*Desalination and Water Treatment*
www.deswater.com

doi: 10.1080/19443994.2014.922735

53 (2015) 3066–3071
March

Taylor & Francis
Taylor & Francis Group

# Water quality changes according to the midstream weir construction in the Yeongsan River, Korea

Sung Min Cha[a], Min-Ji Kang[b], Yongeun Park[a], Seung Won Lee[a], Joon Ha Kim[a,*]

[a]*School of Environmental Science Engineering, Gwangju Institute of Science Technology (GIST), Gwangju 500-712, South Korea, email: joonkim@gist.ac.kr (J.H. Kim)*
[b]*Water Environmental Research Department, National Institute of Environmental Research, Incheon 404-708, Republic of Korea*

Received 31 July 2013; Accepted 11 December 2013

ABSTRACT

This paper describes the effects of weir construction on water quality in the Yeongsan (YS) River. In general, weirs affect aquatic environments of rivers and streams by interrupting natural water flow. To identify changes in water quality before and after weir construction, analysis of variance and autocorrelation tests were conducted on data from four monitoring stations. Seasonal variations in suspended solids (SS), biochemical oxygen demand (BOD5), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), and pH were analyzed using data from six years of monitoring. No significant changes in mean BOD5 or COD followed the construction of weirs. However, mean TN and TP were changed significantly during and after construction. Moreover, SS and pH changed significantly during construction, and TN and TP concentrations were slightly improved after weir construction. However, continuous monitoring and analysis of water quality changes in each weir are required to prevent environmental disasters such as algal blooms.

*Keywords:* Water quality change; Weir construction; Yeongsan River; ANOVA test

## 1. Introduction

Artificial structures, such as dams and weirs, in rivers generally affect both water quality and flow in aquatic systems [1,2]. Nonetheless, weirs and dams have several positive economic effects, providing social services, navigation, power generation, irrigation, flood control, and water resource management [1,3,4]. However, research has revealed that artificial structures, including dams and weirs, can negatively influence water quality in rivers or reservoirs, leading to the accumulation of trace metals, nutrients, and organics, and establishment of obstacles to transport organic and inorganic materials [1,5–7]. Presently, dams and weirs with two faces are being constructed globally.

In Korea, 16 weirs were constructed from 2009 to 2011 to provide water security, flood control, and ecosystem vitality in the four rivers Han, Nakdong, Geum, and Yeongsan (YS). As of 2013, all weirs are operating, and water quality and flow are continuously monitored upstream and downstream of each weir. Of particular interest are two weirs in the

*Corresponding author.

*Presented at the 16th International Conference on Diffuse Pollution and Eutrophication (DIPCON), 18–23 August 2013, Beijing, China*

1944-3994/1944-3986 

midstream of the YS River. According to the WCD, the criteria for small dams is a height lesser than 15 m and a storage capacity lesser than $3 \times 10^6\,m^3$ [8]. The two midstream weirs of the YS River are classified as small dams in terms of height.

In addition to these two small YS river dams, four other artificial dams were constructed in 1979 and 1981 to provide agricultural water to paddy fields, including three upstream dams and a dyke dam downstream of the YS River, which impaired the water quality by blocking natural water flow into the YS River [9,10]. Hence, the YS River has water flow obstacles in its upper, mid, and downstream watersheds.

Under these environmental conditions, the assessment of water quality changes after the construction of weirs and small dams is a requirement of future water quality management. The impact of small dams on water quality is generally not quantified on a regional scale [11]. Thus, the objectives of this study were to identify seasonal periodicity of water quality changes upstream and midstream of the two weirs and to investigate water quality changes during and after weir construction.

Table 1
Description of SC and JS weirs in the YS River

| | SC weir | JS weir |
|---|---|---|
| Longitude | 35° 03′ 56.17′′ | 34° 58′ 19.11′′ |
| Latitude | 125° 45′ 57.91′′ | 125° 37′ 31.22′′ |
| Height (m) | 7.5 | 3.5 |
| Length (m) | 512 | 184 |
| Watershed area ($m^2$) | 1,977 | 2,359 |
| Total storage capacity ($10^6\,m^3$) | 90 | 260 |
| Designed flood discharge (CMS) | 4,200 | 6,710 |
| Distance from Dyke dam (km) | 69.5 | 49.1 |

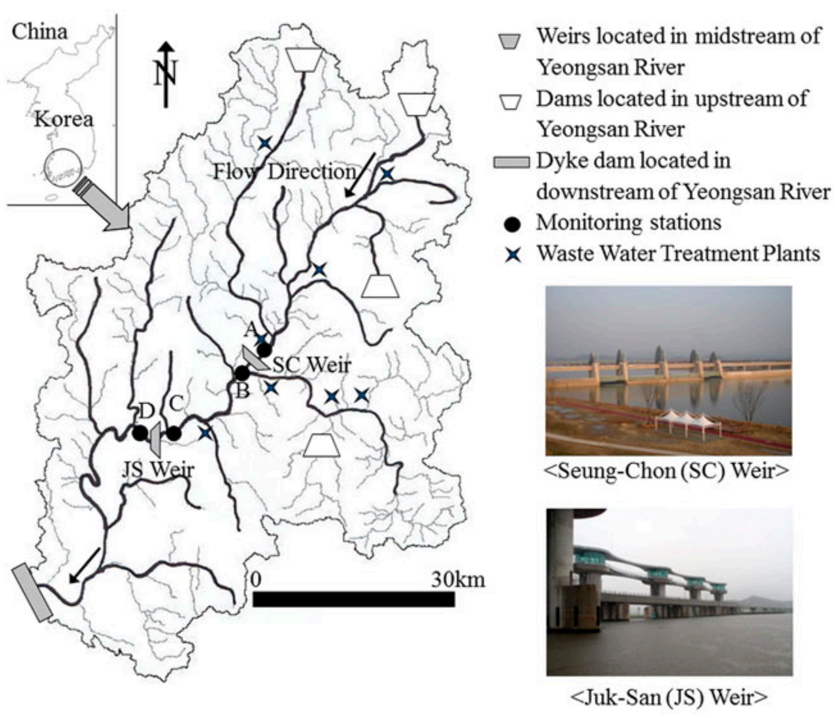


Fig. 1. Simplified map indicating the locations of monitoring stations (black circles), wastewater treatment plants (black star), one dyke dam (gray rectangle) downstream of the YS River, four agricultural dams (open trapezoids) upstream in the YS River, and the two weirs (gray trapezoids) SC weir and JS weir in the midstream of the YS River.

## 2. Materials and methods

### 2.1. Site description

The Seung-Chon (SC) and Juk-San (JS) weirs are among the 16 largest weirs in the four major Korean rivers Han, Nakdong, Geum, and Yeongsan, and are located in the midstream of the YS River. Both were constructed from 2009 to 2011 as part of the Four-River Restoration Project of the Korean Ministry of Land, Transport, and Maritime Affairs. The SC weir is located on the boundary between Gwangju and Naju and has a height of 7.5 m, a length of 512 m, and a watershed area of 1,977 $km^2$. The JS weir is located on the boundary between Naju and Hampyung and has a height of 3.5 m, a length of 184 m, and a watershed area of 2,359 $km^2$ (Table 1). Eight domestic, industrial, and agricultural wastewater treatment plants are located upstream of both dams. The monitoring stations A and B are located 1.1 km upstream of the SC weir and 4.6 km downstream of the SC weir. The monitoring stations C and D are located 0.8 km upstream of the JS weir and 4.3 km downstream of the JS Weir (See Fig. 1). The distance between SC and JS weirs is approximately 20 km.

### 2.2. Data collection

The Korean Ministry of Environment (ME) monitors mainstream water of the YS River at 12 stations. Among these, four monitoring stations around SC and JS weirs were selected to compare water quality parameters, including pH, suspended solids (SS), biochemical oxygen demand (BOD5), chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP). All data used in this study were collected from the National Institute of Environmental Research (NIER) database (http://water.nier.go.kr). All monthly data were measured using standard methods [12].

### 2.3. Statistical analyses

To identify changes in water quality at both weirs, multiple comparisons were performed using analysis of variance (ANOVA) and *post hoc* tests [13,14].

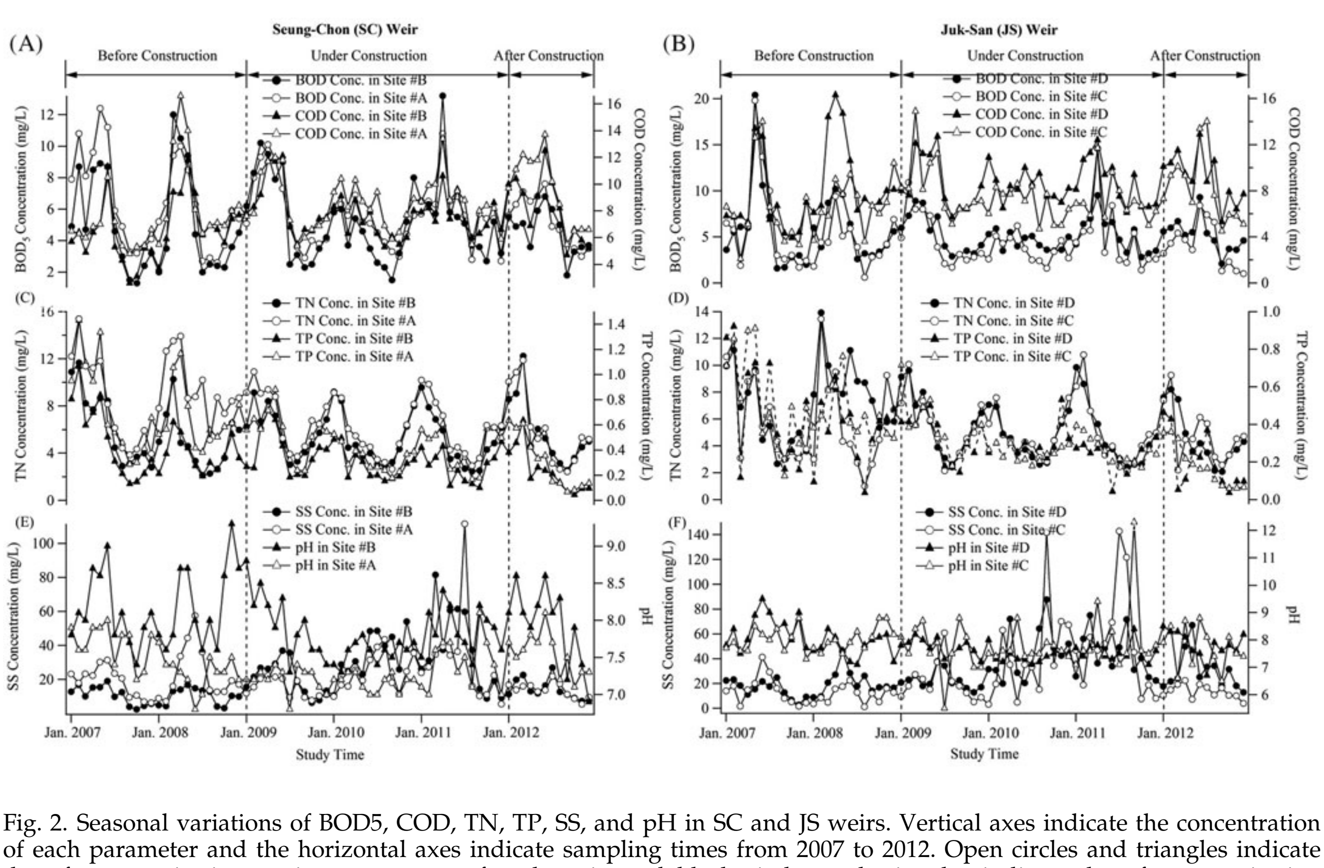


Fig. 2. Seasonal variations of BOD5, COD, TN, TP, SS, and pH in SC and JS weirs. Vertical axes indicate the concentration of each parameter and the horizontal axes indicate sampling times from 2007 to 2012. Open circles and triangles indicate data from monitoring stations upstream of each weir, and black circles and triangles indicate data from monitoring stations downstream of each weir. Graphs (A), (C), and (E) pertain to the SC weir. Graphs (B), (D), and (E) pertain to the JS weir.

Scheffe's test was selected as the most conservative statistical method for *post hoc* tests.

Autocorrelation tests were conducted to identify periodicity of the six water quality parameters during the study period. The maximum number of lags was 1/4 of the total number [15]. All statistical analyses were performed with SPSS 17.0 software.

## 3. Results and discussion

### 3.1. Water quality variations in the four monitoring stations

Variations of the six water quality parameters BOD5, COD, TN, TP, TSS, and pH were investigated in both weirs to identify changes in water quality. As shown in Fig. 2, both weirs were constructed from 2009 to 2011. Seasonal variations in BOD5, COD, TN, and TP were detected. In the YS River, these changes in water quality reflected decreased the water flow [9]. Autocorrelation analyses showed 12-month periodicity of BOD5, COD, TN, and TP throughout the study period, and indicated seasonal variations at the four monitoring stations. In contrast, no periodicity was shown for pH and SS during the six-year study (Fig. 3). These analyses indicate no effects of weir construction on BOD5, COD, TN, or TP. Given that changes in pH and SS were not seasonal (1), we determined whether these water qualities were affected by the construction of weirs (2) using ANOVA.

### 3.2. Differences in water quality before and after weir construction

Weir construction in a river can potentially cause water quality changes by obstructing water circulation. To identify water quality changes around both weirs, ANOVA was applied to data from the four monitoring sites. Table 2(A) and (B) shows *p*-values from ANOVA and *post hoc* tests of six water quality parameters from the four monitoring stations.

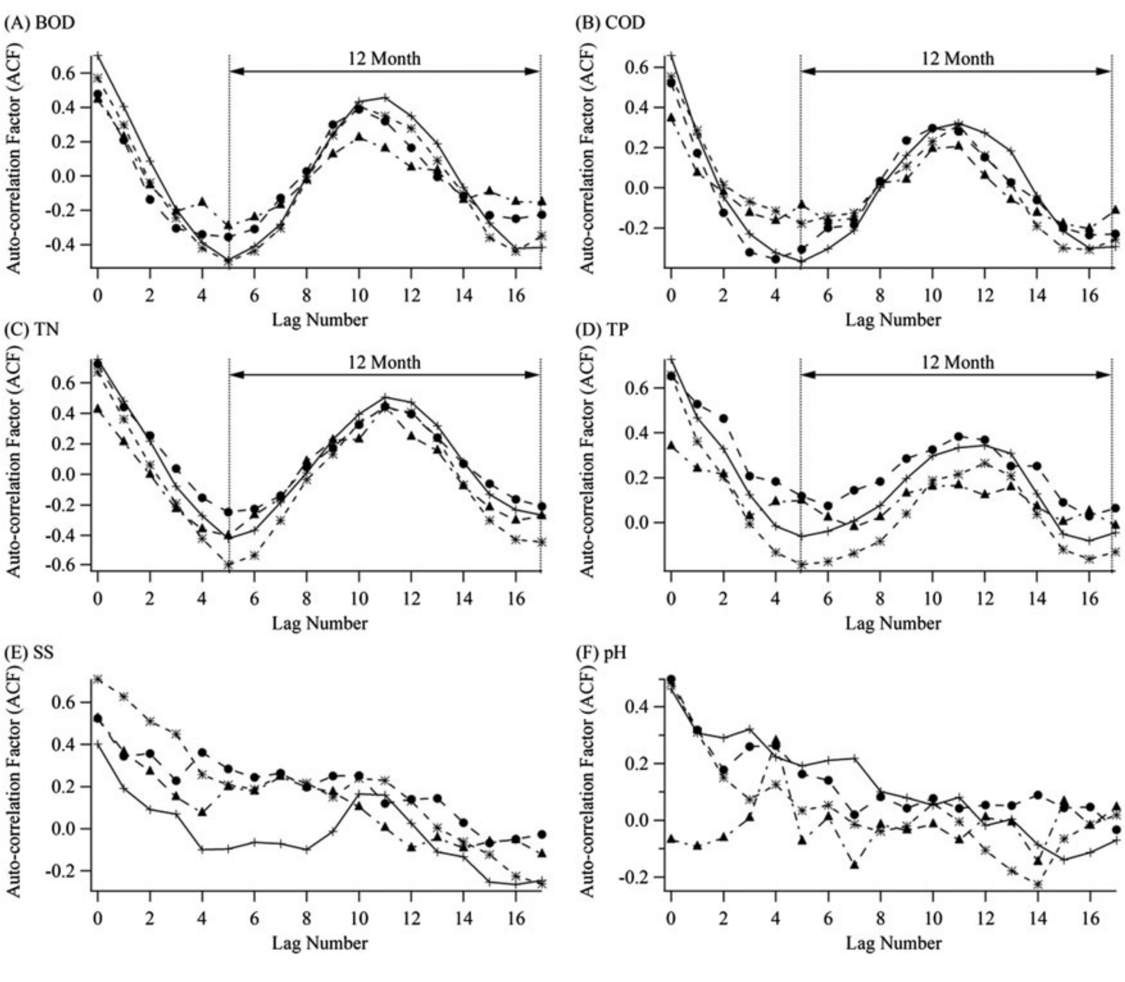


Fig. 3. Relationship between autocorrelation factor ACF and lag number for the six parameters.

Table 2
Results of ANOVA and *post hoc* tests of changes in six water quality parameters at four monitoring stations.

| | $BOD_5$ | COD | TN | TP | SS | pH |
|---|---|---|---|---|---|---|
| (A) ANOVA test results ($p$-values) | | | | | | |
| Site #A | 0.245 | 0.132 | 0.002 | 0.000 | 0.158 | 0.002 |
| Site #B | 0.789 | 0.037 | 0.886 | 0.012 | 0.000 | 0.018 |
| Site #C | 0.476 | 0.188 | 0.324 | 0.001 | 0.000 | 0.544 |
| Site #D | 0.662 | 0.460 | 0.001 | 0.000 | 0.000 | 0.000 |
| (B) *Post hoc* test results ($p$-values) | | | | | | |
| Site #A 1–2 | 0.443 | 0.498 | 0.005 | 0.000 | 0.832 | 0.014 |
| Site #A 1–3 | 0.301 | 0.138 | 0.026 | 0.000 | 0.389 | 0.881 |
| Site #A 2–3 | 0.813 | 0.489 | 0.963 | 0.291 | 0.158 | 0.018 |
| Site #B 1–2 | 0.949 | 0.101 | 0.927 | 0.088 | 0.000 | 0.018 |
| Site #B 1–3 | 0.923 | 0.078 | 0.995 | 0.020 | 0.728 | 0.419 |
| Site #B 2–3 | 0.794 | 0.772 | 0.919 | 0.450 | 0.001 | 0.668 |
| Site #C 1–2 | 0.595 | 0.496 | 0.420 | 0.018 | 0.001 | 0.679 |
| Site #C 1–3 | 0.573 | 0.205 | 0.464 | 0.002 | 0.997 | 0.613 |
| Site #C 2–3 | 0.952 | 0.627 | 0.963 | 0.249 | 0.016 | 0.939 |
| Site #D 1–2 | 0.669 | 0.706 | 0.004 | 0.000 | 0.000 | 0.000 |
| Site #D 1–3 | 0.868 | 0.485 | 0.009 | 0.000 | 0.133 | 0.370 |
| Site #D 2–3 | 0.989 | 0.825 | 0.827 | 0.062 | 0.406 | 0.221 |

#### 3.2.1. Site #A, upstream of the SC weir

Whereas BOD5, COD, and SS were not changed significantly by weir construction ($p > 0.05$), significant differences in ($p < 0.05$) between mean TN, TP, and pH were identified before and after weir construction. Furthermore, *post hoc* tests revealed significant differences between mean concentrations of TN and TP before, after, and during the construction, and pH was significantly, but transiently, changed during construction.

#### 3.2.2. Site #B, downstream of the SC weir

COD, TN, and SS in site #B differed significantly from those in site #A. Moreover, localized means of COD and SS were significantly affected by weir construction. However, TN did not change significantly with weir construction, as supported in *post hoc* tests of TN means. Significant differences in TP were identified between samples taken before and after weir construction ($p < 0.05$) but not during construction ($p > 0.05$). SS concentrations were only affected during construction. Thus, of these variables in site #B, only TP concentrations differed between samples taken before and after weir construction.

#### 3.2.3. Site #C, upstream of the JS weir

No significant differences in BOD5, COD, TN, and pH were identified between samples taken before, after, and during construction of the JS weir ($p > 0.05$). However, ANOVA indicated significant differences in TP and SS between locations and samples taken before, after, and during construction of the JS weir. These were corroborated by *post hoc* tests that indicated significant differences between samples taken before and after construction, but not between samples taken during and after construction. Hence, only SS concentrations were affected during construction of the weir, but did not differ between samples taken before and after construction ($p > 0.05$).

#### 3.2.4. Site #D, downstream of the JS weir

No significant differences in BOD5 and COD were identified between sampling times ($p > 0.05$). However, ANOVA and *post hoc* tests indicate significant changes in TN and TP during construction and thereafter. Significant between time point differences in SS and pH were identified using ANOVA, though *post hoc* tests only indicated significant differences between samples taken before construction and during construction.

## 4. Conclusions

(1) Artificial weirs in rivers or streams can positively or negatively affect water quality. In Korea, a total of 16 weirs have been constructed and operated in the four major rivers Han, Nakdong, Geum, and YS as a part of the Four-River Restoration Project. This study was conducted at SC and JS weirs in the YS River. Whereas BOD5 and COD concentrations varied seasonally, they were not affected by weir construction. Although TN and TP concentrations did not change significantly, an insignificant tendency to reflect eutrophication of the rivers or lakes before, after, and during construction is apparent. In contrast, seasonal variations of TN and TP concentrations were observed over 12-month intervals, and were slightly improved after weir construction. Whereas no seasonal variations in SS and pH were identified, and significant changes during construction were demonstrated. However, these were transient, indicating that the weirs did not affect water quality adversely.

(2) Although no significant differences in concentrations of the six environmental parameters were identified between samples taken before and after construction, long-term monitoring is required to accurately assess the impact of these weirs on aquatic environments of rivers and lakes.

## Acknowledgment

This research was supported by the Korean Ministry of Environment; "The Eco-innovation Project: Non-point source pollution control research group."

## References

[1] G.L. Wei, Z.F. Yang, B.S. Cui, B. Li, H. Chen, J.H. Bai, S.K. Dong, Impact of dam construction on water quality and water self-purification capacity of the Lancang River, China, Water Resour. Manage. 23 (2009) 1763–1780.

[2] J.-M. Kileshye Onema, D. Mazvimavi, D. Love, M.L. Mul, Effects of selected dams on river flows of Insiza River, Zimbabwe, Phys. Chem. Earth 31(15–16) (2006) 870–875.

[3] L.T.V. Hoa, N.H. Nhan, E. Wolanski, T.T. Cong, H. Shigeko, The combined impact on the flooding in Vietnam's Mekong River delta of local man-made structures, sea level rise, and dams upstream in the river catchment, Estuar. Coast. Shelf Sci. 71 (2007) 110–116.

[4] F.T. Mugabe, M.G. Hodnett, A. Senzanje, Opportunities for increasing productive water use from dam water: A case study from semi-arid Zimbabwe, Agr. Water Manage. 62(2) (2003) 149–163.

[5] S.G. Ewa, M.B. Grázyna, Deposition of copper in the eutrophic, submontane Dobczyce dam reservoir (Southern Poland)-role of speciation, Water Air Soil Pollut. 140(1–4) (2002) 203–218.

[6] Y.G. Lee, K.G. An, P.T. Ha, K.Y. Lee, J.H. Kang, S.M. Cha, K.H. Cho, Y.S. Lee, I.S. Chang, K.W. Kim, J.H. Kim, Decadal and seasonal scale changes of an artificial lake environment after blocking tidal flows in the Yeongsan Estuary region, Korea, Sci. Total Environ. 407 (2009) 6063–6072.

[7] K.H. Cho, J.H. Kang, S.J. Ki, Y. Park, S.M. Cha, J.H. Kim, Determination of the optimal parameters in regression models for the prediction of chlorophyll-a: A case study of the Yeongsan Reservoir, Korea, Sci. Total Environ. 407 (2009) 2536–2545.

[8] WCD (World Commission on Dams), Dams and Development: A New Framework for Decision-Making, Earthscan Publications Ltd., London, 2000.

[9] S.M. Cha, S. Ki, K.H. Cho, H. Choi, J.H. Kim, Effect of environmental flow management on river water quality: A case study at Yeongsan River, Korea, Water Sci. Technol. 59(12) (2009) 2437–2446.

[10] Y.G. Lee, J.H. Kang, S.J. Ki, S.M. Cha, K.H. Cho, Y.S. Lee, Y. Park, S.W. Lee, J.H. Kim, Factors dominating stratification cycle and seasonal water quality variation in a Korean estuarine reservoir, J. Environ. Monitor. 12 (2010) 1072–1081.

[11] S.K. Mantel, D.A. Hughes, N.W.J. Muller, Ecological impacts of small dams on South African rivers Part 1: Drivers of change-water quantity and quality, Water SA 36(3) (2010) 351–360.

[12] APHA (American Public Health Association), Standard Methods for the Examination of Water and Wastewater, 18th ed., APHA, Washington, DC, 1995.

[13] J.F. Sandahl, D.H. Baldwin, J.J. Jenkins, N.L. Scholz, A sensory system at the interface between urban stormwater runoff and salmon survival, Environ. Sci. Technol. 41 (2007) 2998–3004.

[14] F. Xiao, M.F. Simcik, J.S. Gulliver, Perfluoroalkyl acids in urban stormwater runoff: Influence of land use, Water Res. 46 (2012) 6601–6608.

[15] G. Box, G. Jenkins, Time Series Analysis: Forecasting and Control, Holden-Day, San Francisco, CA, 1970.