } M \text{ is the capacity on reaching standard of water function zone (g/s), whose models are from} \]
\[ \text{the “Code of practice for computation on permissible pollution bearing capacity of water bodies”.} \]

The types of the dilution ratio model are divided by the dimension and the section. Zero dimensional model is simpler than one dimensional model. Three types of the 1-D model are divided by different discharge section and standard section.

2.1 0-D model
Zero dimensional model is suitable for the rivers whose stream has uniform mixing contamination. The formula of pollutant concentration is given below:
\[ C = (C_p Q_p + C_0 Q)(Q + Q_p) \]  
\[ \text{Where, } C : \text{ pollutant concentration in discharge section (mg/l); } \]
\[ C_p : \text{ pollutant concentration in sewage outfall section (mg/l); } \]
\[ C_0 : \text{ initial concentration in upper section (mg/l); } \]
\[ Q : \text{ initial flow of upstream (m}^3/\text{s); } Q_p : \text{ sewage discharge of outfall (m}^3/\text{s).} \]

Focus on the reaching standard of water function zone, the identical equation is as follows:
\[ C_s = C \]  
\[ \text{Where, } C_s \text{ is concentration of reaching standard in mixing section (mg/l).} \]

By Formula 1 and Formula 2, the quantitative dilution rate model can be derived as below:
\[ \frac{Q_p}{Q} = \frac{C_s - C_0}{C_p - C_s} \]  

2.2 1-D model
One dimensional model is suitable for the rivers whose cross-section with uniform mixing contamination.

The 1-D model needs to consider the location combination of the reaching standard section and the discharge section. The model is divided into three categories according to the combination of different position of sections, namely, sections in the same position, discharge in middle section and standard section in lower, existed outfall and sections in the same position.

2.2.1 All sections in lower or medium. The capacity model refers to the same code in the last section of this paper.
\[ M = C_s (Q + Q_p) - C_0 \exp(-K \frac{L}{u})Q \]  
\[ \text{Where, } L \text{ is the length of river (m); } K \text{ is the degradation coefficients(s}^{-1}); u \text{ is velocity of river(m/s).} \]

By Formula 1 and Formula 5, the model also can be derived as below:
\[ \frac{Q_p}{Q} = \frac{C_s - C_0 \exp(-K \frac{L}{u})}{C_p - C_s} \]  

If all sections in medium of the function zone, the model is same as Formula 6,
\[ \frac{Q_p}{Q} = \frac{C_s - C_0 \exp(-K \frac{L}{2u})}{C_p - C_s} \]  

2.2.2 Discharge in middle section and standard section in lower. The capacity model is as follows:
\[ M = C_s \exp(K \frac{L}{2u})(Q + Q_p) - C_0 \exp(-K \frac{L}{2u})Q \]  

By Formula 1 and Formula 8, the model also can be derived as below:
\[ Q_p = \frac{C_s \exp(K \frac{L}{2u}) - C_0 \exp(-K \frac{L}{2u})}{C_p - C_s \exp(K \frac{L}{2u})} \]  

(9)

Furthermore, in order to compare with the Formula 9, we propose a new way to the model. As the capacity of lower section, the value of the Formula 1 is 0, so we can get:

\[ M = C_s (Q + Q_p) - C_0 \exp(-K \frac{L}{u})Q - C_p \exp(-K \frac{L}{2u})Q_p = 0 \]

(10)

And the follow model is essential as well as Formula 9:

\[ \frac{Q_p}{Q} = \frac{C_s - C_0 \exp(-K \frac{L}{u})}{C_p \exp(-K \frac{L}{2u}) - C_s} \]

(11)

2.2.3 Existed outfall. In this section, we focus on the special conditions that a sewage outfall was in the middle section, so how much can the pollution bear permissibly in the lower section to reaching standard.

This paper defined the basic assumptions to the pollutants, with two parameters of \(C_{p0}\) (mg/l), and \(Q_{p0}\) (m³/s), so the capacity model modified is as follows:

\[ M = C_s (Q + Q_{p0} + Q_p) - C_0 \exp(-K \frac{L}{u})Q - C_{p0} \exp(-K \frac{L}{2u})Q_{p0} \]

(12)

Also with Formula 1, we derive the model as follows, too:

\[ \frac{Q_p}{Q} = \frac{C_s - C_0 \exp(-K \frac{L}{u}) + \frac{(C_s - C_{p0} \exp(-K \frac{L}{2u}))Q_{p0}}{Q}}{C_p - C_s} \]

(13)

Essentially, the Formula 13 is the same as the Formula 6. The differences are the value of initial concentration and the effective degradation distance.

2.3 Summary

The basic structure of the quantitative model is like the Formula 4, with three parameters of concentration and characteristics of river, such as \(L, K, u\) in the 1-D model. However, all the models have the unreasonable assumptions: 0-D model has the mixing in the whole stream and 1-D model has the mixing in the whole section of the contamination.

The quantitative model indicates that the ratio is independent of stream flow (Q). But in fact, the other influencing factors of 1-D model, such as \(K\) and \(u\), were affected indirectly by Q.

3 Result and discussion

This paper assumes that all the sewage is reaching the standard of discharge through the sewage treatment plant. Table 1 shows the different levels of emission values from the simplified code of “Discharge standard of pollutions for municipal wastewater treatment plant” (GB 18918—2002). The reaching standard of water function zone is decided by the standard of “Environmental quality standards for surface water” (GB3838-2002).

### Table 1. The national standard for wastewater discharge guideline, highest emission concentration  
(unit: mg/L)

| No. | Parameter | First grade | Second grade | Third grade |
|-----|-----------|-------------|--------------|-------------|
|     |           | First A     | First B      |             |

3
The performance of the 0-D model was investigated at different COD standard concentration. Table 2 shows that the minimum of the ratio is 12.5% by the class II (water quality standard, 15mg/L), First grade- B (discharge standard, 60mg/L), and class III (reaching standard, 20mg/L). And the maximum of the ratio is 33.33%, by the class III (water quality standard, 20mg/L), Second grade (discharge standard, 100mg/L), and class V (reaching standard, 40mg/L). The type of the discharge combinations were met the requirements of the discharge standard. The result clearly confirm that the dilution ratio has inverse correlation relationship with \( \frac{CP}{Cu} \). Contrary, there is a positively correlated between the ratio and \( Cs \).

**Table 2.** Percentage of dilution of 0-dimension model (unit: mg/L)

| Grade | Value | Grade | Value | Grade | Value | Percentage |
|-------|-------|-------|-------|-------|-------|------------|
| III   | 20    | II    | 15    | First A | 50   | 16.67%     |
| III   | 20    | II    | 15    | First B | 60   | 12.50%     |
| IV    | 30    | II    | 15    | Second | 100  | 21.43%     |
| IV    | 30    | III   | 20    | Second | 100  | 14.29%     |
| V     | 40    | III   | 20    | Second | 100  | 33.33%     |
| V     | 40    | IV    | 30    | Second | 100  | 16.67%     |

Table 3 indicates that the three parameters of COD, BOD and \( \text{NH}_4\text{-N} \) has different dilution ratio in the same conditions. The reason for the different value is that the national standard value of each parameter is different and disproportionate. Thus, generally, we propose to choose the minimum as the emission standard, so it leads to some parameters which exist invalid pollution capacity [5] [6].

**Table 3.** Percentage of dilution of different water quality parameters of 0-dimension model (unit: mg/L)

| C\(_S\) | C\(_0\) | C\(_p\) | Q\(_b/Q\) |
|--------|--------|--------|-----------|
| COD    | III    | II     | First B   | 100%      |
| BOD    | 4      | 3      | 20        | 6.25%     |
| \(\text{NH}_4\text{-N}\) | 1      | 0.5    | 8         | 7.14%     |

The data used in the 1-D model was taken from a local technical report in which the K value of COD, BOD and \( \text{NH}_4\text{-N} \) is 0.18d\(^{-1}\) 0.27d\(^{-1}\) and 0.28d\(^{-1}\) (unit conversion to S\(^{-1}\)); the length of case river is 50km(unit conversion to m), the velocity is 0.5m/s, the stream flow is 60m\(^3\)/s; the existing sewage flow is 3m\(^3\)/s and pollutant concentration is 60mg/L.

Compared with the dilution ratio, Table 4 shows that the effective degradation distance leads that the ratio of 1-D model is more than 0-D model. The dilution ratio is also significantly affected by the location of sewage outfall, and the ratio of medium section is 3.41% which is more than lower section. Table 4 also indicates that the value by Formula 9 is the same as Formula 11. Similarly, the ratio of lower section discharge (2) and lower section discharge (1) is 15.29% and 19.55%, respectively, and the ratio of the existed outfall in initial condition is 5%(3 m\(^3\)/s /60 m\(^3\)/s), so the ratio of lower section discharge (2) is more than lower section discharge (1) by 0.74%.

However, under the assumption that the pollutants are mixed instantaneously in section, the 1-D model is only feasible in theory, so the sewage outfall is only discharged at upper reaching standard.
section. Besides, 22.96% of middle section discharge in Table 4 is reasonable and should be used as the control standard.

Table 4. Comparison of dilution-ratio of different discharge section of 1-dimension model (unit: mg/L)

| Zero-dimension discharge | Middle section discharge(1) | Middle section discharge(2) | lower section discharge(2) |
|--------------------------|-----------------------------|-----------------------------|---------------------------|
| 12.50%                   | 19.55%                      | 22.96%                      | 22.96%                    |
|                          |                             | 15.29%                      |                           |

4 Conclusions

1. The basic structure of the quantitative model is like Formula 4, the dilution ratio is dependent on three concentration parameters but independent of stream flow (Q). But 1-D model has other influencing factor of river characteristics, such as L, K and u, which was affected indirectly by Q. However, all the models in this paper have the assumptions of contamination mixing in the whole stream or section.

2. Dilution ration has inverse correlation relationship with $C_p$ and $C_o$, and positively correlation relationship with $C_s$. The maximum of the control standard is 12.50% of 0-D model and 22.96% of 1-D model.

3. Dilution ration of COD, BOD and NH$_4$-N has different values with the same characteristics of river. The reason is that the national standard value of each parameter is different and disproportionate. Moreover, we propose to choose the minimum as the emission standard and give up invalid pollution bearing capacity.

4. Theoretical derivation of the quantitative model is under the assumption that the pollutants are mixed instantaneously in stream or section, so further studies will be on the 2-D model and the application to the case.

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