The Method to Optimize Conduit for Conserving River Water Quality

Jing TAN Hailong YIN
State Key Laboratory of Pollution Control and Resource Reuse, Tongji University, Shanghai, China, 200092
Email:yinhailong@stcsm.gov.cn

Abstract: Urban construction blocks river flowing, resulting in river water quality deterioration. The conduit is usually constructed to conserve river flow. This study presented the optimized conduit design for conserving river water quality, concerning the methods to assess water quality changing with conduit flow. Specifically, it concerns how to estimate conduit flow, unknown pollutants loads discharing into rivers and river water quality response, depicted by a quantitative overall water quality assessment method. The Yangshupu River system in Shanghai plain river network region is taken as an expample to explain how to optimize conduit size for preventing the re-occurrence of river's black color and umpleasant odor.

Keywords: conduit; water quality assessment; pollutant load; water flow

1. Introduction

Artifical water flowing dispatch is a routine method to ameliorate river water quality, due to its ability to dilute water polluants as well as enhance river self-purification effect. For example, artificial water flowing diapatch in Suzhou Creek of Shanghai, China had played an important role in abating its serious pollution, showing balck in color and unpleasant odor before the year of 2000[1]. Even at present, water flowing dispatch in whole river network of Shanghai still remians a necessary measure to conserve river water quality.

Large-sacle urban infrustruction construction may bring adverse effect on river water flowing. For example, some river area is blocked during metro-line construction; under this circumstance, the conduit may used as an alternative measure to maintain river flowing, although the water flowing amount is forced o be reduced. So the optimized design of water conduit arises, for the purpose of preventing water quality deteioration as possible as can, especially preventing the re-occurrence of river's blackness in color and unpleasant odor.

Mathematical models have been widely used to simulate water flowing through hydraulic control structures like sluice gates, weirs, culverts, conduits and the river water quality response[2-3]. However, for the engineering design, the method to estimate conduit flow and the resulting water quality changing should be more practicle and more easy to use. In addtion, unknown water pollutants discharging into rivers make simulation of mathematical models more difficult. So, establishing the analytical models to reflect quantitative overall water quality response to water flowing under hydraulic structure control is required.

Sponsored by Program on the S & T for the Pollution Control and Treatment of Water Bodies (2009ZX07316-005)

2. Study Area

The study area is the catchment surrounded by water system of Yangshupu River in Shanghai river network. As shown in Figure1, the river water system is linked to the Huangpu River to the north and south. The artificial water flowing is controled by two sluice gates at Yangshu River and Qiu River, running from south to north accroding to the water level of Huangpu River during high tide and low tide. Specifically, when the water level of Huangpu River rises to be higher than that of Yangshu River during high tide, the water flows into Yangshupu River through the sluice gate while the other sluice gate at Qiu River remains closed; when the water level of Huangpu River falls to be lower than that of Qiu River during low tide, the water flows out of Qiu River through the sluice gate while the other sluice gate at Yangshupu River remains closed.

According to the plan, metro line 12 will runs across Yangshupu River underground. During the construction, the river will be blocked at Changyang Road Bridge, resulting in potential water quality deterioration. The critical water flowing throuth the conduit and the corresponding conduit size should be studied.

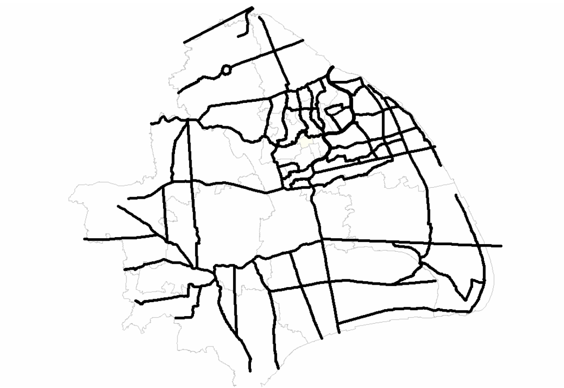
3. Materials and Methods

3.1 Water Flowing Capacity through the Conduit

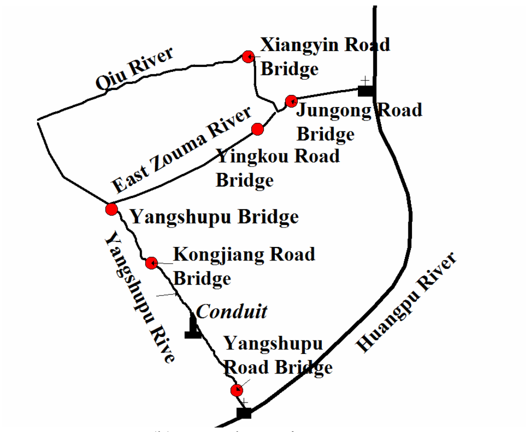
Conduit flow is calculated as follows[4]:

$$Q = \mu_c A\sqrt{2gH} \quad (1)$$

where Q is conduit flow rate; μ_c is discharge coefficient; A is full cross-sectional area of conduit barrel; g is gravatational acceleration; ΔH is culvert head, $\Delta H = H_1 - H_2$, H_1 is headwater elevation (water sur-



(a) Main rivers of Shanghai tidal plain region



(b) Yangshupu river system

Figure 1. Depiction of study area

face elevation at upstream end of conduit), H_2 is tailwater elevation (water surface elevation at downstream end of conduit).

The discharge coefficient is calculated based on the following expression:

$$\mu_c = \frac{1}{\sqrt{\lambda \frac{l}{d} + \Sigma \zeta}} \tag{2}$$

Where λ is frictional head loss coefficient; l is conduit barrel length; d is conduit diameter; ζ is local head loss coefficient, inlet headloss coefficient is 0.5, submerged outlet headloss coefficient is 1.0.

3.2 Water Pollutants Discharing into Rivers

Although all of the pollution sources in the catchment had been intercepted into wastewater treatment plant (WWTP) by sewage treatment project (stage III) in Shanghai in theory, water quality monitoring data revealed pollutants discharging into rivers. It is difficult to survey the pollutants not intercepted into WWTP, including dry-weather pollutants inappropriate entry into storm drainage, and rainfall runoff. So, according to the water quality monitoring data between the upstream and downstream boundary of a river reach, the method to estimate pollutants received by rivers is presented as follows:

$$m = Q_h \left\{ [C(x) - C_h \cdot \exp(-\frac{kx}{u})] \cdot \exp(\frac{kx}{u}) \right\} \tag{3}$$

where m is pollutants received by one river reach; $Q(h)$ is upstream inflow; $C(x)$ is water quality of downstream boundary; C_h is water quality of upstream boundary; k is pollutant decaying coefficient; u is cross-sectional velocity of one river reach; x is length of one river reach.

Under condition of conduit flow, the water quality at downstream boundary can be further predicted based on the following expression:

$$C'(x) = \frac{m}{Q} \cdot \exp(-\frac{kx}{u}) + C_h \exp(-\frac{kx}{u}) \tag{4}$$

Where $C'(x)$ is water quality at downstream boundary of one reach under conduit flow.

3.3 Overall River Water Quality Assessment

Overall river water quality assessment is conducted based on water quality identification index (*WQII*), a new assessment method providing more qualitative and quantitative determination of the river water quality, as well as assessing the river opacity and odor (black in color and unpleasant odor). *WQII* is expressed as follows[5]:

$$WQII = X_1 \cdot X_2 \tag{5}$$

where *WQII* is the water quality identification index for one specific water quality indicator, X_1 is the water quality Grade used to assess the water quality qualitatively, X_2 is the position of measured value of a specific water quality indicator used to assess water quality quantitatively.

Based on the monitoring data sets in recent 10 years, water quality of Shanghai river network is mainly characterized by oxygen-consuming indicators like NH_3-N, COD, BOD_5[6], so, in this study overall water quality assessment is conducted based on the following expression with equal weighted value of each indicator:

$$CWQII = \frac{1}{3}(WQII_{NH_3-N} + WQII_{COD} + WQII_{BOD_5}) \tag{6}$$

where *CWQII* is the overall river water quality identification index; $WQII_{NH_3-N}$, $WQII_{COD}$ and $WQII_{BOD_5}$ are *WQII* of NH_3-N, COD, BOD_5 respectively.

Corresponding to *Chinese environmental quality standard for surface water* (GB3838-2002) with five categories of water functions, i.e., five water quality grades, criteria of assessing overall river water quality as well as river opacity & odor is presented, as shown in Table 1.

Table 1 Criteria of the overall river water quality based on *CWQII*

CWQII	Overall river water quality
1.0≤*CWQII*≤2.0	Grade Ⅰ
2.0< *CWQII*≤3.0	Grade Ⅱ
3.0< *CWQII*≤4.0	Grade Ⅲ
4.0< *CWQII*≤5.0	Grade Ⅳ
5.0< *CWQII*≤6.0	Grade Ⅴ
6.0< *CWQII*≤7.0	inferior to Grade Ⅴ without opacity and odor (black in color and unpleasant odor)
CWQII >7.0	inferior to Grade Ⅴ with opacity and odor (black in color and unpleasant odor)

4 Results and Discussion

4.1 Current Overall River Water Quality

Based on the water quality data at 6 monitoring stations (shown in Figure 1), overall river water quality in 2009 was assessed in Figure 2.

From Figure 2, it is known that averaged *CWQII* of the whole Yangshpu River system was in the range of 5.0~6.0, that is, overall water quality of the whole river system met the water use objective of grade Ⅴ.

However, water quality of Qiu River deteriorated along the river flowing direction, showing the water pollutants discharging into rivers. Especially, Qiu River became opacity and odor during some period.

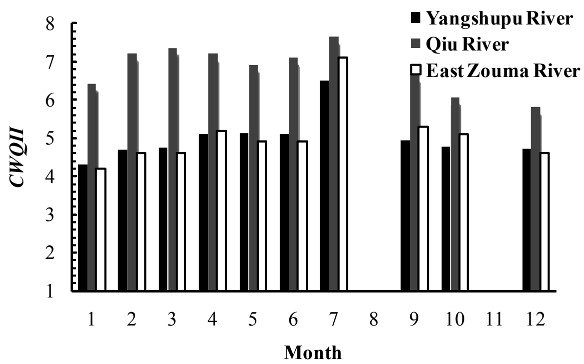


Figure 2. Overall river water quality of Yangshupu River system in 2009

4.2 Conduit Flow under Design Schemes

Based on the hydrologic survey and flowing simulation of Shanghai tidal river network, it is know that discharge from artificial water dispatch is about 274000 m^3/d, and the time for water dispatch is about 5~6 hours.

As for the conduit head, that is, water elevation difference between conduit upstream and downstream water elevation, it is ascertained according to critical value for preventing flood. The normal water elevation of Yangshupu River system is below 3.0 m, normally 2.6m; the critical water elevation for precenting flood is 4.3m. After setting conduit, the water elevation upstream of conduit should rise to be lower than that of critical value of 4.3m. It is proposed that the conduit head shouldn't be greater than 1.0m.

Under designing schemes of conduit head (0.1~1.0m) and conduit diameter (0.5~2.5 m), the conduit flow is estimated based on Equations (1) and (2) , as shown in Figure 3.

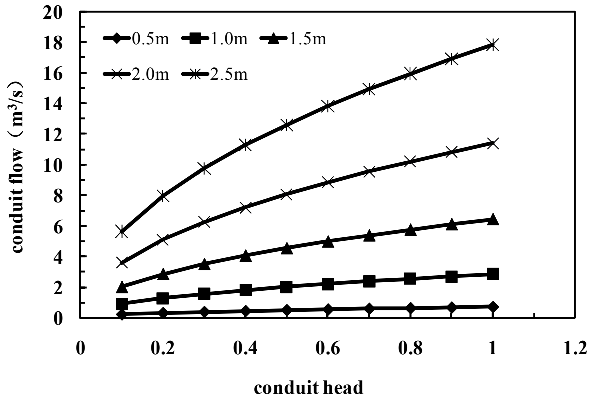


Figure 3. Conduit flow corresponding to conduit head and diamater

From Figure 3, it is know that when conduit head reaches 1.0m, the maxium conduit flow under conduit diamater of 1m, 1.5m and 2.0m is about 22%, 50% and 90% of the current artificial water dispatch flow respectively.

4.3 Pollutants Received by Rivers

Based on Equation (3), pollutants received by rivers were estimated, shown in Table 2. It shows that large amounts of pollutant loads discharging into Yangshu River and Qiu River are still left to be intercepted, while nearly no pollution sources discharge into East Zouma River nowadays.

4.4 Optimized Conduit Design

In general, constructing conduit makes river flowing less than before, resulting in potential water quality deterioration. The optimized conduit design lies in how to ascertain critical conduit size, preventing the re-occurrence of river opacity and odor. So, based on Equation (4), (5) and (6), river water quality and *CWQII* under conduit size of 0.5~2.5m diameter was predicted. It is found that conduit flow under 1.5 and 2.0m diamater should be the critical condition that river opacity and odor couldn't occur, as shown in Table 3. If designing conduit diamater is 1.5m, Yangshupu River and East Zouma River willn't become opacity and odor, while Qiu River will deteriorate to be opacity and odor due to the serious backgound situation. If designing coduit diamaeter increases to be 2.0m, overall *CWQII* of Qiu River will not be greater than 7.0, which further means that all of the three rivers will not become black in color and odors.

Table 2 Pollutants load discharging into Yangshupu River system (unit: t/d)

River	River reach	COD	BOD_5	NH_3-N
Yangshupu River	Huangpu River~Yangshupu Road Bridge	2.47	1.35	0.15
	Yangshupu Road Bridge~Kongjiang Road Bridge	/	/	/
	Kongjiang Road Bridge~Yangshupu Bridge	2.03	1.09	0.28
East Zouma River	Yangshupu Bridge~Yingkou Road Bridge	/	/	/
	Yingkou Road Bridge~Jungong Road Bridge	/	/	/
Qiu River	Yangshupu Bridge~Xiangyin Road Bridge	0.93	0.67	0.37
	Xiangyin Road Bridge~Jungong Road Bridge	3.99	3.86	1.15

Table 3 Predicited *CWQII* under conduit flow

River	River station	*CWQII*		
		Background	Conduit with 1.5m diameter	Conduit with 2.0m diameter
Yangshupu River	Yangshupu Road Bridge	5.3	5.9	5.3
	Kongjiang Road Bridge	4.9	5.9	5.3
	Yangshupu Bridge	5.7	6.6	5.9
East Zouma River	Yingkou Road Bridge	5.2	6.5	5.9
Qiu River	Xiangyin Road Bridge	6.3	7.5	6.4
	Jungong Road Bridge	7.3	9.4	7.6

References

[1] Xu Zuxin. Theory and Practice of River Pollution Control [M]. Beijing: China Environmental Science Press, 2003.(Ch)

[2] Xu Zuxin, Yin Hailong, Yao Yijun. Prediction of Water Quality of Huangpu River Using a Tidal River Network Model [J]. *Environmental Engineering Science*, 2008, 25(10): 1463-1475.

[3] Xu Zuxin, Lu Shiqiang. Research on Hydrodynamic and Water Quality Model for Tidal River Networks [J]. *Journal of Hydrodynamics*, 2003, 18(2): 64-70.

[4] Wang Huimin, Zhao Zhenxing. Engineering fluid dynamics [M]. Nanjing: Huohai Press, 2005. (Ch)

[5] Xu Zuxin. Single Factor Water Quality Identification Index for Environmental Quality Assessment of Surface Water [J]. *Journal of Tongji University,* 2005, 33(3):P321-325 (Ch).

[6] Xu Zuxin. Comprehensive Water Quality Identification Index for EnvironmentalQuality Assessment of Surface Water [J]. *Journal of Tongji University,* 2005, 33(4):P482-488 (Ch).

978-1-935068-16-7 © 2010 SciRes.