Evaluation of Source Water Quality Standards for Total Coliforms, TOC, and COD in Taiwan

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Abstract: The objective of this research is to review the current status of source water as compared with the Taiwanese source water quality standards promulgated in 1997. The total coliforms, total organic carbon (TOC) and chemical oxygen demand (COD) were selected as the major parameters for review because of their specific characteristics associated with the disinfection efficiency and disinfection by-products formation and in compliance with source water quality in Taiwan. The water treatment plant with unacceptable source water needs to improve its source water quality and establish the implementation plan based on the results of comprehensive performance evaluation. Throughout this investigation, it suggests that revisions to water quality standards be divided into two execution phases, to achieve the long-term goal of improving source water quality.

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Introduction

The quality of source water in Taiwan is deteriorating rapidly due to discharges of domestic and industrial wastewaters. In addition to wastewater discharges, non-point source pollutants also play an important role to source water pollution. In order to avoid heavier source water pollution, popularize pollution-prevention program and ensure safe drinking water for public health, the Taiwan Environmental Protection Administration (Taiwan EPA) enacted the Drinking Water Management Act (DWMA), which was promulgated and became effective on November 10, 1972, and then amended on May 21, 1997. The major contents issued in this DWMA are as follows: general provisions, water source management, facility management, water quality management, penalties, and supplementary provisions.

Concern over defining standards for source water quality around the world is not only recent. In April of 1970, the Water Quality Committee of the Japanese Living Environment Council published water quality standards for water resources area to protect the source water quality as well as public health (Kiluchi 1975). In 1971, the United States Public Water Supplies Panel at the request of the U.S. Environmental Protection Agency proposed water quality criteria for source water (Van der Leeden et al. 1990). In June of 1975, the council of European Communities (EC) adopted a Council Directive for the Member States concerning the required quality of surface waters intended as sources of drinking water (EC 1975). As for the source water quality standards, criteria or guidelines adopted by countries around the world, either a uniform set of standards for all sources or various levels of standards for different source waters are formulated. For example, the United States and Australia adopted uniform standards for source water quality instead of mandatory standards to guide the water supply industry to improve drinking water quality (NAS 1972; ANZECC 2000). However, Japan, Canada, France and the EC adopted various levels of standards (Kikuchi 1995; MELP 1995; EC 1975). In Taiwan, the current regulations classify water bodies into various classifications with corresponding water quality standards.

Since source water contamination is a universal issue, it appears that enforcing mandatory source water quality standards may encounter compliance problems. Besides, seeking new drinking water sources is becoming more difficult in Taiwan so that it is important to protect the source water as well as upgrade the treatment process in response to the poor source water quality. In order to ensure the safety of treated water to consumers, both the CCP (Composite Correction Program) and CPE (Comprehensive Performance Evaluation) techniques suggested by USEPA (1998) can be used herein to provide the technical information to determine if searching for an alternative raw water source or optimizing (or upgrading) the existing water treatment is required. The CPE method is a systematic step-by-step evaluation of a facility's design capabilities and associated administrative, operational, and maintenance practices to achieve the optimum performance of the facility in an existing plant. Then, a comprehensive assessment of the facility's operation capability will be made and included in the performance-limiting factors for the selected water treatment plant. The water treatment plants in Taiwan that do not comply with the source water quality standards are requested to conduct the CPE program to evaluate the current capability of the unit treatment process, and have to develop the implementation plan as suggested by the CPE team to achieve the desired water quality.

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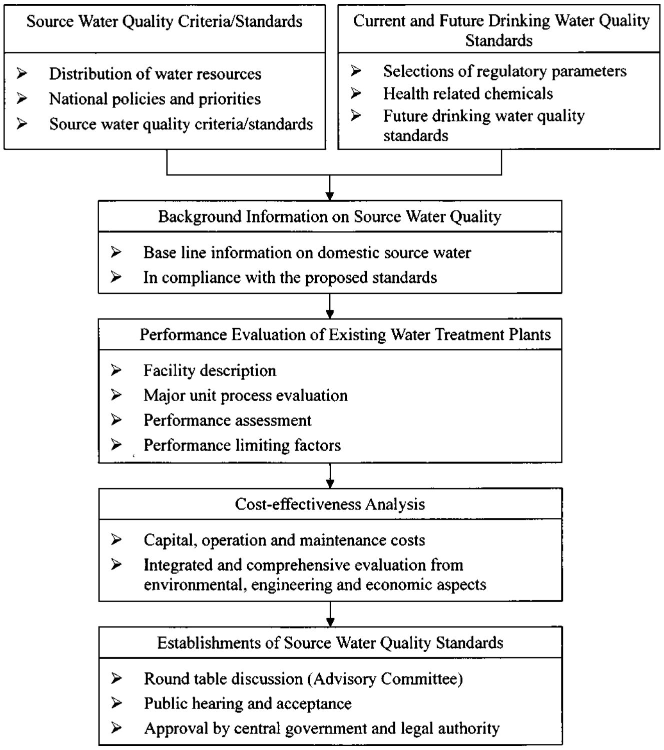

Fig. 1. Procedures to develop the source water quality standards in Taiwan

The objective of this research work is intended to review the current status of source water as compared with the source water quality promulgated in 1997. Total coliforms, total organic carbon (TOC) and chemical oxygen demand (COD) were selected as the major parameters because of their specific characteristic associated with the disinfection efficiency and disinfection by-products (DBPs) formation potentials. The average values of total coliforms, TOC, and COD are below 10,000 CFU/100 mL, 2 mg/L, and 15 mg/L in uncontaminated source water in Taiwan, respectively (Chiang et al. 2001). These parameters are routinely measured and cannot comply with the source water quality standards all the time. Besides, these parameters have the characteristics of availability, representative, precision, and accuracy for review to determine if any further revision should be made. The future source water quality standards have been proposed as a result of the present study.

Rationale for Determination of Source Water Quality Standards

In selecting water quality parameters for source water quality standards, each enforceable parameter should be a representative indicator for water pollution including toxic and hazardous substances. In determining the regulatory limits of each parameter, the following factors should be considered: (1) source water quality criteria and standards from nations around the world; (2) current and future drinking water standards; (3) background information on source water quality; (4) performance evaluation of existing water treatment plants; and (5) cost-effectiveness analysis. Fig. 1 presents the procedures to develop the existing source water quality standards in Taiwan (Chang et al. 1998, 1999).

The general principles regarding the above evaluation factors are stated as follows.

1. Source water quality criteria/standards from nations around the world. Since there are differences in the distribution of water resources, policies, and national priorities, the source water quality standards of various nations were adopted to suit the needs of each country in achieving predetermined goals.

The major sustainable indicators for water quality assessment would depend on the designated use of a water body. The United States Water Pollution Act (Public Law 92-500, commonly known as the Clean Water Act) requires each State to conduct water quality surveys to determine the overall health of all water bodies. Under this survey, each State is responsible for designating its rivers and streams for State-specific use. For example, Maryland classified streams within its State boundary into 7 categories in order to comply with the requirements stipulated in the Clean Water Act. The major sustainable indicators for water quality assessment of a stream designated for public water supply purpose in Maryland are fecal coliform, dissolved oxygen (DO), temperature, pH, turbidity, and toxic substances (Code of Maryland Regulation). In the meanwhile, California takes BOD, coliform, DO, pH, chlorides, iron and manganese together with fluorides, phenolic compounds, color and turbidity as the source water indicators (Van der Leeden et al. 1990).

The Japanese Government classifies rivers and lakes into A, B, C categories according to the level of water quality for water purification treatment methods in waterworks. Indicators of pH, BOD, suspended solids, DO, and coliform groups are chosen to classify the source water quality. Besides these water quality parameters listed in the environmental quality standards, THM formation potential, and NH_3-N are of special concern regarding source water protection (Sato 2002).

In addition to the above-noted information, the promulgated criteria/standards for different countries were summarized in Table 1 as baseline information for determining standards in Taiwan.

2. Current and future drinking water quality standards. The concept of human health risk assessment should be introduced to amend drinking water quality standards in Taiwan, especially for the DBPs and heavy metals. The purpose of regulating source water quality is to produce finished water from traditional coagulation-precipitation water treatment processes to meet existing drinking water standards. Future drinking water standards must also be considered while setting source water quality standards.

3. Background information on source water quality. Every country establishes its own water quality standards based on special domestic needs and characteristics. Recently, the Taiwan EPA has conducted a long-term, integrated and comprehensive project to establish the national drinking water quality standards. A full analysis of relevant background information on water sources and treated water is the key factor leading to a better understanding of how well actual water quality has lived up to the established standards.

It is noted that excessively stringent source water quality standards may not be practical and will certainly increase water treatment costs. Thus, less stringent source water quality standards comparable to the existing water quality may be adopted initially and tightened gradually in phases to avoid sudden impacts to the water supply industry as well as consumers. Mechanisms for this should be established, such as specific statutory deadlines, water rate design, and cost allocation to upgrade the performance and capacity for water treatment plant.

Table 1. Comparison of Source Water Quality Criteria/Standards in Various Nations

Parameter units	USEPA[a]	Alberta Canada	EC (A1)	Japan	Australia	Germany (Rhine River)	Taiwan	
							Current	Future
I. Microorganisms								
Total coliforms (CFU/100 mL)	20,000	5,000	—	5,000	<10	—	20,000	10,000
Fecal coliforms (CFU/100 mL)	2,000	1,000	—	—	ND	—	—	—
II. Physical parameters								
Color (CU)	—	$\leqslant 30$	20	10	15	0.5	—	—
pH	5.0–9.0	6.5–8.5	—	6.5–8.5	6.5–8.5	6.5–8.5	—	—
III. Inorganics								
As (μg/L)	10	10	50	10	1	5	50	50
Ba (μg/L)	1,000	1,000	50	—	1	700	—	—
Cr (μg/L)	—	20	50	50	0.01	25	50	50
Cd (μg/L)	—	10	5	10	0.06	3	10	5
Hg (μg/L)	—	0.1	1	0.5	0.06	0.5	2	1
Pb (μg/L)	—	50	50	10	1.0	5	50	50
Se (μg/L)	170	10	10	10	5	5	50	10
Ag (μg/L)	—	50	—	—	0.02	—	—	—
Cu (μg/L)	1,300	20	50	1,000	1.0	—	—	—
Fe (μg/L)	300	300	300	300	—	—	—	—
Mn (μg/L)	50	50	—	20	1,200	—	—	—
Zn (μg/L)	7,400	50	3,000	1,000	2.4	—	—	—
NH_3-N (mg/L)	—	1 (TKN)	—	0.5	0.32	0.3	1	—
Cl^- (mg/L)	—	1.5	—	200	0.0004	100	—	—
CN^- (μg/L)	700	15	50	10	0.004	25	—	—
NO_3^- (mg/L)	10	—	50	9	0.00017	—	—	—
SO_4^{2-} (mg/L)	—	0.05 (S^{2-})	250	—	0.0005	100	—	—
IV. Organics								
Surfactants (MBAS) (μg/L)	—	—	—	500	—	—	—	—
Phenol (μg/L)	21,000	5	1	5	85	—	—	—
Total pesticides (μg/L)	—	—	0.2	—	—	50	—	—
COD (mg/L)	—	—	—	3 ($KMnO_4$)	—	—	25 ($K_2Cr_2O_7$)	20
PCB[c] (μg/L)	0.00064	—	—	ND[b]	—	—	—	—
PAHs[d] (μg/L)	—	—	0.2	—	—	0.1	—	—
TOC (mg/L)	—	—	—	—	—	3 (DOC)	4	2

Note: TOC=total organic carbon.

[a] U.S. Environmental Protection Agency (USEPA) national recommended water quality criteria: 2002, for consumption of "water+organism."

[b] Not detectable.

[c] Polychlorinated biphenyls.

[d] Polycyclic aromatic hydrocarbon.

4. Performance evaluation of existing water treatment plants. Prior to determining source water quality standards, it is necessary to evaluate the treatment capacity of existing water plants in treating raw water at predetermined water quality standards and in meeting drinking water quality standards. An unreasonable standard may result in excessive treatment costs for water treatment plants. Most water purification facilities in Taiwan still rely on traditional methods, i.e., coagulation, sedimentation, filtration, and chlorination. The efficiency of these methods for achieving the target water quality parameters should be taken into consideration when establishing interim standards.

5. Cost-effectiveness analysis. Chemical and microbial water quality criteria, supplemented with a limited number of biological water quality criteria, are the principal indicators of water quality used in the developed nations at this time. However, the implementation of more integrated and comprehensive indicators of environmental health and biological diversity need great efforts to be developed.

Before adopting standards, it is recommended that the cost-effectiveness analysis be conducted to evaluate if the new standards or criteria will cause compliance difficulties. If poor source water quality affects the operating performance of water treatment processes, the water supply company should define performance goals for each water treatment process.

In summary, to protect public health, pathogens and toxic substances including arsenic, lead, chromium, mercury, cadmium,

Table 2. Evaluation of Microbial Indicators in Water Quality Criteria/Guidelines for the Developed Nations

Micro-biological contaminants	Drinking water management regulation	Source water management regulation	Occurrence in source water	Health effect	Disinfection efficiency
Total coliforms	United States, Japan, England, Canada (Alberta), Germany	United States, United States (California), Canada (Alberta), Japan, Australia	High	Low	High
Fecal coliforms	Unites States, EC, Australia	United States, Canada (Alberta), Australia	Medium	Medium	High
E Coli	Unites States, WHO, Germany, EC, Australia, England, Canada (Alberta), New Zealand,Holland	Canada (Alberta), France	Low	High	High
Fecal *streptococci*	Germany, EC	France	Medium	Medium	High
Enteroccoci	EC, England, Holland	Canada (Alberta)	Low	Medium	Medium
Pseudomonas aeruginosa	—	Canada (Alberta)	Low	Low	Low
Cryptosporidium	United States, Holland	—	Low	High	High
Giardia lambia	United States, Holland	—	Low	High	High
Cyanobacteria	New Zealand	—	Low	High	High
Pathogenic bacteria	New Zealand	—	Low	High	Medium
Protozoa (pathogenic)	New Zealand	—	Low	High	Medium
Helminths (pathogenic)	New Zealand	—	Low	High	Medium
Algae	New Zealand	—	High	Medium	Low
Virus	New Zealand, United States (enteric virus), Holland	—	Low	High	Low
Thermotolerant	Australia, WHO	—	Low	Medium	Low

and selenium should be regulated. In setting source water quality standards for these toxic substances, it must be noted that conventional water treatment plants may not effectively remove these substances. Therefore, the source water quality standards for these substances should be set as equal to the drinking water standards. However, it is recommended that the source water standards be compared with those from other countries to reduce the health risk in existing source water quality in Taiwan before being finalized. Other regulatory parameters including coliform bacteria, ammonia, COD, and TOC should be based mainly on existing source water quality.

Development of Microbial Indicators in Source Water Quality Standards

In general, low counts of fecal coliforms and *E. Coli* are indicative of safe waters but not always. Table 2 evaluates the microbial indicators in source water criteria/guidelines for the developed nations from the aspects of regulation, occurrence, and health effect. It is suggested in this paper that total coliforms, despite its low correlation with health effect should be a representative parameter due to its unique characteristics in conjunction with the source water management regulations, and effective assessment in disinfection efficiency.

The Taiwanese source water standards require that total coliforms cannot exceed 20,000 CFU/100 mL for plants with traditional facilities and 50 CFU/100 mL for plants with only disinfection treatment. The total coliform standards adopted by California (United States), Canada, and Japan are divided into several categories according to the selected treatment processes (Table 3). They regulate that high total coliform levels require more advanced treatment processes to meet the drinking water standards at the point of service.

The concentration profiles of total coliform in source water published by the Taiwan Water Company for the periods of 1995–1996 and 1997–1998 are shown in Fig. 2. Total coliform concentrations in source water greater than 20,000 CFU/100 mL were 9 and 8% of the total samples in 1995–1996 and 1997–1998, respectively. Total coliform concentrations in source water greater than 10,000 CFU/100 mL were about 15% of the total samples for both periods. There was a slightly decreasing trend of the average concentration of total coliforms which suggests that there is an improvement in the source water quality.

Acceptable disinfection efficiency was set at 99.99% inactivation of the total coliform count (the average level of total coliforms measured in source water is about 30,000 CFU/100 mL), which would also meet the Taiwan EPA drinking water standard (6 CFU/100 mL). All water treatment plants with total coliform violations in source water standards are equipped with pre-chlorination facilities. Since excessive chlorine residual and disinfection by-products have not been found in the finished water, most of the plants can meet the current drinking water standards. However, the slow improvement in source water protection makes it unlikely that source water standards will be met by some of the water treatment plants in the near future. As a result, it suggests that a source water total coliform standard of 10,000 CFU/100 mL be adopted in 2006 and be enforced to 5,000 CFU/100 mL in 2007. The following items should also be addressed in the source water quality regulations: the growing concern of the presence of DBPs in the finished water, as well as disinfection efficiency measured by $C \times T$ (chlorine dose-contact time) values.

It is noted that on the aspect of pathogen, there is a current

Table 3. Source Water Quality Standards for Total Coliforms in Various Nations

Nations	Standard	Unit	Remarks
Taiwan (ROC) (1997)	I. 20,000 II. 50	MPN/100 mL or CFU/100 mL	
USEPA (1972)	<20,000	CFU/100 mL	Used for public water supplies
California, United States	I. 50–100	MPN/100 mL	I. Excellent grade; safe drinking water treated by disinfection
	II. 240–5,000		II. Good grade, water treated by conventional water treatment plant
	III. 10,000–20,000		III. Poor grade, water treated by advanced or specialized treatment processes
Canada (1995)	I. 0	CFU/100 mL	I. Without treatment
	II. 10		II. Only treated by disinfection (allowed <20% samples exceeding 5000 MPN/100 mL)
	III. 100		III. Partialy treated by conventional treatment processes (allowed <5% samples exceeding 20,000 MPN/100 mL)
	IV. N/A		IV. Completely treated by conventional treatment processes (allowed <10% samples exceeding 10/100 MPN/100 mL)
Alberta, Canada (1993)	5,000	CFU/100 mL	Based on surface water quality criteria
Japan (1975)	I. 50	MPN/100 mL	I. Without treatment
	II. 1,000		II. Only treated by disinfection
	III. 5,000		III. Partialy treated by conventional treatment processes
Australia (1992)	I.	CFU/100 mL	I. Up to ten coliform organisms may be occasionally accepted in 100 mL
	II.		II. Coliform organisms should not be detactable in 100 mL of any two consecutive samples
	III.		III. Throughout any year, 95% of samples should not contain any coliform organisms in 100 mL

search for a good measure or indicator for *Giardia* and *Cryptosporidium*. There is also a desire to find better indicators of human wastewater influence, such as caffeine and coprostanol (Tien 2002). There are developing tools in the field of genetics, for instance, DNA tracking is allowing us to identify the actual source of fecal contamination (e.g., humans, birds, dogs) However, these newly developing microbial indicators need more data base to assess its potency for drinking water supplies (Tien 2002).

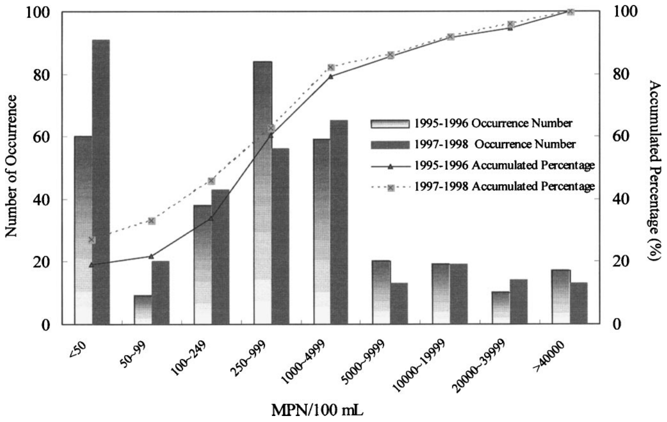

Fig. 2. The concentration profiles of total coliforms in source water utilized by the Taiwan Water Company during 1995–1996 and 1997–1998.

Development of Organic Indicators in Source Water Quality Standards

UV absorption, a useful surrogate measurement of selected organic constituents in fresh water (Wilson 1959; Dobbs et al. 1972; Copper and Young 1984), may exhibit strong correlation with organic carbon content, color, and precursors of DBPs (Edzwald et al. 1985). The COD is used as a measurement of the oxygen equivalent of the organic matter content in water that is susceptible to oxidation by a strong chemical oxidant. TOC is a more convenient and direct expression of total organic content and can be used to evaluate the effects of DBP control strategies. Singer et al. (1995) suggested that chlorine consumption was a reasonably good indicator of DBP formation.

In a previous study, Chang et al. (1998) found that COD had strong correlation with UV_{254} (or humid substance) and chlorine demand in different source water samples with different characteristics. Table 4 evaluates the organic indicators utilized in the source water which suggests that COD and TOC should be regarded as surrogate parameters for source water quality analyses and precursors of DBP concerns.

Table 4. Evaluation of Organic Indicators in Source Water Quality Analyses

Factors to be considered	COD (mg/L)	TOC (mg/L)	Cl_2 demand (mg/L)	UV_{254}	Humic substances
Background information					
International availability	+++	++++	+	+++	++
National availability	+++	+++	+	++	+
Representative	+++	+++	++	++	++++
Water treatment technology					
Monitoring parameters	+	++++	++	++	+
Analytical technique					
Precision/Accuracy	+++	+++	+	++++	++
Time consumption	++	+++	++	++++	+
Equipment/Apparatus cost	+++	+	++++	++	+
Ease of operation	++	+++	+	++++	+
Related to DBPs formation	+	+++	+	+++	++++

Note: COD=chemical oxygen demand; and TOC=total organic carbon. The "+" symbol denotes the advantages of the parameter with the corresponding event. The potency of the advantage increases as the number of "+" increases.

Total Organic Carbon

Around the world, Germany is the only country that regulates dissolved organic carbon (DOC) in the source water. Germany set a limit of 3 mg/L DOC for the Rhine River cleanup project. To protect the public health, the Information Collection Rules (ICR) of the USEPA suggests that a public water system serving more than 100,000 persons must monitor DBPs in the finished water and TOC in the source water. The ICR also requires batch tests for DBP precursors as well as pilot plant tests. However, water suppliers can be exempted from this requirement if the quarterly average of THMs is less than 40 μg/L and HAAs is less than 30 μg/L or the yearly average of TOC is less than 4 mg/L in the influent. Besides, THM/HAA must be no greater than 40/30 μg/L under Stage 2 of the USEPA D/DBP Rule (to be enforced after 2004).

From 1994–2000, the Taiwan EPA supported a research project which involved evaluation of the source water quality in Taiwanese water treatment plants (Table 5). The results of this investigation indicated that 25% of the samples had a TOC greater than 2 mg/L ($n=46$). Also, 13% of the samples had a TOC greater than 3 mg/L. Based on the average TOC value of each water plant, there were 6 water plants with an average TOC greater than 2 mg/L and 3 plants with TOC greater than 3 mg/L. It is also noted that of the 12 samples with a TOC concentration in source water less than 2 mg/L, only 1 had a total THM concentration greater than 40 μg/L. This implies that if the TOC standard is set at 2 mg/L, it will significantly decrease the DBP concentrations in the finished water. The water authority is urged to adopt this TOC standard to achieve the goal of minimizing the formation of DBPs in the finished water. This proposal is very consistent with previous research findings (Chiang et al. 1997) presented in Fig. 3, which indicates that the formation of THMs increases with TOC. For instance, at a contact time of 40 min, and TOC=4 mg/L, the concentration of THMs is approximately double that formed when TOC=3 mg/L at the same contact time. Therefore, the TOC concentration prior to the application of disinfectant should be kept under 3 mg/L to meet the more stringent THM standard of 60 μg/L.

According to the above-mentioned data, TOC in some Taiwanese source water is low. A standard of 3 mg/L TOC should not greatly affect compliance and we therefore recommend that this be enforced in 2005. In 2007, the standard should be reduced to 2 mg/L. To enforce the source water TOC standard, the regula-

Table 5. Analyses of Total Organic Carbon in Source Water at Various Water Treatment Plants

Water treatment plant code	Average (mg/L)	Range (mg/L)	Sample size
A	1.4	0.59–2.73	45
B	0.8	1.47–1.35	25
C	2.6	1.42–7.20	23
D	1.1	0.63–3.16	9
E	0.3	0.24–0.32	4
F	1.0	0.44–1.90	19
G	2.2	0.95–8.03	13
H	1.6	0.81–3.41	10
I	0.6	0.29–1.15	7
J	1.5	0.68–3.40	5
K	2.3	1.16–5.04	6
L	1.8	1.50–2.20	5
M	4.9	3.82–6.57	5
N	10.2	7.03–14.41	5
O	9.9	8.99–11.54	4

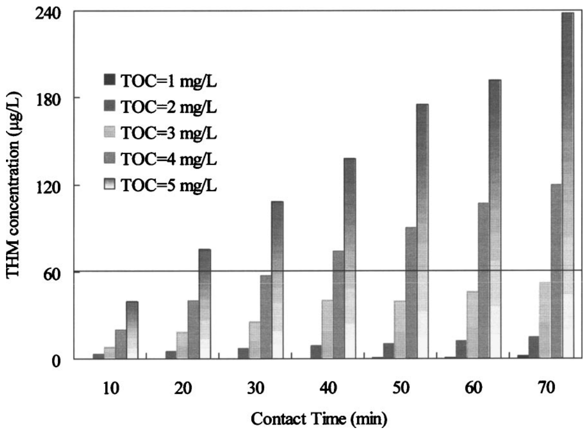

Fig. 3. Effects of total organic carbon) concentration on THM formation at applied chlorine dose=2.0 mg/L for various levels of contact time

Table 6. Source Water Quality Standards for Chemical Oxygen Demand (mg/L) in Various Nations

Nations	Standard (mg/L)	Remarks
Taiwan (ROC) (1997)	I. 25	I: Surface water or ground water used for water supplies and small systems
	II. —	II: Surface water or ground water used for small community, bottled or packaged water
Japan[a] (1975)	I. 1 II. 2	I: Simple purification, i.e., filtration and disinfection
	III.3	II: Conventional treatment process, i.e., coagulation, filtration, and disinfection
		III: Advanced treatment processes, i.e., activated carbon, and ozonation
France	1A. 20	1A: Ideal value
	2A. 20–25	2A: Allowable value
EC (1975)	A1. — A2. —	A1: Simple purification, i.e., filtration and disinfection
		A2: Conventional treatment process, i.e., coagulation, filtration, and disinfection
	A3. 30	A3: Enhanced treatment processes, i.e., activated carbon, and ozonation

[a]Determined by using $KMnO_4$ as an oxidized agent.

tory agency can follow the requirements stipulated by the USEPA ICR, i.e., THM/HAA must meet 40/30 μg/L when TOC exceeds the standard. Otherwise, a source water improvement plan of quality must be implemented.

Chemical Oxygen Demand

In reviewing the source water COD standard adopted by various countries, it was found that France adopted an ideal standard of 20 mg/L and allowable value of 20–25 mg/L (Table 6). EC assigned a COD guideline value of 30 mg/L for enhanced treatment process (EC 1975). Japanese COD standards range from 1 to 3 mg/L, using $KMnO_4$ as an oxidation agent (Kikuchi 1975). In 1998, the Taiwanese Water Company reported that six water treatment plants violated the source water COD standard.

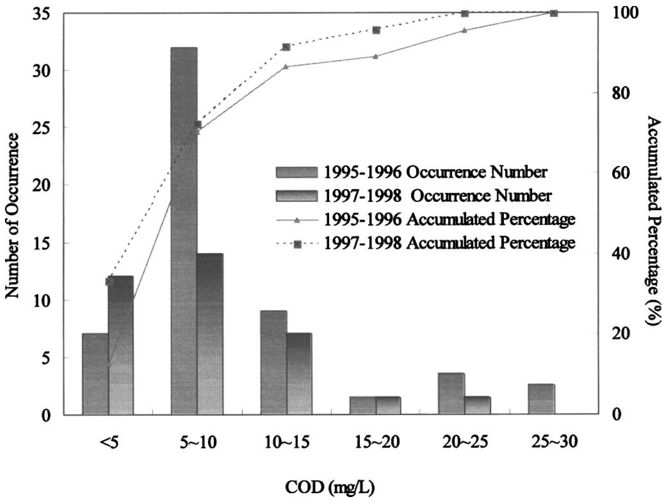

Fig. 4. The concentration profiles of chemical oxygen demand in source water utilized by the Taiwan Water Company during 1995–1996 and 1997–1998

Table 7. Revised Source Water Quality Standards for Total Coliforms, total organic carbon (TOC), chemical oxygen demand (COD) in Taiwan (ROC)

Parameters (Units)	Standard	2003	2004	2005	2006	2007~
Total coliforms (CFU/100 mL or MPN/100 mL)	20000	●				
	10000	○		◎	●	
	5000	○			◎	●
TOC (mg/L)	4	●				
	3*	○	◎	●		
	2*	○			◎	●
COD (mg/L)	25	●				
	20	○		◎	●	
	15	○			◎	●

○ : Proposed Regulations
◎ : Final Regulations
● : Regulations Effective
* : TTHM/THAA must meet 40/30 μg/L when TOC exceeds the standard

According to the 1997–1998 Background Surface Source Water Quality Report submitted by the Taiwan Water Company for 40 water treatment plants, there was a 5% chance (2 out of 40 plants) that the average COD in source water exceeded 15 mg/L (Fig. 4). By reviewing the maximum COD values submitted, there was a 27% chance (11 out of 40 plants) that COD was greater than 15 mg/L and a 7% chance (3 out of 40 plants) that COD was greater than 20 mg/L. Compared with the existing COD standard (25 mg/L) for source water, the background COD concentration in source water was relatively low. It implies that the existing (25 mg/L) COD standard is too lenient to protect source water quality. After reviewing source water samples ($n=32$) taken from seven water treatment plants for this investigation, it was found that 8 samples had COD between 15 and 25 mg/L, and 63% of these 8 samples had total THM greater than 40 μg/L. Among the 19 samples with COD less than 15 mg/L, there is a 32% chance that THM is greater than 40 μg/L. These statistical data suggest that a source water COD standard of 15 mg/L would minimize the risk of producing DBPs. The existing source water quality should not have much difficulty in meeting the COD standard of 15 mg/L. Consequently, it is recommended that a COD standard of 20 mg/L be adopted in 2006 (similar to France 1A COD standard) and reduced to 15 mg/L in 2007.

On the other hand, several technical advisory meetings were conducted to solicit input from experts regarding source water standards in Taiwan. It also suggests that Taiwan source water quality should be revised in phases according to the proposed total coliforms, TOC, and COD standards because there are technical problems associated with the enforcement of these standards at the present time. That is, a uniform single standard should be adopted in Phase I which can be divided into two stages as shown in Table 7 and additional regulated parameters will be amended in Phase II after objectives of source water protection in Phase I are accomplished.

Implementation Plans

The water treatment plant with unacceptable source water quality needs to improve its source water quality and establish the implementation plan based on the results of CPE. The evaluation approach of CPE uses a rating system to classify each major treatment process as Type 1, Type 2, or Type 3. The methodology to determine whether a unit process is classified as which type is based on the results of the measured capability and the instantaneous operating flow rate for a specific unit process. A unit process would be rated Type 1 if its operated capability exceeds the peak instantaneous operating flow rate; Type 2 if its measured capability is 80–100% of the peak flow; or Type 3 if its projected capability is less than 80% of the peak flow. The performance problems associated with Type 1 plants are likely related to plant operation, maintenance, and/or administration which can be improved by technical assistance. However, the Type 2 plants need to provide the minor corrections for process improvement to meet the performance goal. For Type 3 facilities, major modifications are required to achieve the objectives of performance. After CPE evaluation, comprehensive technical assistance (CTA) is processed for facilities improvement in water treatment plant. The initial step in assessment of CTA applicability is to determine if improved performance is achievable by evaluating the capability of major unit processes. A CTA is typically recommended if unit processes are deficient in capability (e.g., Type 3), acceptable performance from each “barrier” may not be achievable; and the focus of follow-up efforts may have to include construction alternatives. Another important consideration with Type 3 facilities is the immediate need for public health protection regardless of the condition of the plant.

A case study of the Chen-Chin-Lake water treatment plant located in the Kaoping watershed was performed to demonstrate how the CPE technique can successfully establish the appropriate Type 3 implementation plans. The flow chart of standard operational procedures for reviewing a performance of water treatment plant whose source water quality exceeds the national limit is shown in Fig. 5. To enhance drinking water quality in Kaohsiung metro, both the appropriate sound source water protection program and innovative water purification facilities are to be implemented as follows.

1. Source water protection program. Kaopin River, which supplies around 650,000 cubic meters daily for 2,370,000 residents within Kaoshiung metro areas, is polluted by livestock wastewater from hog farms, domestic sewage, industrial wastewater, landfill leachout, and non-point source (NPS) pollutants from agriculture areas, accounting for 52.5, 11.2, 28.8, 2.2, and 5.3% with total of 23,187 kg of BOD per day, respectively (Lin et al. 2002). The average source water quality data are shown in Table 8. The major water treatment plant in this area is the Chen-Chin-Lake water treatment plant. Although the average NH_3-N levels shown in Table 8 are under 1 mg/L, several unacceptable observations have been found. Besides, the unpleasant taste and odor of tap water caused by the high organic matter and ammonia nitrogen in source water are the major issues always complained about by the local residents.

Enhanced Stream Water Quality Model (QUAL2E) developed by the US EPA was selected as a water quality-planning tool to assess the water quality based on its carrying capacity. It can simulate up to 15 water quality constituents including BOD, nutrients, DO, temp, algae as chlorophyll A, and total coliforms. QUAL2E can operate as a steady-state model which can be used to estimate the impact of waste loads (magnitude, quality, and location) on stream water quality. The constants used in the QUAL2E model were obtained from our previous study (Chiang et al. 2001).

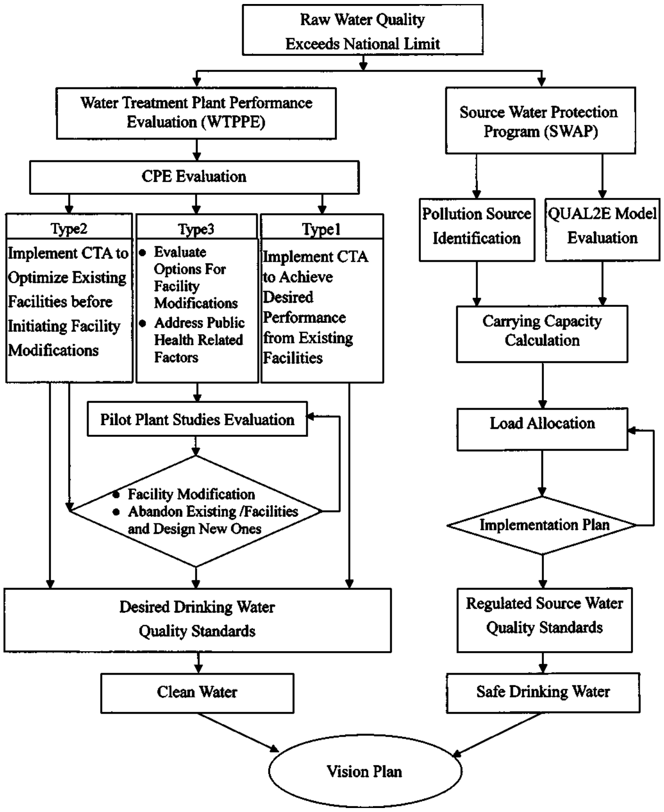

Fig. 5. Standard operational procedures for reviewing and/or approving a water treatment plant whose source water quality exceeds the national limit

The estimated carrying capacities of BOD, NH_3-N, and TP are 27,700, 4,200, and 600 kg per day. Daily total coliforms carrying capacity is found to be 4.8×10^{15} CFU. The current BOD, NH_3 -N, TP, and total coliform loadings are about 2.7, 9.4, 8.5, and 7.3 times higher than the calculated carrying capacities, respectively. To protect public health and improve the river water quality, the river pollution control management plans are proposed as follows: (a) hog ban in the whole Kaoping River basin; (b) sewer system construction to achieve 30% of population served area within 10 years; (c) removal of 10 riverbank landfills; and (d)

Table 8. Average Water Quality Data of the Chen-Chin-Lake Water Treatment Plant from 2000 to 2003

Water quality parameters	Source water	Finish water
Turbidity (NTU)	18.1 (±13.2)	0.42 (±0.15)
Bicarbonate (mg/L)	157 (±24)	140 (±27)
NH_3-N (mg/L)	0.21 (±0.18)	0.06 (±0.01)
TDS (mg/L)	334 (±64)	334 (±64)
Total hardness (mg/L)	223 (±40)	222 (±42)
Conductivity (mmho/cm)	476 (±94)	476 (±116)
Chloride (mg/L)	9.4 (±4.9)	14.1 (±6.9)
Nitrate (mg/L)	1.08 (±0.35)	1.01 (±0.31)
Fluoride (mg/L)	0.15 (±0.04)	0.15 (±0.05)
Sulfate (mg/L)	81.5 (±17.1)	96.6 (±16.5)
TOC (mg/L)	9.4 (±4)	—
COD (mg/L)	2.5 (±1)	—
Total coliforms (CFU/100 mL)	2.7×10^3 ($\pm 1.0 \times 10^3$)	<1
Total counts (CFU/100 mL)	2.0×10^4 ($\pm 4.0 \times 10^4$)	2 (±8)

Note: TOC=total organic carbon; and COD=chemical oxygen demand.

Table 9. Simulated Loading after the Implementation of each Proposed Plan

		Reduced loading				Remaining loading			
Scenario	Measure	BOD (kg/day)	NH_3-N (kg/day)	TP (kg/day)	Total coliforms (CFU/day)	BOD (kg/day)	NH3-N (kg/day)	TP (kg/day)	Total coliforms (CFU/day)
1	Hog ban in the upper catchment to reduce 1/2 hogs	6,000	1,800	500	1.40*E*+15	68,700	37,600	4,600	3.40*E*+16
2	Hog ban in the whole basin	37,800	17,300	2,800	1.57*E*+16	36,900	22,100	2,300	1.97*E*+16
3	Construction of sewer system (20% of connection in 10 years)	3,900	50	—	6.70*E*+15	70,800	39,350	—	2.87*E*+16
4	Sewer system construction (30% of connection in 10 years)	5,900	100	—	7.90*E*+15	68,800	39,300	—	2.75*E*+16
5	Removal of riverbank landfills	2,800	800	80	—	71,900	38,600	5,020	—
6	Reduction of industrial wastewater discharge	1,500	—	—	—	73,200	—	—	—
7	Scenarios 2+4+5+6	48,000	18,200	3,600	2.36*E*+16	26,700 <27,700 (carrying capacity)	21,200 >4,200 (carrying capacity)	1,500 >600 (carrying capacity)	1.18*E*+16 >4.81*E*+15 (carrying capacity)

Table 10. Comparisons of Finish Water Quality for Different Processes at the Pilot Plant in the Chen-Chin-Lake Water Treatment Plant

		Process[a] (I) O→C→S→F→O→G	Process[a] (II) O→C→S→F→P→O→G	Process[a] (III) O→C→S→F→O→G→N
Water quality parameters	Source water	Finish water		
Turbidity (NTU)	NA[b]	0.20	0.07	0.03
NPDOC (mg/L)	1.10	0.90	0.29	0.17
AOC (μg acetate-C eq/L)	NA	25	13	4
Total Hardness (mg/L)	238	230	109	18
TTHM (μg/L)	NA	8.4	0.7	0.3
TTHMFP (μg/L)	79.1	31.4	NA[b]	NA[b]

[a] C=coagulation basin; S=sedimentation tank; F=rapid filtration basin; G=GAC column; O=ozonation reactor; P=pellet softening bed; N =nanofiltration.

[b] Not available.

Table 11. Overall Performance Evaluation of the Selected Processes from the Aspect of Engineering, Environment, and Economy

		Engineering		Environment			Economics		
	Process[a]	Efficiency	Flexibility	Reliability	Energy consumption	Environmental impact	Water quality	Installation cost	Operation and maintenance cost
(I)	O→C→S→F→O→G	Medium	Low	Medium	Low	Low	Good	Low	Low
(III)	O→C→S→F→P→O →G	High	Medium	High	Medium	Medium	Good	High	Medium
(III)	O→C→S→F→O→G →N	High	High	High	High	Medium	Excellent	High	High

[a] C=Coagulation basin; S=Sedimentation tank; F=Rapid filtration basin; G=GAC column; O=Ozonation reactor; P=Pellet softening bed; N =Nanofiltration.

reduction of the industrial wastewater discharge. Reduced and/or remaining pollutants loading after the implementation of each proposed plan are shown in Table 9. With these implementation plans, it is expected that approximately 48,000 kg of daily BOD loading can be reduced, and the remaining BOD loading (26,700 mg/day) is lower than the 27,700 mg per day BOD carrying capacity. However, NH_3-N, TP, and total coliforms loads are still far beyond the calculated carrying capacities.

2. *Water treatment plant performance evaluation*. Since the source water quality cannot be upgraded within a limited time, the CPE technique was also performed to evaluate the performance of the existing facilities in the Chen-Chin-Lake water treatment plant. After the on-site visit, it was observed that performances of the flotation and the coagulation-sedimentation tanks are poor and floc-forming condition is not satisfactory. Additionally, high level of NH_3-N has led to the overdose of pre-chlorination. In order to overcome these problems, pilot plant studies on process modification of the Chen-Chin-Lake water treatment plant were performed. Tables 10 and 11 present the overall performance evaluation of the selected processes from the aspect of finish water quality, engineering, environment and economy.

Among the three test processes of the pilot plants, process (III) exhibits the best performance in terms of high efficiency, flexibility, reliability, and excellent water quality. Therefore, the plan to introduce advanced water treatment processes in Chen-Chin-Lake water treatment plant was chosen as process (III), i.e., preozonation, coagulation, sedimentation, filtration, postozonation, GAC column, and nanofiltration. With these suggested treatment processes, it is expected: (a) to reduce the hardness from 240 to 150 mg/L; (b) to replace pre-chlorination and post-chlorination with ozonation; (c) to remove taste and odor by biological activated carbon filtration process. After completing the upgrading project, the water can meet the drinking water quality standard.

Conclusions and Recommendations

Source water quality criteria and standards from Taiwan and other countries were reviewed in this investigation. Chemical and bacterial water quality criteria, supplemented with a limited number of biological water quality criteria, are the principal indicators of water quality to be established by the developed nations. But, these comprehensive water quality indicators are not yet used and implemented regularly. This study suggests that Taiwan source water quality standards for total coliforms, TOC, and COD be revised in the future.

To achieve the long-term goal of improving water quality, it is recommended that stricter water quality standards in Taiwan be enforced gradually and divided into two execution phases. A uniform single standard should be adopted in Phase I, which can also be divided into two stages as shown in Table 7. The regulated parameters should include representative parameters such as toxic substances, chemical and biological water quality indicators. The water treatment plant with an unacceptable source water quality needs to propose a source water protection program and/or seek on alternative source. Meanwhile, the CPE method is also introduced to find out the performance limiting factors and make improvement and modification of the existing facilities in the water treatment plant.

After Phase I objectives of source water protection are accomplished, various source water quality standards can be established and executed. In Phase II, additional regulated parameters will be added. Minimum treatment processes required for various source water quality will be defined. Applicable water pollution regulations for abating source water contamination will be enforced. All these activities should result in a much improved drinking water quality.

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