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Sewage flow control using an inflow controller with an electrical conductivity sensor in the outfall

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ABSTRACT

The aim of this study was to investigate the effect of an inflow controller equipped with an electrical conductivity (EC) sensor on sewage flow during rainfall events. To investigate the relationship between the water quality characteristics and EC of sewage in the field, the EC sensor was used for real-time monitoring. The correlation coefficient (R^2) of COD_{mn} vs. EC was more than 0.97. A reliable hourly maximum flow was calculated using the real-time monitoring data and a water level sensor. The capacity of regulating devices was evaluated during rainfall events by comparing the predicted flow with flow measured by field survey. When the gate was closed at an EC of less than 300 μs/cm, the flow control rate of overflow for the total discharge was about 44% and 75% during the short-term rainfall (once a day) and long-term rainfall events (over 3 d), respectively, and the COD load control rate was about 16% and 61%, respectively. The flow control rate changed according to the EC control setting: the higher the EC control setting, the more the flow control rate increased. The flow control rate was about 40% an EC of 250 μs/cm. However, it showed that there was some difference below the EC. The results indicated that controlling sewage inflow based on EC increased the removal efficiency of sewage treatment plants during rainfall events by reducing hydraulic load.

Keywords: COD load control rate; Electrical conductivity; Flow control rates; Inflow controller; Regulating devices

1. Introduction

Sewer systems are essential for protecting public health in areas of high population density and development. Sewers perform the vitally needed functions of collecting and conveying sewage through a series of intercepting lines to a sewage treatment plant (STP) [1]. If the sewer system, which is buried underground, has been poorly constructed or poorly managed, it can suffer problems, such as incorrect connections between the sanitary sewage system and storm sewers, breakdown of sewer pipes, leaky joints, and broken regulating devices, which can ultimately overload the STP.

There are two types of urban sewer systems used in South Korea to collect sanitary sewage. These are known as the combined sewer system (CSS) and the separate sewer system (SSS). CSSs collect and convey sanitary sewage and urban runoff together in a common piping system, while SSSs collect and convey sanitary sewage separately from urban runoff. During rain events, hydraulic loads containing sanitary sewage are conveyed through CSSs and the combined volume can quickly exceed the hydraulic and treatment capacity of the STPs. Because of time and financial constraints, it is difficult to treat the total volume of heavy rain events [2]. Instead when intensive rainfall occurs during summer time, the runoff is sent to STPs and the combined sewer overflows (CSOs) are discharged directly into a receiving stream without treatment.

CSOs containing high suspended solids and nutrients are considered a non-point sources of pollution. If these pollutants can be reduced, the water quality of streams can be preserved [3–5]. Because excess infiltration/inflow (I/I) is

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collected by the regulating devices during the dry season, and the sewage does not flow into the sewer, the removal efficiency of the STP is reduced when the inflow is increased, diluting the influent.

There are many outfalls near urban streams, and most of outfalls are equipped with an inflow controller which operate based on the water level. Sewage is collected into a sewer interceptor during the dry season. The rainfall-runoff following the initial period of a rainfall, which has a higher level of pollution, is also collected into the sewer interceptor based on the water level of the controller, and conveyed to the STP. A regulating device such as inflow controller [6] is installed in the outfall, which reduces the hydraulic load conveyed to the STP, and is needed to ensure the effective operation of the STP during periods of rainfall.

However, the conventional inflow controller is a gate opening type with a water level switch, and this creates some disadvantages. For example, it is difficult to control the inflow since it is determined by water level, regardless of water quality. As a result, a large amount of inflow is delivered to the STP.

In domestic research [7], the first flush of which the COD concentration increased suddenly or was reduced, which is shown as the EC value represented relationship with COD. A method for predicting the flow and water quality of CSO by EC data has also been reported [8,9].

The present study evaluated the performance of an inflow controller equipped with a regulating device that has the ability to measure the electrical conductivity (EC) of the sewage inflow. We investigated the relationship between the EC and the degree of pollution in the inflow. On site experiments with the proposed equipment were conducted, based on the different range of conductivity that corresponded to the pollution levels of sewage inflow during the wet and dry seasons. The effects of the inflow controller on the maintenance of the STP and the total discharge of organic load to urban streams were evaluated.

2. Materials and methods

2.1. Survey site and inflow controller

A survey site was selected at the outfall of sewer near Sanseong-dong, Jung-gu, Daejeon City. This site was the point of combined sewer, and had a basin area of 0.262 km^2. The experiment was conducted over a period of 6 months (from May to October 2015). Data were collected continuously using continuous monitoring unit. The size of the outfall was 2.5 m width and 1.5 m height, and the outfall was composed of one concrete box. Sewage in the sewer flowed into the regulating device which was 2.0 m width, and contained 4.5 cm of water depth during the dry season. Fig. 1 shows the sampling point and area of the target region.

The electric motor of the inflow controller was connected by mechanical coupling to a motor (model: A16K-M569) under the regulating device, the gate on the inflow controller, and a motor cylinder (model: LEY63NZL-500PD-X344). Sensors to detect EC (model: GF-SIGNET2821) and water level sensors (model: SGE-25) were installed on the side wall of the sewer, and the sensors were placed at an appropriate depth so that they would be in the water. The electric line from the sensor stretched about 15 m from the wall and was connected to the PLC control device system (serial communication: RS-232) outside. Depth of the sewage water was kept at an average of 10 cm by installing a girder for the sensors to be put deeply to set the EC and water depth data in the control system. Whenever the conditions in the field reached a preset data point, the flow was allowed to overflow or was collected in the intercepting sewer, as controlled by the automatic opening of the gate on the inflow controller.

2.2. Surveying method

The flow was measured using a velocity-section method. The flow velocity was measured using a simple buoy, and the depth of the water was measured with a plastic ruler in the field. Then the flow was calculated using a graph of the relationship of the water level and flow. The measured data could be saved as real time data at 1-min intervals, or other appropriate time intervals. As the monitoring data in this study, an EC value of less than 1,000 μs/cm and a water depth of about 30 cm could be measured. Fig. 2 shows a cross sectional diagram of the sensor and the inflow controller in the outfall.

Sampling was conducted to observe the characteristics of the sewage in the field, along with the variations in flow,

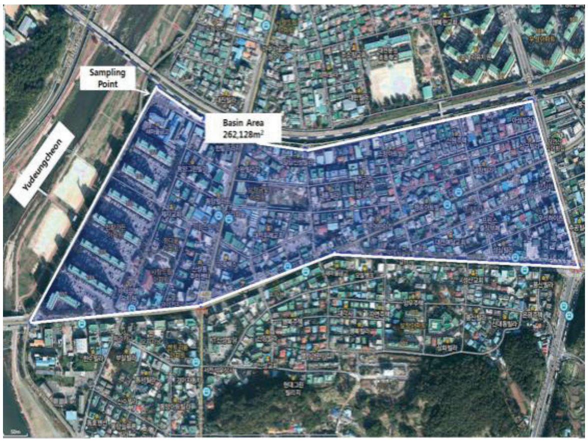


Fig. 1. Sampling point and basin area.

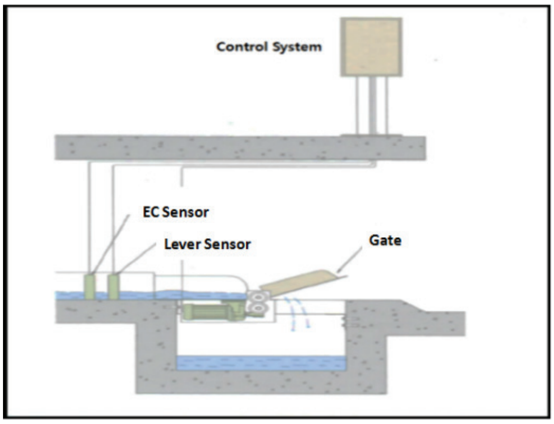


Fig. 2. Cross sectional diagram of sensor and inflow controller in the outfall.

and velocity at the time of sampling. When the flow was judged to be severe during a rainfall, the rate of sampling collection increased, to monitor changes in the pollution and other conditions. Samples in the field were kept in an ice box, and the samples were analyzed by transferring them to a laboratory as quickly as possible after the sampling was finished.

The analyzed parameters were biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), total nitrogen (TN), and total phosphorus (TP), according to the standard Korean method [10]. COD analysis was performed using potassium permanganate ($KMnO_4$) and potassium dichromate ($K_2Cr_2O_7$) as the oxidizing agents, designated here as COD_{mn} and COD_{cr}, respectively. COD_{cr} analysis followed Standard Methods [11].

The total overflow was calculated by multiplying the flow and the period at the start and end points by the overflow time during a rainfall. The calculation was performed using the following equation [12]:

$$\text{Total overflow (m}^3\text{)} = \sum(Q \cdot t) \tag{1}$$

where Q = flow and t = time interval during the overflow.

The event mean concentration (EMC) at the overflow intervals was calculated by dividing the sum of the multiplied flow, with concentration, and time by the total runoff volume. The overflow load was calculated by multiplying overflows by EMC. The two equations were used for the calculation are as follows:

$$\text{EMC (mg/L)} = \frac{\text{Total pollution load (Kg) by rain event}}{\text{Total run off volume (m}^3\text{) by rain event}} = \frac{\Sigma Q_i \cdot C_i \cdot t_i}{\Sigma Q_i \cdot t_i} \tag{2}$$

$$\text{Overflow load (kg)} = \text{EMC} \cdot \text{total overflow (m}^3\text{)} \tag{3}$$

where Q_i = flow, C_i = concentration, and t_i = time interval at the wet period.

3. Results and discussion

3.1. Relationship of EC and water quality

Table 1 shows the analytical results for water quality characteristics and flow during the dry season. Table 2 shows the correlation coefficient (R^2) for the water quality characteristics and the EC. The EC and COD_{mn} exhibited the highest correlation coefficient value, the other water quality characteristics showed good grades from 0.7 to 0.9. The COD_{cr} and COD_{mn} had a correlation coefficient of 0.8, and the ratio of COD_{cr}/COD_{mn} was as high as 3.5.

Table 3 shows the results of the analysis of the water quality characteristics and flow during the wet season. The amount of rainfall ranged from 5 to 9 mm/h, and the overflow started at about 17:30, and finished at about 19:30. The correlation coefficient had an excellent grade of 0.98, as shown in Table 2.

To determine the relationship between the water quality and EC in the sewer, the evaluation was based on the method of I/I reported in previous research. The equation was BOD (mg/L) = 0.1862·EC (μs/cm) [13]. In the analysis of the relationship between EC and TDS, turbidity, etc., EC was determined to be the most suitable item in terms of durability, maintainability, and economic feasibility [14].

Table 2
Comparison of the correlation coefficient of EC vs. water quality characteristics

Item	Correlation coefficient		Grade
	Dry	Wet	
EC vs. COD_{mn}	0.97	0.98	Excellent
EC vs. COD_{cr}	0.89	–	Excellent
EC vs. BOD	0.71	0.94	Good
EC vs. SS	0.72	–	Good
EC vs. TN	0.75	0.80	Good
EC vs. TP	0.70	0.80	Good

Table 1
Results of flow and water quality during the dry season

Time (May 20–21, 2015)	Flow (m^3/d)	EC (μs/cm)	SS	COD_{cr}	COD_{mn}	BOD	TN	TP
			(mg/L)					
May 20, 2015 14:00	1,604	614	50	165	57	23	8.83	2.79
17:00	1,507	616	50	188	62	28	10.37	3.12
20:00	1,853	609	72	270	76	32	10.32	3.19
23:00	1,507	725	75	182	62	29	10.48	3.46
(May 21, 2015) 2:00	915	585	22	97	50	21	9.38	3.00
3:30	771	577	31	89	35	16	9.33	2.84
5:00	855	484	19	54	34	16	7.79	2.09
7:00	1,750	679	159	492	100	56	19.99	6.17
8:00	3,103	597	177	430	79	38	16.69	6.26
11:00	1,638	614	50	188	57	23	8.83	2.79
Average	1,550	610	70	216	61	28	11.20	3.57

Table 3
Results of the flow and water quality during the wet season

Time (June 22, 2015)	Flow (m^3/d)	EC (μs/cm)	COD_{mn}	BOD	SS	TN	TP
			(mg/L)				
12:00	2,712	621	106	63	2,178	16	4.69
5:25	2,595	602	104	59	2,318	28	3.91
5:31 (Overflow)	9,495	1,690	316	153	2,658	72	14.00
5:41	11,249	1,130	208	86	575	30	5.59
5:51	11,976	558	88	48	188	7	2.03
6:01	11,762	904	153	70	435	23	5.23
6:11	11,537	568	92	43	200	14	2.55
6:21	11,452	560	83	39	158	14	2.70
6:31	10,866	620	100	58	103	11	1.94
6:56	10,215	569	96	51	3,750	13	1.80
7:16	11,794	631	114	60	9,268	14	1.98
7:27 (Finish)	12,316	884	148	78	143	23	3.52
7:40	7,262	803	120	63	285	10	1.77
7:54	5,090	752	110	67	10,913	12	1.85
9:00	3,535	798	130	71	8,355	15	2.32
Average	8,924	779	132	67	2,768	20	3.72

This study also selected COD_{mn}, which had the highest relationship with EC as indirect water quality characteristics. The first flush showed both high conductivity and high pollutant concentration (Table 3). These results are also well correlated with the report by [15].

3.2. Estimation of hourly maximum flow

In previous methods, the hourly maximum flow (Q_{peak}) in the sewer was roughly estimated by multiplying the daily average flow by the peaking factor (the ratio of $Q_{peak}/Q_{average}$) which was assumed by using the average flow measured at a regular time interval during the dry season. Overflow in the wet season was estimated to be three times Q_{peak} [12], but the amount of overflow was not precise. In this study, the accurate hourly maximum flow was estimated using the real time flow value based on the flow-water depth graph and the water depth sensor. By using the flow measured at 1-min intervals from July 31 through October 31 as the 4-month monitoring period, the daily average flow was determined to be 1,100 m^3/d, and the daily maximum flow was estimated to be 1,370 m^3/d at the flow, on October 25.

Based on the variation in the daily average flow, which was determined by converting the flow at 1-min intervals to 1-h intervals, the highest rise in the hourly maximum flow occurred at around 20:30. Fig. 3 shows the variation in the daily average flow at 1-min intervals, used for estimating hourly peak flow. The hourly maximum flow was estimated to be 1,812 m^3/d, the average value of flow for 30 min of the front and the back in the middle of the highest flow time. The overflow was estimated to be 5,436 m^3/d using three times Q_{peak}. The measured overflow of 9,495 m^3/d was about 1.7 times larger than the estimated overflow. Therefore, it was possible to evaluate the capacity of the regulating devices during rainfall.

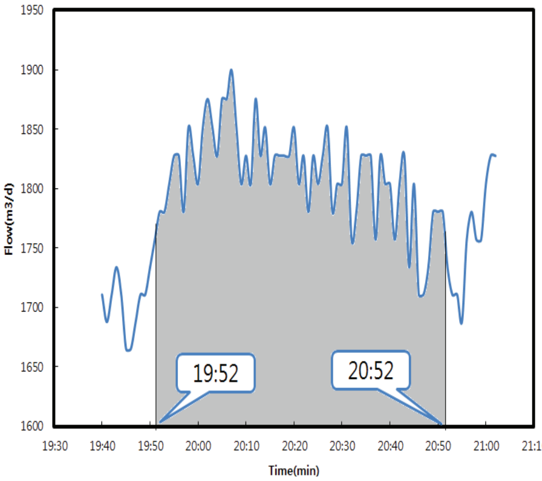


Fig. 3. Variation in the daily average flow at 1-min intervals for estimating the hourly maximum flow.

3.3. Effect of opening and closing the gate of the inflow controller

In Japan, to control combined sewer overflow, the effluent standard for overflow in a combined sewer is regulated to be less than a BOD of 40 mg/L [9], but there is no effluent standard in South Korea. Assuming COD_{mn} was 30 mg/L during the dry season, which is less than the average COD concentration of sewage 60 mg/L, the EC was set to 300 μs/cm for the COD_{mn}. Sewer operators can also flexibly control the intercepted overflow based on the appropriate policy standards.

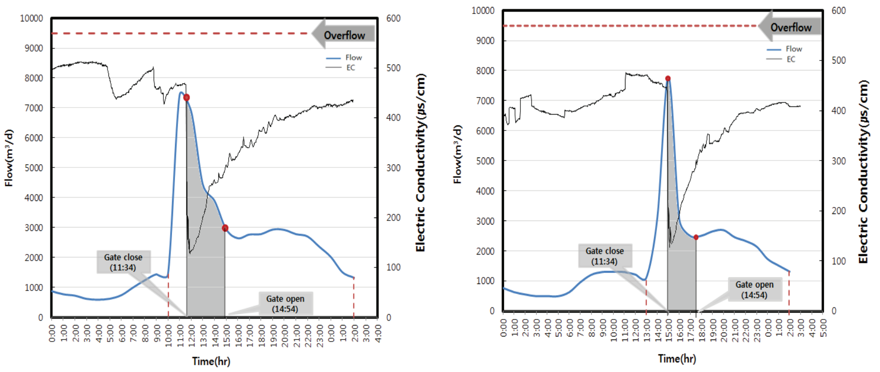
3.3.1. Analysis of effects of short-term rainfall events

Fig. 4 shows three cases of flow reduction which occurred when the gate was closed during single day for short-term rainfall events. Fig. 6(a) shows that the EC value kept dropping after the gate closing time of 11:34 a.m., as the EC was reduced by the dilution effect with increasing flow [16]. The total gate closing time was about 3 h among the total 6 h for the rainfall period. In this event, the inflow of the STP was reduced by the diluted sewage (designated by the oblique part in the figure) overflowed into the stream not to enter the intercepting sewer. Figs. 6(b) and (c) show the other cases, on different days, respectively.

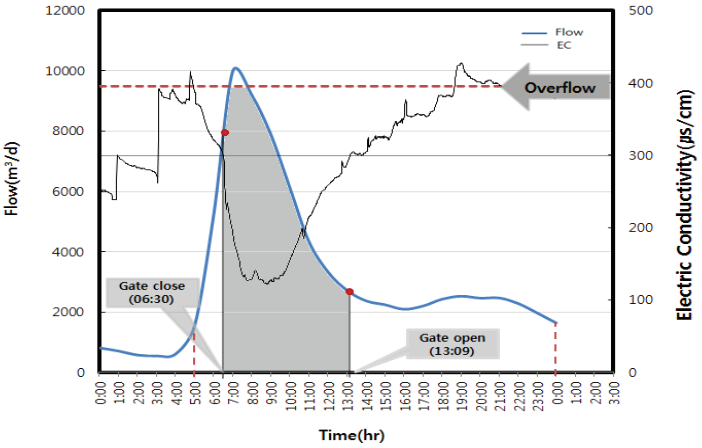
Table 4 shows the controlled rate of flow and the COD load produced by the closed gate during the short-term rainfall events. The controlled rate of flow was estimated using the ratio of overflow to the total discharge for the stream. The COD load control rate was also estimated by the ratio of overflow load to the total COD load. The average controlled rate of flow and COD load were about 44% and 16%, respectively, even though the rainfall amount was somewhat different for the three rainfall events.

3.3.2. Analysis of the effects of long-term rainfall events

Fig. 5 shows two cases of flow reduction during long-term rainfall events over 3 d. Fig. 5(a) shows the control effects produced by closing the gate over 3 d. The time of rainfall



(a) August 2, 2015 (b) August 8, 2015



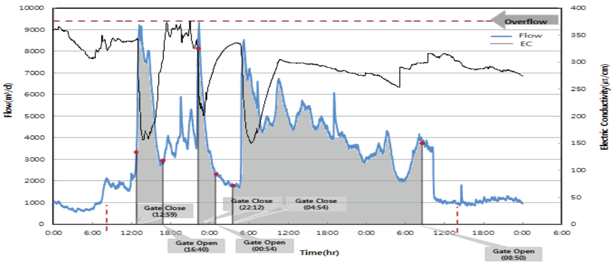
(c) October 27, 2015

Fig. 4. Three cases of flow reduction produced by closed gates for short-term rainfall events: (a) August 2, 2015, (b) August 8, 2015, and (c) October 27, 2015.

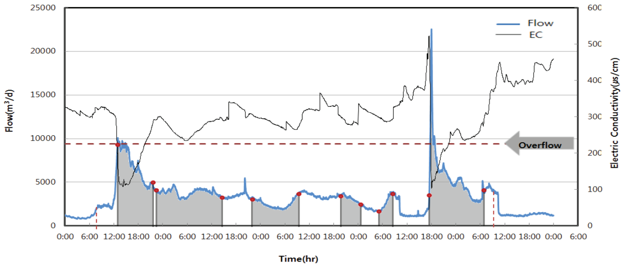
Table 4
Controlled rates of flow and COD load produced by the closed gate in the short-term rainfall events

Date	Total discharge		Intercept		Overflow	
	Flow (m³)	COD load (kg)	Flow (m³)	COD load (kg)	Flow (m³)	COD load (kg)
August 2, 2015	2,078 (100%)	83 (100%)	1,290 (62%)	70 (84%)	788 (38%)	13 (16%)
August 8, 2015	1,428 (100%)	57 (100%)	912 (64%)	49 (85%)	516 (36%)	8 (15%)
October 27, 2015	3,094 (100%)	101 (100%)	1,258 (41%)	82 (81%)	1,836 (59%)	19 (19%)
Average	–	–	56%	84%	44%	16%

duration was about 51 h, and the gate closing time was about 35 h. The three gates were closed as shown in Fig. 5(a), but as in Fig. 5(b) the rainfall duration was about 75 h, the gate closing time was about 56 h, and six gates were closed.



(a) From November 7 to 9, 2015



(b) From November 13 to 16, 2015

Fig. 5. Two cases of flow reduction produced by closed gates for the long-term rainfall events: (a) from November 7 to 9, 2015 and (b) from November 13 to 16, 2015.

Table 5 shows the controlled rate of flow and COD load for the long-term rainfall events. The controlled rate for flow and COD load were about 75% and 61%, respectively. The controlled rate for the long-term rainfall events was higher than for the short-term rainfall events. Essentially, the longer the rainfall duration time, the higher the controlled rate of flow.

3.4. Effects of controlling flow and COD load by controlling EC

Table 6 shows the flow control rates and COD load rates based on controls using the EC of the sewage inflow. The flow control rate was about 44% and 75% at an EC of 300 µs/cm, for the short-term and long-term rainfall events, respectively. Fig. 6 shows the relationship between the average flow control rates and the EC. The flow control rate was about 40% at an EC of 250 µs/cm. However, the EC of the short-term rainfall events was relatively lower than that of the long-term rainfall events. Even when the control rates were somewhat different based on the amount of rainfall, rainfall duration time, and antecedent dry day, etc., the flow control rates could be predicated from the relationship between EC and flow control rates (Fig. 6).

4. Conclusions

This study was performed to evaluate a method of controlling sewage flow using an inflow controller with an EC sensor in the outfall. To investigate the relationship between the water quality characteristics of the sewage and its EC in the field, the EC sensor was used for real-time monitoring. According to the results it was found that the correlation coefficient (R^2) of COD_{mn} vs. EC was higher than 0.97. A reliable

Table 5
Controlled rates of flow and COD load produced by closed gates for long-term rainfall events

Date	Total discharge		Intercept		Overflow	
	Flow (m³)	COD load (kg)	Flow (m³)	COD load (kg)	Flow (m³)	COD load (kg)
November 7–9, 2015	8,447 (100%)	260 (100%)	1,933 (23%)	84 (33%)	6,514 (77%)	176 (67%)
November 13–16, 2015	14,674 (100%)	430 (100%)	4,009 (28%)	194 (45%)	10,665 (72%)	236 (55%)
Average	–	–	25%	39%	75%	61%

Table 6
Flow control rates and COD load rates based on controls using the electrical conductivity

Date	200 µs/cm		300 µs/cm		400 µs/cm	
	Flow (%)	COD load (%)	Flow (%)	COD load (%)	Flow (%)	COD load (%)
August 2, 2015	20	3	38	16	60	43
August 8, 2015	18	3	36	15	75	61
October 27, 2015	43	6	59	19	85	53
Average	27	4	44	16	73	52
November 7–9, 2015	9	3	77	67	100	100
November 13–16, 2015	20	3	72	55	100	100
Average	15	3	75	62	100	100

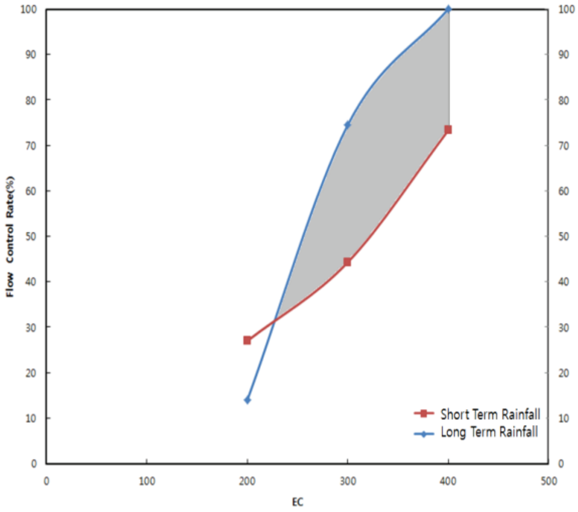


Fig. 6. Relationship between flow control rates and electrical conductivity.

hourly maximum flow was calculated using the real-time monitoring data and a water level sensor. The capacity of the proposed regulating devices was evaluated during actual rainfall events by comparing the predicted flow with the flow measured by field survey. When the gate was closed at an EC of less than 300 µs/cm, the flow control rate of the overflow for the total discharge period was about 44% and 75% during the short-term rainfall events (once a day) and long-term rainfall events (over 3 d), respectively, and the COD load control rate was about 16% and 61%, respectively. The flow control rate varied according to the EC control setting, and the higher the EC control setting was, the more the flow control rate increased. The flow control rate was about 40% at an EC of 250 µs/cm. However, the EC of the short-term rainfall event was relatively lower than that of the long-term rainfall event.

Acknowledgments

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References

[1] ASCE, WPCF, Design and Construction of Sanitary and Storm Sewers, New York, 1979, pp. 1–2.
[2] J. Kim, I. Ko, Modeling of discharge characteristics of combined sewer overflows (CSOs) from a small urban watershed in Daejeon City, J. Korean Soc. Environ. Eng., 28 (2006) 654–660.
[3] B. Lee, S. Kim, Basic concept of nonpoint source pollution counterplan, J. Korean Soc. Civil Eng., 55 (2007) 75–80.
[4] B. Lim, D. Kim, K. Lee, Effect and control of the sediment in the combined sewer on CSOs, J. Korean Soc. Water Qual., 27 (2011) 36–43.
[5] C. Kwon, B. Lim, Effect of separation walls on reduction of suspended solids loading in a combined sewer system, Korean Soc. Water Qual., 26 (2012) 787–796.
[6] B. Lim, Y. Park, T. Kim, Improvements of inflow controller installed in storm overflow diverging tank for CSOs control, Korean Soc. Water Qual., 31 (2015) 428–435.
[7] Ministry of Environment, Development of Core Technologies for Existing Sewage Rehabilitation, Gwacheon, 2004.
[8] W. Choi, C. Song, The flow rate estimation of CSOs using EC data, Korean Soc. Water Qual., 25 (2011) 751–757.
[9] W. Choi, C. Chung, J. Nam, W. Koo, K. Jung, The flow and water quality estimation of CSOs using EC data and civil engineering research model, J. Korean Soc. Environ. Eng., 39 (2014) 178–184.
[10] Ministry of Environment, Korean Standard Methods of Water Pollution, Gwacheon, 2014.
[11] APHA, AWWA, WEF, Standard Methods for the Examination of Water and Wastewater, 21th ed., Washington, D.C., 2005.
[12] Korean Water and Wastewater Works, Design of Sewerage Treatment Plant, Gwacheon, 2011.
[13] S. Gong, Evaluation on I/I and Mixed Characteristics of Sewage Using Data of Electrical Conductivity, Master Thesis, University of Seoul, 2010.
[14] W. Choi, Study on the Development of CSOs Monitoring Method Using EC, Honam University, PhD Thesis, 2011.
[15] A.A. Zorpas, L.A. Ilia, I. Voukkali, V. Inglezakis, Micropollutants identification affecting the nearby environment from highway runoff: the case study of Cyprus highway, J. Chem., (2015) 1–12.
[16] J. Park, N. Lee, H. Kim, W. Lee, C. Lee, Effect for CSOs storage construction, J. Korean Soc. Water Wastewater, 25 (2011) 949–957.