Water Science & Technology—WST | 61.9 | 2010

Field observations and management strategy for hot spring wastewater in Wulai area, Taiwan

J. Y. Lin, C. F. Chen, F. R. Lei and C. D. Hsieh

ABSTRACT

Hot springs are important centers for recreation and tourism. However, the pollution that may potentially be caused by hot spring wastewater has rarely been discussed. More than half of Taiwan's hot springs are located in areas where the water quality of water bodies is to be protected, and untreated wastewater could pollute the receiving water bodies. In this study, we investigate hot spring wastewater in the Wulai area, one of Taiwan's famous hot spring resorts. Used water from five hot spring hotels was sampled and ten sampling events were carried out to evaluate the changes in the quality of used water in different seasons, at different periods of the week, and from different types of hotels. The concentrations of different pollutants in hot spring wastewater were found to exhibit wide variations, as follows: COD, 10–250 mg/L; SS, N.D. −93 mg/L; NH_3-N, 0.01–1.93 mg/L; TP, 0.01–0.45 mg/L; and *E. coli*, 10–27,500 CFU/100 mL. The quality of hot spring wastewater depends on the operation of public pools, because this affects the frequency of supplementary fresh water and the outflow volume. Two management strategies, namely, onsite treatment systems and individually packaged treatment equipment, are considered, and a multi-objective optimization model is used to determine the optimal strategy.

Key words | hot springs, optimization model, pollution, wastewater treatment

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INTRODUCTION

Hot springs, also known as geothermal water or thermal water, are important natural resources for tourism. Countries such as Iceland, New Zealand, Chile, and Japan are renowned for their hot springs. Hot springs are also abundant in Taiwan, where 95 have been identified thus far (ITRI 2003). However, half of these springs are located in areas where the quality of water needs to be protected, and the ever-increasing number of tourists visiting hot spring resorts is a potential source of pollution. Untreated hot spring wastewater could contaminate receiving water bodies.

The background levels of some naturally occurring substances are of concern from the viewpoint of public health and the environment. Alkaline hot spring waters contain high levels of K, Na, F, Cl, SiO_2, and dissolved solids (TDS) (Zhang *et al.* 2008). In addition, toxic elements such as arsenic may be present. Arsenic speciation from hot springs was determined by Kaise *et al.* (1997). Koch *et al.* (1999) found that in Canada, the level of arsenic is naturally high. The diffusion of As and Sb from thermal water into freshwater and crops could be a threat to public health (Zhang *et al.* 2008).

However, the characteristics of untreated wastewater from hot springs have not been studied in adequate detail. Many studies have focused on diseases, including viruses (Schoenfeld *et al.* 2008), bacteria (Hall *et al.* 2008), and phages (Breitbart *et al.* 2004). Very few, however, have focused on wastewater pollution. In 2005, the Hot

doi: 10.2166/wst.2010.088

Spring Act was legislated in Taiwan to manage hot spring resources. Similar regulations are in force in Japan, Korea, and China. These regulations do not specify an effluent standard for hot spring wastewater. In the United States and Europe, hot springs are utilized mainly for their therapeutic properties and as sources of thermal energy. The management of hot spring wastewater in the tourism industry has hardly been regulated.

Hot spring wastewater is usually treated in one of two ways. The first method is to discharge the wastewater directly into the sewage system and to charge a treatment fee to the discharger. This approach has been implemented in Japan, where the treatment fee for hot spring wastewater is cheaper than that for domestic sewage and different fees are charged in different areas. The second method is to use the effluent wastewater standards applicable to restaurants, hotels, and recreational resorts or enterprises to control hot spring effluents. This approach is commonly used in China and Korea. In the US and Europe, hot spring wastewater is discharged directly into sewers. However, in Taiwan, hot spring wastewater is not adequately controlled. Because many resorts are located in the highlands where no sewage system has been established, most hot spring wastewater is discharged without treatment into receiving water bodies.

To understand the pollution that may potentially be caused by hot spring wastewater, we carried out a field investigation in the Wulai area. Wulai is a famous hot spring resort in Taiwan. Because of its proximity to the capital, Taipei City, it has become a popular recreation and tourism area. However, Wulai is located upstream of Nanshih Creek, which supplies drinking water to Taipei. Lin *et al.* (2005) observed a noticeable degradation in water quality in Nanshih Creek downstream of the Wulai area. Yang (2005) reported inconsistent distributions of plankton and algae in the upstream and downstream areas and found that pollution is worse downstream. Therefore, our field investigation assessed the properties of hot spring wastewater and its effects on water quality. We also discuss management strategies. A multi-objective optimization model is designed to determine the optimal solution. Through this multi-objective model, we can devise an optimum treatment strategy for the Wulai area with minimum cost and maximum water quality improvement.

METHODS

Description of case study

The Wulai area is located in the Nanshih Creek protection area. A total of 74 hot spring hotels, resorts, and recreation centers have been built in this area, and in 2007, the number of visitors was 750,000 (IOT 2009). The Nanshih Creek protection area is one of the sources of drinking water for citizens in Taipei City and Taipei County. To protect the water quality, development is controlled more strictly here than elsewhere. Domestic sewage and recreational wastewater have conventionally been regarded as the two main pollution sources for Nanshih Creek. However, previous studies also suggested untreated hot spring wastewater as a pollution source (Lin *et al.* 2005; Yang 2005).

The Wulai area can be divided into four subdivisions according to their geographical distribution along Nanshih Creek: Wulai itself, Wenchiuan, Huangshan, and Yanti (Figure 1). The types of hotels in these subdivisions are different. Large hotels are concentrated in Yanti, which has few hotels but each has many rooms. Medium- and small-scale hotels are located in Wulai and Huangshan. In Wenchiuan, private spa rooms are popular, but tourists do not stay overnight.

Five hot spring hotels allowed us to obtain samples, as shown in Figure 1, and the sampling period was from May 2006 to January 2007. Ten samples were obtained and

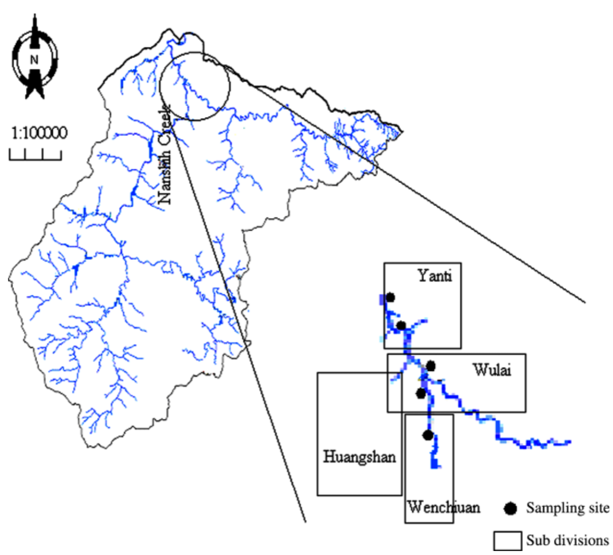

Figure 1 | Location of the Wulai area in Taiwan.

were grouped as weekday and weekend samples to clarify the effects of the number of tourists. The seasonal variability was considered as well. The samples obtained in May and June were defined as summer samples, and those obtained in November, December, and January, as winter samples. In addition, because the type of hotel might influence the wastewater characteristics, five different types were chosen. The sample points in Yanti and Wulai respectively have large and small public pools and private pools. That in Wenchiuan has no public pools, and the private rooms have both a bath and a spa.

The sampling date and water quality at the five sample points are listed in Table 1. All water samples were preserved in an icebox and delivered to the laboratory on the same day; temperature, pH, and dissolved oxygen (DO) measurements were performed onsite using monitoring meters. The water quality analysis was based on the following national standards: NIEA W210.57A, NIEA W515.54A, NIEA W448.51B, NIEA W444.51C, and NIEA E202.53B for suspended solid (SS), chemical oxygen demand (COD), ammonia-nitrogen (NH_3-N), total phosphorous (TP), and coliform group (*E. coli*), respectively. Because Nanshih Creek is a drinking water source, the eight water-quality characteristics analyzed were chosen by considering issues related to water eutrophication and ecosystem preservation.

Determination of hot spring wastewater management strategy

Multi-objective optimization model

Environment management is a multiple-attribute system, in which a balance between conflicting objectives such as economic efficiency and environment protection must be sought. Multi-objective optimization programming is a useful approach for determining environmental policies. In hot spring wastewater management, there are three objectives, namely, minimizing treatment cost (Z_1) (Equation (1)), maximizing quantity of treated wastewater (Z_2) (Equation (2)), and minimizing effluent concentration (Z_3) (Equation (3)). Q_{ij} indicates how much wastewater is tackled by treatment method j in subdivision i (m^3/day) and p_j is the treatment cost for method j in New Taiwan Dollars (NTD) (NTD/m^3). C_{out} is the effluent concentration after treatment. The constraints in the model are determined by the quantity and quality of treated water. Equation (4) limits the quantity of treated water to no more than that of the total wastewater, and Equation (5) ensures that the treated water quality complies with the quality standard, where C_{in} is the constituent concentration of raw hot spring wastewater, which is based on the COD, and r_j is the pollution removal rate of different treatment methods j (%). C_s is the water quality standard.

Table 1 | Field samples and water quality in hot spring wastewater in Wulai area, Taiwan

Date mm/dd/yy	Temperature (°C)	pH	DO (mg/L)	COD (mg/L)	SS (mg/L)	NH_3-N (mg/L)	TP (mg/L)	*E. coli.* (CFU/100 mL)	Notes
05/17/06	–	–	–	–	N.D. −6*	1.590–1.930	0.087–0.116	10–70	Weekday
05/27/06	30.8–38.5	7.33–7.99	4.58–7.05	10–75	2–14	0.084–0.211	0.019–0.453	250–2,175	Weekend
06/05/06	27.3–36.5	7.51–7.63	5.84–7.31	20–60	–	0.077–0.084	0.019–0.453	25–27,500	Weekday
06/17/06	27.0–39.5	7.33–8.25	7.53–13.04	60–250	7–13	0.099–0.251	0.015–0.114	500–10,000	Weekend
06/29/06	29.4–37.5	7.15–8.07	7.89–10.93	5–10	3–13	0.105–0.152	0.008–0.03	550–10,600	Weekday
11/04/06	24.3–35.3	7.07–8.02	8.34–13.02	10–40	10–93	0.080–0.710	0.021–0.056	50–3,850	Weekend
12/19/06	24.3–35.3	7.07–8.02	8.34–13.02	10–40	12–15	0.144–0.686	0.021–0.091	50–6,750	Weekday
12/30/06	20.6–39.2	6.28–8.15	8.56–13.00	20–60	4–17	0.076–0.642	0.011–0.043	50–5,050	Weekend
01/13/07	23.6–37.0	6.2–8.1	7.88–10.11	5–60	N.D.-83	0.010–0.020	0.010–0.017	4,250–7,550	Weekend
01/23/07	21.6–37.3	5.9–7.96	6.38–10.59	20–50	N.D.-81	0.360–1.400	0.010–0.010	5,750–10,000	Weekday

*N.D. denotes non-detected value.
–, No data.

Objective function:

$$\text{Min}\, Z_1 = \sum_i \sum_j f(Q_i, p_j) \quad (1)$$

$$\text{Max}\, Z_2 = \sum_i \sum_j Q_{ij} \quad (2)$$

$$\text{Min}\, Z_3 = C_{\text{out}} \quad (3)$$

subject to

$$\sum_j Q_{ij} \leq Q_i \quad (4)$$

$$C_{\text{out}} = f(Q_{ij}, C_{in}, r_j) \leq C_s \quad (5)$$

NSGA-II algorithm

Multi-objective programming is complex, and many different algorithms that can search for an optimum solution have been developed. NSGA-II, developed by Deb *et al.* (2002), is a genetic algorithm (GA) consisting of three main steps: (1) Non-Dominated Sorting, (2) Crowding Distance Computation, and (3) Crowded Computation Operator. The Pareto frontier for multi-objective optimization is derived by genetic evolution and stratification classification. The applicability of NSGA-II to various fields has been verified previously (Nassif *et al.* 2004; Farmani *et al.* 2005; Kapelan *et al.* 2005; Wei *et al.* 2006; Kollat & Reed 2007).

RESULTS AND DISCUSSION

Properties of hot spring wastewater

Five sample points and ten sample events, five each in summer and winter, were obtained. Moreover, five each were obtained estimated on weekends and weekdays. The temperature of the hot spring wastewater ranges from 20.6–39.5°C, which is higher than that of the receiving water body, Nanshih Creek, of 21.2°C. Because of high turbulence in the hot spring pools and fluctuation in the discharge, a high DO value ranging from 4.58–13.02 mg/L is observed. The ranges of the constituent concentrations of COD, SS, NH_3-N, TP, and *E. coli.* in untreated wastewater are 10–250 mg/L, N.D.-93 mg/L, 0.01–1.93 mg/L, 0.01–0.45 mg/L, and 10–27,500 CFU/100 mL, respectively (Table 1).

The water quality over different seasons and holidays is listed in Table 2. There are clearly more visitors on weekends; however, for privacy reasons, the hotels did not provide the exact number of users in the sampled pools. It was observed that there were around two to three times more visitors on weekends than on weekdays. The field data show that the water temperature, pH, DO, TP, and SS are similar on weekdays and weekends; however, the concentrations of COD, NH_3-N, and *E. coli.* are different. The values of NH_3-N and *E. coli* were maximum on weekdays. To illustrate the variability of sample data, Figure 2 shows the probabilistic distribution of wastewater quality: the x-axis corresponds to the constituent concentration and the y-axis, to the accumulation probability for that concentration. The probabilistic scenario shown in Figure 2 illustrates the variability in the constituents, e.g. the COD concentrations on weekdays are below 50 mg/L, whereas those on weekends are highly variable. Figure 2 also indicates the probability of exceeding the water quality standard. For example, on weekends, the given COD standard of 50 mg/L may be exceeded by approximately 20%, but it is satisfied on weekdays.

The SS concentrations are very similar on weekends and weekdays, both values being less than 80 mg/L;

Table 2 | Constituent concentration range of wastewater and raw hot spring water

Events	Temperature (°C)	pH	DO (mg/L)	COD (mg/L)	SS (mg/L)	NH_3-N (mg/L)	TP (mg/L)	*E. coli.* (CFU/100 mL)
Weekday	21.6–37.5	5.9–8.07	5.84–13.02	5–60	N.D.-81	0.077–1.930	0.010–0.453	10–27,500
Weekend	20.6–39.5	6.2–8.25	4.58–15.04	5–250	N.D.-83	0.010–0.710	0.010–0.453	50–10,000
Summer	27.0–39.5	7.15–8.25	4.58–15.04	5–250	N.D. −14	0.077–1.930	0.008–0.453	10–27,500
Winter	20.6–39.2	5.9–8.15	6.38–13.02	5–60	N.D. −83	0.010–1.400	0.010–0.091	50–10,000
Raw hot spring*	73	–	–	2.95	1.6	1.85	0.018†	–

*Lin (2006).
†Indicated in PO_4^{3-}.

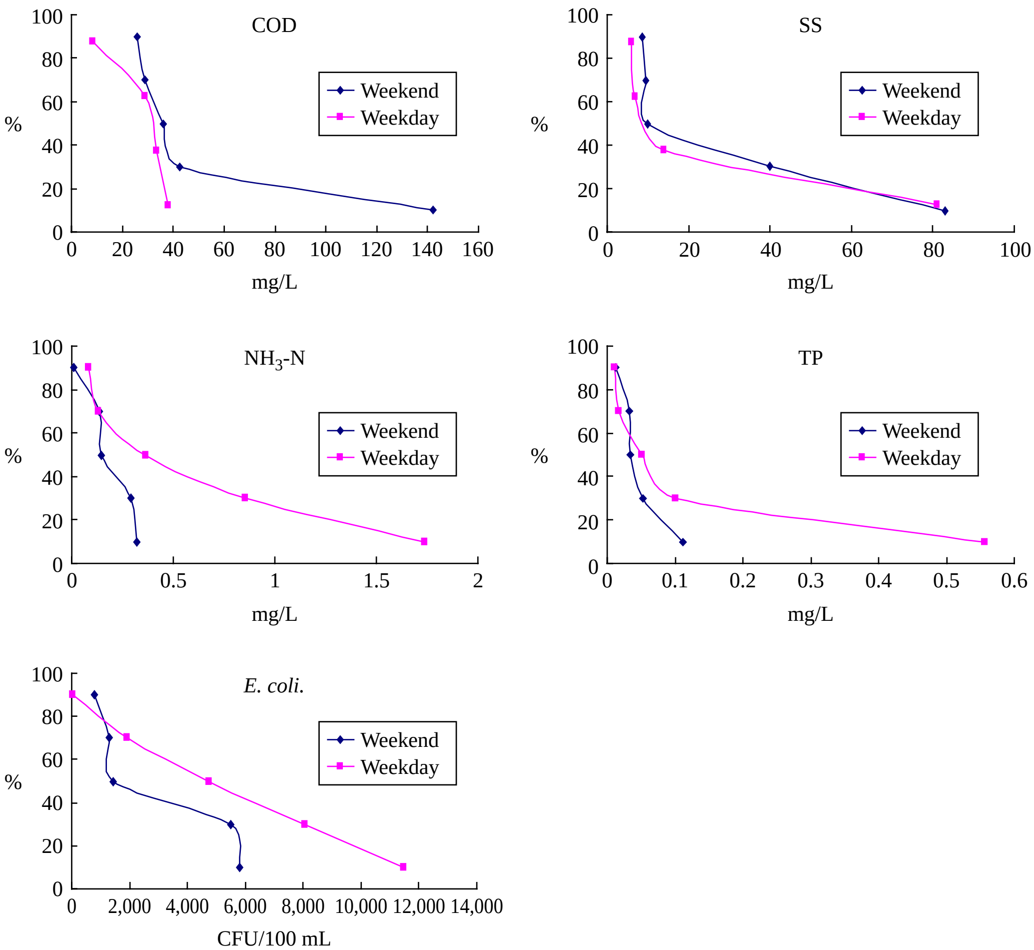

Figure 2 | Probabilistic distribution of effluent quality of wastewater discharged from hot spring hotels in the Wulai area (*x*-axis corresponds to the constituent concentration and *y*-axis, to the accumulation probability for that concentration).

however, the concentrations of NH_3-N, TP, and *E. coli.* are higher on weekdays than on weekends. This variation might be related to the frequency of cleaning and the amount of fresh influent water. There are more visitors on weekends, and the frequent use of public pools requires more water to be introduced into the pools, which might decrease the pollution concentration. The wastewater quality from three different types of hot spring hotels shows that the used water effluent from public pools might have less contaminants due to more fresh water flow into pools. On the contrary, the effluent from private rooms might contain some bath liquids and increased contaminants. The operation of public pools significantly affects the wastewater quality of hot springs. Nevertheless, the number of visitors has an indirect effect on wastewater quality because the outflow volume might increase with these numbers. Less overflows are observed on weekdays. This is confirmed from the quantity of sample wastewater, which was estimated using containers (NIEA W020.51C). The total wastewater on weekends (4,500 m^3/day) is greater than that on weekdays (3,500 m^3/day). In addition, people stay in the pools for only 1–2 h. The pollutants brought into the pools might be diluted by frequent inflow of fresh water.

Optimal treatment for hot spring wastewater in the Wulai area

Based on the results of our field observation, further treatment of hot spring wastewater is recommended and two management strategies are proposed. One strategy is

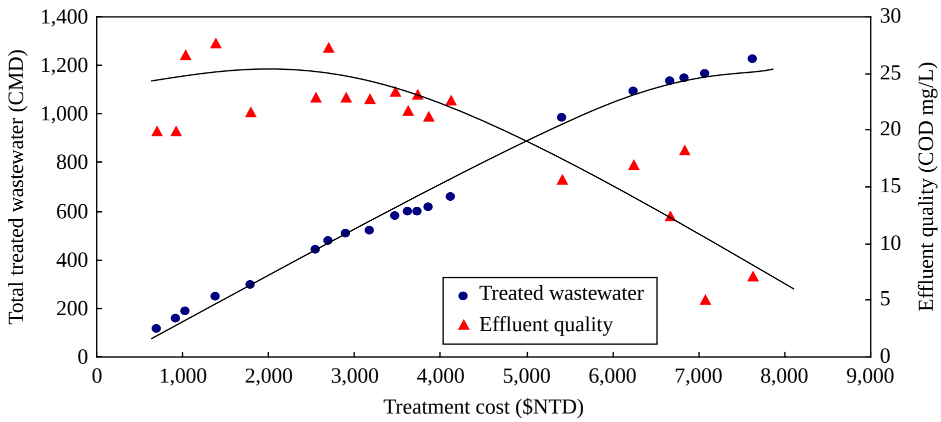

Figure 3 | Results of the optimization model with three objectives.

to collect the wastewater for treatment in a combined treatment system. The other is to install small packaged treatment equipment at individual emission sources. The combined system involves environmentally friendly onsite treatment; however, it requires considerable space. In contrast, individual treatment requires little space, but is much more expensive.

Because Wulai is a hilly area, an approach that provides high treatment efficiency while requiring less space is preferable, and therefore, an aeration system with packed material is suggested for the combined system. The critical requirement of this system is an aeration tank with packed material for biomass growth. The optimum COD removal rate suggested by the model developed in this study is 70%. Because of the diversity in the landscape of the area, the unit treatment cost, which is calculated by considering land requirements and the collection system, varies for each subdivision. On the other hand, the individual equipment used for wastewater treatment is commercially available, and filtration is the main treatment process in this equipment. The equipment should be heat- and corrosion-resistant and should have a high wash-back efficiency. Such equipment has an average COD removal rate of 85%.

To determine the optimal treatment strategy, an optimization model with three objectives–minimizing cost, minimizing effluent concentration, and maximizing quantity of treated wastewater–is used and the NSGA-II algorithm is applied. The optimal solution is shown in Figure 3. The points on the figure indicate different optima, each representing a different level of compromise among the three objectives. To make a final decision, a weighting of the objectives or an additional integrated criterion is commonly used. For example, if the three objectives are assigned equal weights, the final decision might be determined on the basis of the crossing point, which in this case corresponds to a treatment cost of 5,000 NTD, a total treated wastewater quantity of 850 m^3/day (cubic metres per day, CMD), and an effluent COD concentration of 18 mg/L. The optimal curve of effluent

Table 3 | Example of optimal programming for the Wulai area

	Subdivision				
Treatment approach	**Wenchiuan**	**Wulai**	**Huangshan**	**Yenti**	**Total**
Combined system (m^3/day)	5.8 (0.7%)	2.5 (0.2%)	68.7 (5.1%)	465.1 (43.5%)	542.1 (12.4%)
Individual system (m^3/day)	0 (0%)	0.4 (0%)	0 (0%)	571 (53.4%)	571.4 (13.0%)
Non-treated (m^3/day)	806.2 (99.3%)	1,153.1 (99.8%)	1,286.3 (94.9%)	32.9 (3.1%)	3,278.5 (74.6%)
Total	812 (100%)	1,156 (100%)	1,355 (100%)	1,069 (100%)	4,396 (100%)

quality indicates that the effluent quality is clearly improved when the cost of treatment is above 4,000 NTD and when the quantity of treated wastewater is more than 600 CMD.

A solution that involves a treatment cost of 5,406 NTD and treated wastewater quantity of 1,103 CMD can be suggested, and this strategy leads to a COD concentration of 15.7 mg/L in the effluent. Table 3 lists the values of the decision variables in this solution. If 25.4% of the wastewater is treated, the effluent COD concentration can be minimized. Because the treatment cost is less in Yanti than in the other subdivisions, more wastewater is treated there. By considering the local characteristics of land in the different areas, an optimum treatment strategy to improve wastewater at less cost can be obtained. The cost of this solution is much less than the cost of treating all the wastewater using either a combined treatment system (32,438 NTD) or an individual system (39,981 NTD).

CONCLUSIONS

The properties of hot spring wastewater have been studied by means of a field investigation in the Wulai area, Taiwan. Before the field investigation, the premise that more visitors to hot springs might increase the pollutant concentration in effluents is made. Unexpectedly, the wastewater quality is significantly affected by the operation of public pools, and not directly by the number of visitors. The frequency of pool cleaning and the amount of inflow of fresh water can dilute the potential pollution. As field observations, the effluent from private pools contains a large amount of bath liquids with a particularly high concentration of phosphorous. The wastewater quality of public pools is generally better than that of private pools. Two major recommendations are derived from this study. First, before selecting a wastewater treatment system, using public pools and replacing pool water regularly are encouraged to reduce hot spring wastewater pollution. Second, before designing a treatment system, because of the limited land area and mountainous topography in the resort region, management strategies that require less space, onsite treatment facility, and individually packaged equipment are suggested rather than a large and complicated treatment system.

ACKNOWLEDGEMENTS

This work was funded by a grant from the Taipei Water Management Office (TWMO) of the Water Resources Agency at the Ministry of Economic Affairs in Taiwan. We thank the members of TWMO for their useful comments.

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