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IMPACT OF HOT SPRING BATHING WATER ON THE WATER QUALITY IN THE NAN-SHIH CREEK

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***Key Words* :** Hot spring spas, bathing water discharge, water quality impact, modeling analysis

ABSTRACT

For many years, hot spring spas have been a major tourist attraction in Taiwan. During peak tourist seasons a very large amount of bathing water is usually discharged into streams without treatment, which could result in the degradation of the receiving water quality. The Nan-shih Creek, which supplies drinking water to the Taipei Metropolitan area residents, was chosen for a case study. To investigate whether the untreated bathing water discharge of hot spring spas would adversely impact the Nan-shih Creek water quality, the stream model QUAL2E was used to simulate the impact. It was found that when the stream flow was close to the design low flow, (Q_{75} is used in Taiwan), the NH_3-N and coliform levels in the Nan-shih Creek would exceed river water quality standards as a result of the hot spring spa bathing water discharge. QUAL2E simulates both the concentrations of NH_3-N and coliform in the conditions of stream flow with and without hot spring bathing water. It indicates if no hot spring bathing water is drained into the Nan-Shih Creek, the concentration of NH_3-N and coliform can be reduce by 13% and 19%, respectively. The results indicate that during high tourist seasons, untreated bathing water discharges may cause violation of river water quality standards in receiving streams. It is therefore imperative for the environmental authorities in Taiwan to regulate such discharges to protect its water environment.

INTRODUCTION

The definition of hot spring [1] in Taiwan refers to warm water, mineral water, vapor and other gases emerging from underground, except natural gas containing hydrocarbons. In addition to water temperature, the basic elements in hot spring definition include chemical composition. The temperature of water emerging from underground should be higher than 30 °C. If water temperature is lower than 30 °C but contains certain chemical composition, it could also be defined as hot spring water.

Taiwan is abounding with hot spring resources. Many major hot spring spas in Taiwan were developed in the early years and most of them were not well planned and regulated. Hot spring spas, being one of the most popular vacation and relaxation designations, have long played an important role in the tourism businesses in Taiwan. During cooler months (normally from October to March) in a year all the hot spring resorts have been always over-crowded. Facilities at many hot spring resort areas are considered inadequate. For example, problems such as messy landscape, worn-out equipment, poor hygiene conditions, lack of registration for water right, and illegal use of public land have been discovered at some spas. Seeking to remedy the above-mentioned problems, the Taiwan Water Resources Agency (TWRA) has recently proposed a hot spring regulatory framework. The proposed regulation will enable the existing recreational and tourist operators to obtain a legal business status; to promote properly planned tourism development; and to enact an environmentally friendly and sustainable approach to exploring hot spring resources. In the mean time, the TWRA is working to improve conditions at the hot spring spas by using exiting relevant laws and regulations such as hot spring water use permit regulations.

Water quality of the released bathing water is an important issue for managing hot spring spas. To obtain the necessary information for developing a regulatory plan, the TWRA is sponsoring the current study presented herein on the impact of the hot spring bathing water on the receiving water quality.

Previous research on Taiwan's hot springs can

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be traced back to hot spring surveys by Cheng [2]; in which Cheng suggests that it is possible to utilize geochemical prospecting and chemical reaction equilibrium to determine hot spring temperatures. Chen [3] determined that the hot spring in the central mountain area of Taiwan contains $NaHCO_3$. Lin and Chiu [4] began to sample and analyze the Taiwan's hot spring bathing water. Rytuba [5] indicated that mercury could deposit from hot spring. Hinman revealed that the concentration of soluble silica varies little with seasons, temperature, discharge, water stage, and microscopic organisms [6]. Renaut suggested that when hot spring infused into a lake, would produce some crispy organism silica [7]. Samsudin observed that hot spring could appear in granite beds, enriching abundant water and highly permeable geology nearby [8]. Zhao indicated that underground water passing by hot granite, is heated by a concentrated heat process and then transported to earth surface via buoyancy [9]. The water temperature and quality does not change with time. The concentration of some constituents in hot spring water are higher than those in normal stream water, including K^+, Na^+, Ca^{2+}, Mg^{2+}, SO^{2-}, HCO^-_3, F^-, Cl^-, SiO_2, HBO_2, CO_2, pH, total dissolved solids (TDS), Hg, As, Sb, Be, Li, Rb and Cs [10].

Literature cited above all deal with characteristics of hot spring water. Although no more information is available on the impact of the hot spring spa bathing water on receiving water quality, Yang [1] indicated that NH_3-N must be a concerned factor in the "source water protection area" especially. The present study has its focus on the released hot spring bathing water in Wu-Lai Village in Northern Taiwan and its impact on water quality and quantity of the receiving stream.

DESCRIPTION OF THE STUDY WATERSHED AND DATA

The major water sources for the Taipei Metropolitan Area are the Nan-Shih Creek and the Feitsui Reservoir, shown in Fig. 1. When the flow in the Nan-Shih Creek is not enough to meet the water demand, the Feitsui Reservoir, located on the Pei-Shih Creek will release water as a supplement. Most of the time water demand for Taipei is adequately supplied by the Nan-Shih Creek. If water in the Nan-Shih Creek is contaminated, the cost for water treatment will most likely to increase. Therefore it is important to protect the Nan-Shih Creek water quality. There are five rain gage stations in the Nan-Shih Creek watershed, namely, Guei-Shan, Tung-Hou, Hsin-Sien, Hsao-Yi and Fu-Hsan, all operated by the TWRA. The annual rainfall is between 3,000 mm to 4,000 mm and distributes fairly evenly throughout the year. Based on the latest 10 years' hydrological data, the average annual flow of the Nan-Shih Creek is 41.46 m^3/s.

Wu-Lai, one of the most popular hot spring tourist attractions, is located at the upstream portion of the Nan-Shih Creek and near a major tributary, the Tung-Hou Creek. In 2002 more than 900,000 people visited this small mountain town. The water flow for Wu-Lai's hot springs is 15 ton/min, i.e. 21,600 CMD. The hot spring temperature of Wu-Lai is between 80 to 86 ^oC. The water is colorless, smell-free, has a pH value of 7.4 and is rich in bicarbonate. Most of the hot spring water is used by the resorts and local residences.

Fig. 1. Location of the area under study.

IMPACTS ON STREAM WATER QUALITY

In the Wu-Lai area, the wastewater is composed of domestic wastewater, tourist's wastewater, and hot spring bathing water. Estimation of the domestic wastewater flow is based on the following equation:

$$Q_D = KW_D P \quad (1)$$

where Q_D is the domestic wastewater flow; K is a coefficient, usually 0.8 in Taiwan [11]; W_D is the daily wastewater quantity per person; P is the population. In 2002, W_D was 352 L/day and P was 3,469 in Wu-Lai. The domestic wastewater flow entering the Nan-Shih Creek was therefore 978 cubic meters per day (CMD). In 2002 there were 952,575 tourists or 2,713 tourists per day. The wastewater produced by the tourists can be estimated by:

$$Q_T = W_T T \quad (2)$$

where Q_T is the tourist generated wastewater flow; W_T is the tourist's per capita wastewater, estimated as 50 L/person; T is the number of tourists. Therefore the total tourist wastewater flow was 135.6 CMD. To estimate the hot spring spa bathing waste flow, the following empirical equation was used [12].

$$Q_H = 232.22 - 12.22 n^{0.85} \quad (3)$$

where Q_H is hot spring water used per person; n is the number of people in the same pool. The hot spring bathing water was estimated as 1,008 CMD. Figure 2 shows the proportion of various wastewaters

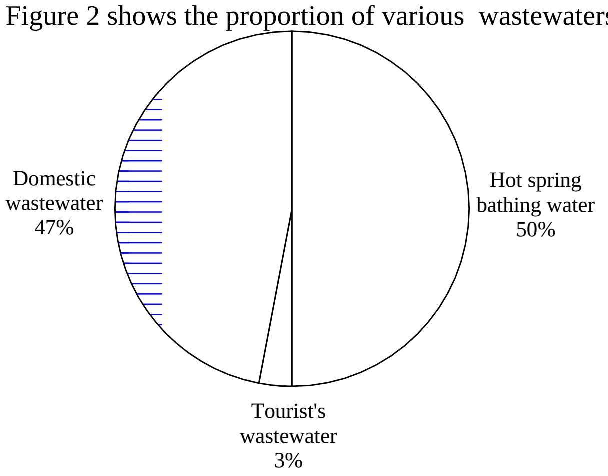

Fig. 2. Percentage of wastewater in the Nan-Shih Creek.

entering the Nan-Shih Creek. It indicates that 50% of wastewater is contributed by hot spring spas in Wu-Lai.

SAMPLING SITE AND MONITORING ITEMS

Water samples were collected at selected sections (Fig. 1) of the Nan-Shih Creek during different time periods, i.e. weekdays and weekends. The most important item in the impact analysis was the number of tourists using hot spring for bathing. Samples collected on weekdays and weekends were used to examine possible differences in water quality impact between the two time periods. Samples were collected at the upstream (in reference to Wu-Lai Village) portion of the Nan-Shih Creek and the Tung-Hou Creek, which represent the water quality in relatively unpolluted stream segments, and at the downstream portion of the Nan-Shih Creek, which represents the polluted segment of the stream.

Water quality parameters analyzed included physical, chemical, and biological properties of the water samples. These included temperature, pH, TDS, SS, TOC, NH_3-N, hardness, ABS, and coliform bacteria. The analytical methods used for water quality testing were in accordance to those issued by the US Environmental Protection Agency. The significance of the selected water quality parameters can be described as follows.

When the stream water temperature increases, it indicates that hot spring bathing water is likely being drained into the stream. Also, the pH value can be used to determine the time of the release of hot spring bathing water due to its high pH values. Because hot spring derives mainly from groundwater, the mineral composition is greater than stream water. The total dissolved solids (TDS) can be used to determine whether the wastewater is hot spring bathing water. SS indicates suspended solids. TOC indicating total organic carbon concentration is an index for organic pollutants. NH_3-N indicates hygiene contamination, which is a characteristic of domestic wastewater discharge. Hardness indicates polyvalent metallic ions dissolved in the water, mainly calcium and magnesium ions. ABS is the major component of surfactant found mostly in soaps and detergents that is an index of pollutant produced by hot spring industry. Coliform is the index for hygiene contamination. Coliform indicates the contamination from human's or animal's excrements.

WATER QUALITY SIMULATION ANALYSIS

Water quality modeling analysis was used to evaluate the impacts on stream water quality of the Nan-Shih Creek by hot spring bathing water. Models such as QUAL2E, WASP, and ESTUARY can be used to simulate water quality of streams. QUAL2E is a comprehensive and versatile stream water quality model widely used to simulate the impact of waste loads on instream water quality. QUAL2E is capable of simulating NH_3-N, coliform and SS fate and transport in streams and was therefore chosen as the water quality model to simulate the impact of hot spring on the Nan-Shih Creek water quality in the present study.

QUAL2E is a complete and flexible model that includes the effects of advection, dispersion, dilution, constituent reactions and interactions in a one-dimensional stream system. Users can simulate up to fifteen water quality parameters under steady-state and pseudo-dynamic stream conditions. It can be used to simulate the biogenetic process and changes of water quality in the stream system receiving point and nonpoint sources of pollution.

The transport processes of a pollutant in a stream can be expressed as

$$\frac{\partial C}{\partial t} = \frac{\partial\left(A_x D_L \frac{\partial C}{\partial x}\right)}{A_x \partial x} - \frac{\partial\left(A_x \bar{u} C\right)}{A_x \partial x} + \frac{dC}{dt} + \frac{s}{V} \qquad (4)$$

where C represents solute concentration; t, time; x, distance in the downstream direction; A_x, cross-sectional area; $\bar{u}$, mean velocity; s, external source or sinks; and V volume. The right hand side of Equation (4) represents transport or change due to dispersion, advection, constituent changes, external sources/sinks, and dilution, respectively. The term on the left hand side represents the variation of concentration with respect to time. Under steady-state conditions, we have $\partial Q / \partial t = 0$. Therefore, the hydrological balance for a computational element becomes

$$\left(\frac{\partial Q}{\partial x}\right)_i = (Q_x)_i \qquad (5)$$

where Q_i is the sum of the external inflows to the element.

Fig. 3. Stream network of computational elements and reaches.

Five data sets are needed in creating a stream water quality simulation with QUAL2E, i.e., geometric data, hydraulic data, meteorological data, water quality data, and values of parameters. The stream system is divided into a number of reaches, each of which is further divided into several elements. Every element within a reach is assumed to have the same hydraulic and biological characteristics. As shown in Fig. 3, the Nan-Shih Creek and the Tung-Hou Creek are divided into 9 and 4 reaches, respectively. There are 84 and 80 elements, with a length of 0.25 km each, for the Nan-Shih Creek and the Tung-Hou Creek, respectively. Hydraulic data consists of stream velocity, discharge and width of the stream. QUAL2E uses a simplified approach to estimating the stream velocity and depth. Thus

$$u = aQ^b \qquad (6)$$

$$H = cQ^d \qquad (7)$$

where Q is discharge in m^3/s; a, b, c and d, parameters; and H, average depth in m. Table 1 shows the coefficient calibrated for the Nan-Shih Creek. The water temperatures of the Nan-Shih Creek and Tung-Hou Creek are 18.9 and 21.1 ^oC, respectively. The needed values for various parameters were estimated by using the field monitoring data.

Table 1. Calibrated parameters.

Parameter	Value	Reference
β_1 (1/day)	0.8	[13]
α_3 (mg/m^2-day)	0.9	[15]
K_5 (1/day)	1.8	[15]
K_6 (1/day)	2.5	[15]
σ_6 (1/day)	3.0	[14]
A	4.435	---
B	0.845	---
C	0.082	---
D	0.256	---

WATER QUALITY SIMULATION OF THE NAN-SHIH CREEK

Eight monitoring runs were made during 2002-2003, namely, 6/8/02 (Sat.), 7/12/02 (Fri.), 7/30/02 (Tue.), 8/28/02 (Wed.), 11/19/02 (Tue.), 1/12/03 (Sun.), 3/2/03 (Sun.), and 4/20/03 (Sun.). Four of the above sampling runs were collected on weekends and the other four were on weekday. Besides sampling at the stream sites, hot spring bathing water released from the hot spring pools at the resorts and spa houses were also sampled in order to examine the characteristics of the hot spring bathing water.

Figure 4 shows the average stream water quality on weekends and weekdays at the stream sampling sites and the hot spring pools. The water quality on weekdays is better than that on weekend except for coliform. This was probably due to the fact that the resorts released large volumes of hot spring bathing water during weekends and that the colon bacillus cannot survive in the hot spring environment. The stream water quality at the upstream stretch of the Nan-Shih Creek is better than that at the downstream location, indicating the impact from the hot spring bathing water entering the stream at the Wu-Lai Village area. Table 2 presents a comparison of the water quality during weekdays and weekends at the downstream location of the Nan-Shih Creek and also the water quality of the hot spring pool released water. The results show that whether on weekends or weekdays the concentration of chemical water quality parameters at the downstream of the Nan-Shih Creek will increase with the wastewater released from the hot spring pools. The stream water quality is undoubtedly affected by the hot spring bathing water.

The sampling data [15] were separated into two groups. One group of data was used to calibrate the parameters of QUAL2E. The other group was used to valid the model. Figures 5 and 6 show the results of the simulation of NH_3-N, coliform, and SS for the Nan-Shih Creek under dry weather conditions for model calibration and verification, respectively. The horizontal axis is the distance from the confluence of the Nan-Shih Creek and the Pei-Shih Creek, whereas

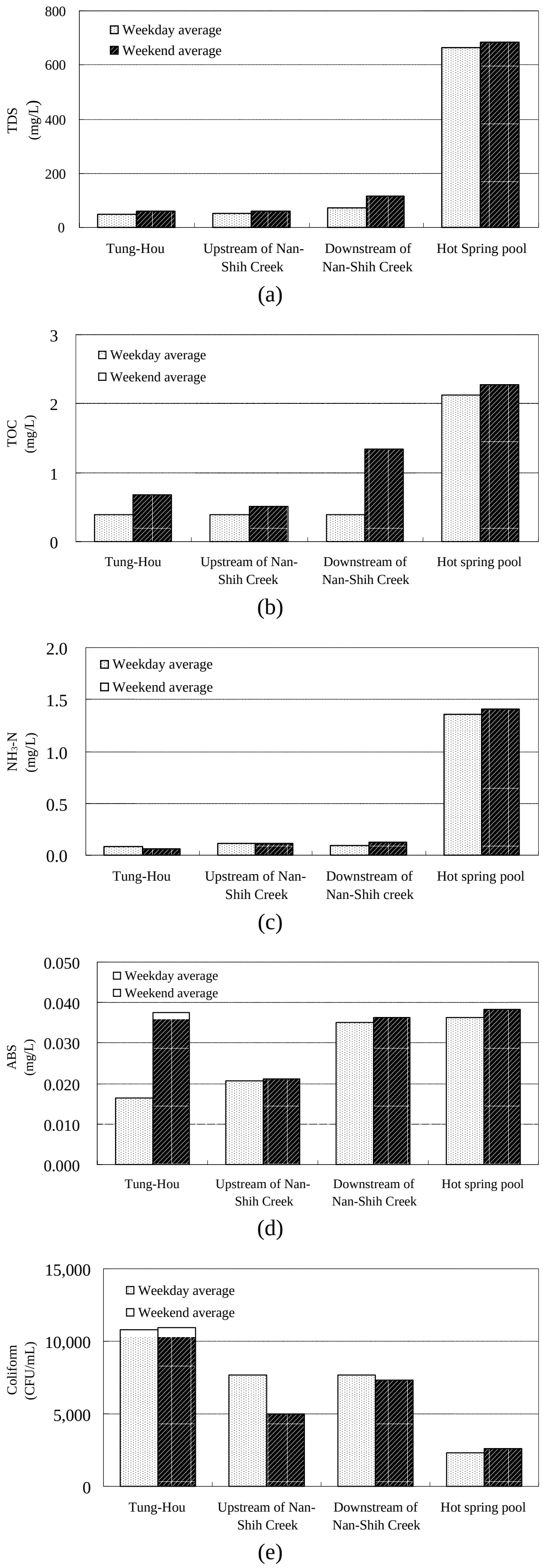

Fig. 4. Stream water quality on weekend and weekday; (a) TDS; (b) TOC; (c) NH_3-N; (d) ABS; (e) coliform.

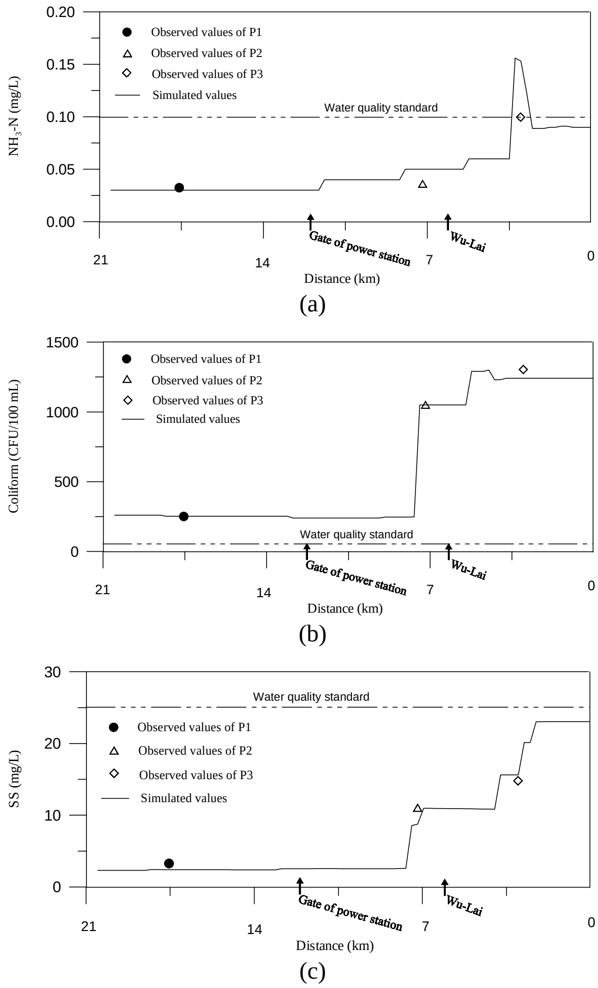

Fig. 5. Model calibration; (a) NH_3-N; (b) coliform; (c) SS.

the vertical axis represents concentrations. The vertical dash line in the figure shows the location of Wu-Lai Village. The horizontal dash line is the river water quality standard. The water quality can meet the river water quality standard if the concentration is below the horizontal dash line. The results indicate clearly that the water quality of the Nan-Shih Creek is getting worse after the Nan-Shih Creek runs through Wu-Lai. Hot spring is pumped into the resorts and then the contaminated hot spring bathing water is released from many spas around Wu-Lai Village. It can be seen from the figures (Figs. 5 and 6) that concentrations of the NH_3-N, coliform and SS dramatically increased around Wu-Lai. Table 1 gives the calibrated parameters used in the QUAL2E.

It should be noted that the droughty water discharge used in the QUAL2E modeling analysis was the 75% low flow, or Q_{75}, which is the flow that exceeded by 75% of all flows and is the design flow for waste allocation analysis in Taiwan. Q_{75} for Fu-Shan at the upstream of the Nan-Shih Creek, Guei-Shan at the downstream of the Nan-Shih Creek and the Tung-Hou Creek are 0.635, 7.555, and 1.6 m^3/s, respectively.

Table 2. Comparison of water quality of the Nan-Shih Creek and mixing hot spring bathing water.

Item	Downstream of Nan-Shih Creek		Out of hot spring pool	
	Weekend	Weekday	Weekend	Weekday
TDS (mg/L)	114	70	506	544
TOC (mg/L)	1.347	0.394	5.202	5.664
NH_3-N (mg/L)	0.127	0.096	2.235	1.090
Hardness (mg/L)	14.141	10.116	18.774	7.927
ABS (mg/L)	0.036	0.035	0.206	0.187
Coliform (CFU/100 mL)	7350	7713	8050	14200

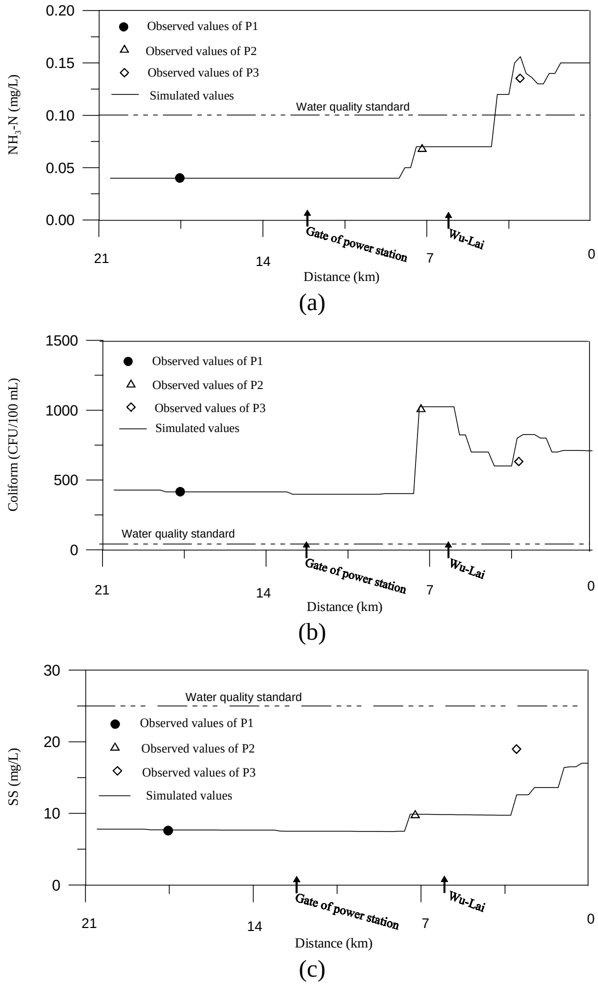

Fig. 6. Model validation; (a) NH_3-N; (b) coliform; (c) SS.

Figure 7 shows the results of the water quality simulations when Q_{75} was used. The horizontal axis is also the distance from confluence of the Nan-Shih Creek and the Pei-Shih Creek. The solid line is the Q_{75}, and the short dash line represents the concentrations. It shows that NH_3-N and coliform cannot meet the river water quality standard at the downstream side of Wu-Lai. However, suspended solids can meet the river water quality standard for the Nan-Shih Creek. These results confirm that tourist wastewater and hot spring released wastewater will impact adversely the stream

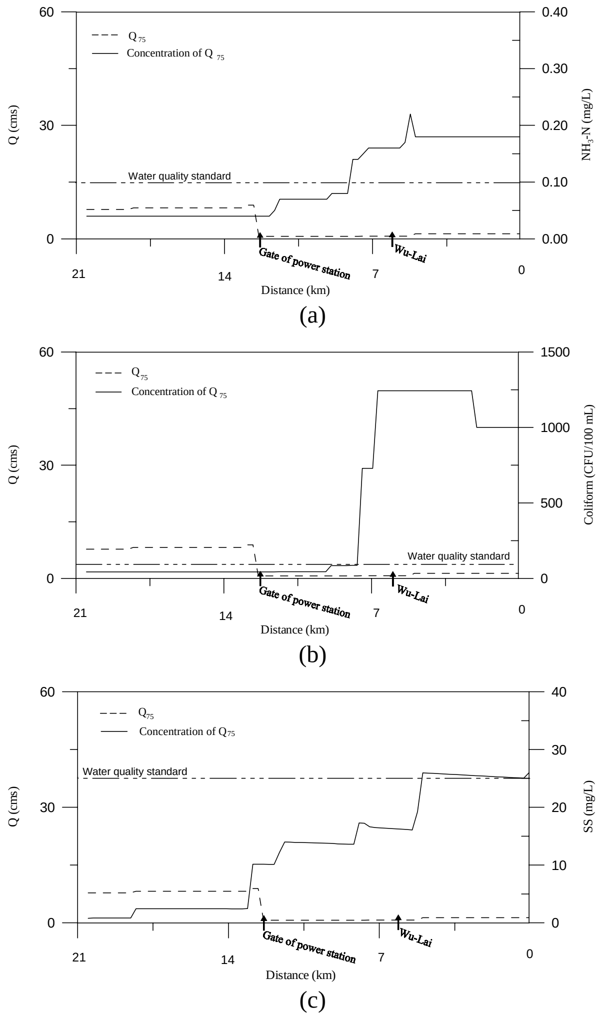

Fig. 7. Simulated water quality of the Nan-Shih Creek during low flow; (a) NH_3-N; (b) coliform; (c) SS.

water quality during low flow conditions.

Table 3 presents the impact of hot spring bathing water on the stream water quality. QUAL2E simulates both the concentrations of NH_3-N and coliform in the conditions of stream flow with and without hot spring bathing water. It indicates if no hot spring bathing water is drained into the Nan-Shih Creek, the concentration of NH_3-N and coliform can be reduce by 13% and 19%, respectively. Figures 5, 6, 7 and Table 3 show that hot spring bathing water does have a significant impact on water quality in the receiving streams.

Table 3. The effect of hot spring bathing water on the Nan-Shih Creek.

Distance from confluence	NH_3-N			Coliform		
	With hot spring bathing water	Without hot spring bathing water	Reduction	With hot spring bathing water	Without hot spring bathing water	Reduction
(km)	(mg/L)	(mg/L)	(%)	(CFU/100 mL)	(CFU/100 mL)	(%)
21	0.041	0.041	0	428.50	428.50	0
20	0.042	0.042	0	428.49	428.49	0
19	0.042	0.042	0	428.45	428.45	0
18	0.042	0.042	0	428.44	428.44	0
17	0.042	0.042	0	42843	428.43	0
16	0.042	0.042	0	428.42	428.42	0
15	0.042	0.042	0	428.41	428.41	0
14	0.042	0.042	0	428.37	428.37	0
13	0.042	0.042	0	429.35	429.35	0
12	0.045	0.045	0	429.94	429.94	0
11	0.073	0.073	0	429.86	429.86	0
10	0.083	0.073	12	429.86	429.86	0
9	0.139	0.130	7	472.78	429.77	9
8	0.163	0.128	21	474.38	431.23	9
7	0.163	0.128	21	641.02	482.71	25
6	0.163	0.154	13	641.24	482.62	25
5	0.178	0.154	13	567.57	458.48	19
4	0.178	0.154	13	567.51	458.43	19
3	0.178	0.154	13	567.45	458.38	19
2	0.178	0.154	13	567.39	458.33	19
1	0.178	0.154	13	567.33	458.28	19
0	0.178	0.154	13	567.28	458.24	19

CONCLUSIONS

This study examines if the hot spring bathing water influence the water quality in receiving streams. Field monitoring results show that water quality in the Nan-Shih Creek, which receives untreated discharges from a number of hot spring spas, becomes poorer during weekends when large numbers of tourists are present. The data were also used to calibrate and validate a water quality model, QUAL2E, which was used to evaluate the water quality impact on the Nan-Shih Creek by hot spring bathing water under low flow conditions. Owing to the release of the hot spring bathing water around Wu-Lai, the water quality of the upstream of the Nan-Shih Creek is better than the downstream. The modeling results show that the hot spring bathing water does have a significant adverse impact on the Nan-Shih Creek water quality, especially during low flow periods. It is therefore necessary for the authorities to control the use of hot spring water and the untreated release of the hot spring bathing water in order to protect receiving water quality.

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NOMENCLATURE

a	constant
A_x	cross-sectional area
b	constant
C	solute concentration
c	constant
d	constant
H	average depth
K	coefficient
n	number of people in the same pool
P	population

Q discharge
Q_D domestic wastewater flow
Q_H hot spring water used per person
Q_i sum of the external inflows to the element
Q_T tourist generated wastewater flow
s external source or sinks
t time
$\bar{u}$ mean velocity
V volume
W_D daily wastewater quantity per person
W_T tourist's per capita wastewater
x distance

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Discussions of this paper may appear in the discussion section of a future issue. All discussions should be submitted to the Editor-in-chief within six months.

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溫泉廢水對於水質之影響

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關鍵詞：溫泉、溫泉廢水、水質衝擊、模式分析

摘 要

近年來每逢假日即吸引大批遊客進入溫泉遊憩區內，如此瞬間高峰的遊客量，造成污染量亦隨遊客數而暴增，因此本研究探討發展溫泉觀光旅遊事業的同時，是否會帶來水環境的問題；研究區域選定大台北都會區之水源－南勢溪集水區，探討溫泉使用因人潮因素所造成河川水所產生的影響，分析 TDS、TOC、ABS、coliform、NH_3-N 及 hardness 六項水質中，結果顯示人潮之差異性對於河川有絕對之影響。本研究並利用採樣所得到之數據，進行河川水質模式 QUAL2E 模擬溫泉廢水之排放對河川水環境影響，由於台灣電力公司在南勢溪流域之主流及支流桶後溪皆設有壩體攔截水源，因此平時之南勢溪流量就不大，當南勢溪枯水期(Q_{75})時，溫泉廢水的排放的確會造成 NH_3-N 與 coliform 兩項河川水質的升高，若將溫泉廢水去除後，則南勢溪下游之水質削減百分率，分別是 NH_3-N 降低 13%，coliform 降低 19%。且鑑於人潮所造成河川水質之影響，旅遊人口亦需管理，以避免造成人口集中而使水質受到污染。本研究之成果將可提供其他各地區河川水質管理之參考，以創造更好的河川水環境。