CHAPTER 12

RELATIONSHIPS BETWEEN SOURCE WATER QUALITY AND CHOICES OF PRIMARY AND SECONDARY DISINFECTANTS

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ABSTRACT

Influent water quality measurements collected during implementation of the Information Collection Rule (ICR) numbered in the tens of thousands of discrete values. Data on total organic carbon (TOC) and bromide varied widely across the United States, and very high concentrations of each parameter did not appear to occur concurrently in the influent of ICR treatment plants. Examination of the treatment techniques used by ICR plants did not show any overall trends related to influent concentrations of TOC and bromide until the data on primary and secondary disinfectants were "binned" with TOC and bromide data. This chapter explores the relationships between source water quality and the primary and secondary disinfectants used at ICR treatment plants.

Graphs of TOC, bromide, and TOC × bromide indicate that ICR utilities selected primary and secondary disinfectants on the basis of influent water quality. Higher concentrations of TOC and bromide in a plant's influent resulted in selection of alternative primary disinfectants such as ozone, chlorine dioxide, and chloramines and, more clearly, selection of an alternative secondary disinfectant—chloramines.

Even so, the data presented in this chapter indicate that many treatment plants whose water sources have relatively high TOC and bromide concentrations are still using free chlorine. These plants could significantly reduce their concentrations of total trihalomethane and the sum of five haloacetic acids by changing either or both of their primary and secondary disinfectants to something other than free chlorine.

INTRODUCTION

The Information Collection Rule (ICR) generated far more water quality data than just information on microorganisms and disinfection by-products (DBPs) (Wysock et al. 2002, Fair et al. 2002). To put the DBP data in context, it is important to examine the overall occurrence and variability of water quality constituents measured during the ICR.

During presentations of ICR water quality information to the Federal Advisory Committee (FACA) in 1999 and 2000, it was observed that DBP concentrations were not well correlated with influent water quality. Sorting out the relationships between source water quality,

types of treatment, and DBPs was difficult because the Disinfectants/Disinfection By-Products (D/DBP) Rule was in final form during the ICR monitoring period, and there was speculation that utilities were making treatment changes to comply with this rule as ICR data were being collected. The only explanation that made sense at the time of the FACA meetings was that changes in treatment and disinfection practices might have obscured the impact of high concentrations of total organic carbon (TOC) and bromide on DBP concentrations.

This chapter presents summary statistics on influent water quality data collected under the ICR, describes general water treatment trends in ICR utilities, and examines the relationships between influent water quality and treatment methods, especially disinfection practices.

SOURCE WATER QUALITY DATA

Water quality data were extracted from the ICR Auxiliary 1 Database (AUX1) version 5.0, which contains data from 296 utilities and their 500 water treatment plants. ICR values below minimum reporting levels were replaced with zeros before further calculations were performed.

Tables 12.1 and 12.2 list a number of important water quality parameters measured in all ICR treatment plant influents. Unlike other chapters in this book, which describe separate investigations of data on surface water and groundwater plants, this chapter examines overall water quality variability and the resulting treatment technologies applied to meet DBP regulations. Table 12.1 shows statistics on water quality parameters that are of particular interest with respect to the production of DBPs after chlorination. High water temperatures and high pH levels are known to increase the formation of trihalomethanes (THMs). Ultraviolet absorbance at 254 nm (UV_{254}) is an integral part of the specific ultraviolet absorbance (SUVA) calculation—or in the case of ICR data, the TSUVA calculation (SUVA estimated using TOC instead of dissolved organic carbon)—that is used as a surrogate for the removable fraction of natural organic matter in water supplies. The AUX1 database contains a wide range of TOC, bromide, and UV_{254} data. The maximum TOC value of 27.5 mg/L is correct and represents very high source water TOC. The descriptive statistics for bromide listed in Table 12.1 are correct after one adjustment. (AUX1 contains six bromide values of 25 *milligrams* per liter or greater from one utility in Massachusetts. It is certain that these six bromide values are off by a factor of 1,000 and

were entered into the ICR Federal Database incorrectly. The next highest bromide concentration reported in AUX1 is 2.2 mg/L.) The rest of the descriptive statistics describe reasonable and representative concentrations of DBP precursors and important DBP-production parameters in U.S. drinking water supplies.

Table 12.1

ICR influent water quality data related to DBP production

Statistic	TOC (mg/L)	Bromide (mg/L)	UV_{254} (/cm)	pH	Temperature (°C)
Mean	2.8	0.069	0.087	7.53	17.7
Median	2.4	0.036	0.06	7.6	18
Maximum	27.5	2.23	1.9	12.1	43.6
Minimum	<0.35	<0.01	<0.0045	3.7	0.1
90th percentile	5.3	0.16	0.174	8.27	26.7
10th percentile	<0.35	<0.01	<0.0045	6.7	8
Total number of values	7,504	7,959	7,508	8,554	8,563
Number of values below MRL*	1,186	2,173	887	NA†	NA†

* MRL = minimum reporting level
† NA = not applicable

Table 12.2

ICR influent water quality data—other parameters

Statistic	Alkalinity (mg/L as $CaCO_3$)	Turbidity (NTU)	Calcium hardness (mg/L as $CaCO_3$)	Total hardness (mg/L as $CaCO_3$)	Ammonia-nitrogen (mg/L)
Mean	103	11.8	92	139	0.14
Median	93	2.2	76	118	0.10
Maximum	500	3200	515	806	5.10
Minimum	1	0	1	1	0
90th percentile	210	24	200	289	0.30
10th percentile	13	0.12	10	18	0
Total number of values	8,539	8,379	8,258	8,238	8,212
Number of values below MRL*	NA†	NA†	NA†	NA†	NA†

* MRL = minimum reporting level
† NA = not applicable

Table 12.2 lists a variety of other water quality parameters measured under the ICR. Alkalinity, calcium, and total hardness were measured as part of the input parameter matrix for the DBP production model. The revised version of this model, based on ICR data (including data on the DBP precursors listed in Table 12.1), is described in Chapter 8 (Swanson et al. 2002). The huge range of values for influent ammonia-nitrogen indicates a significant inorganic chlorine demand at some treatment plants. Destroying the ninetieth percentile concentration of ammonia-nitrogen (0.3 mg/L) would require the application of about ten times as much free chlorine (about 3 mg/L) as ammonia-nitrogen before a free chlorine residual would be created. The turbidity data show that ICR plants were influenced by rainfall-runoff events during a significant percentage of the 18-month monitoring period. In addition to controlling DBPs, the main function of treatment plants is to remove particles and pathogens. High influent turbidity (and, in some cases, very low influent turbidity) can challenge particle and pathogen removal efforts.

Figures 12.1 and 12.2 show national distributions of the same TOC and bromide data described in Table 12.1. Unlike the figures in Chapter 4 that depict quarterly distribution system data on total THM (TTHM) concentrations by U.S. Environmental Protection Agency region, Figures 12.1 and 12.2 present TOC and bromide data by state because three times as many data points are available for TOC and bromide on the basis of monthly sampling. The combined surface water and groundwater TOC data shown in Figure 12.1 indicate high TOC concentrations in Virginia, North Carolina, Florida, Texas, and the Midwest (with a scattering of high values in New England). In some states, high TOC concentrations occur in both groundwater and surface water, but in other states the TOC concentrations differ. Most of the data on TOC in groundwater supplies (not shown) indicate concentrations of less than 1 mg/L, except in Florida where very high TOC concentrations are found in groundwater. High TOC concentrations in the Southeast, the South, and the upper Midwest are found primarily in surface water sources.

The distribution of bromide across the United States is more complicated than TOC occurrence. Figure 12.2, which shows combined bromide values for groundwater and surface water sources, indicates the occurrence of high bromide concentrations in the Midwest and in Florida, Texas, New Mexico, Arizona, and California. High groundwater bromide concentrations (not shown) are confined to these same five states. Most of the other states either had no data on bromide concentrations in groundwater or had moderate concentrations.

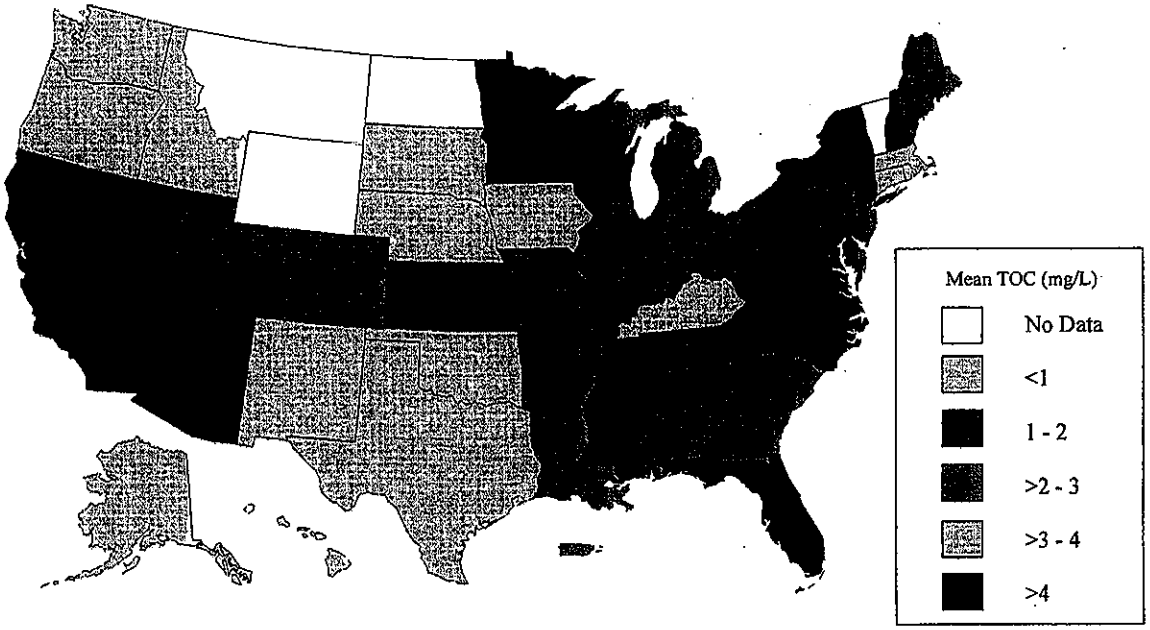

Figure 12.1 National distribution of TOC occurrence in surface water and groundwater

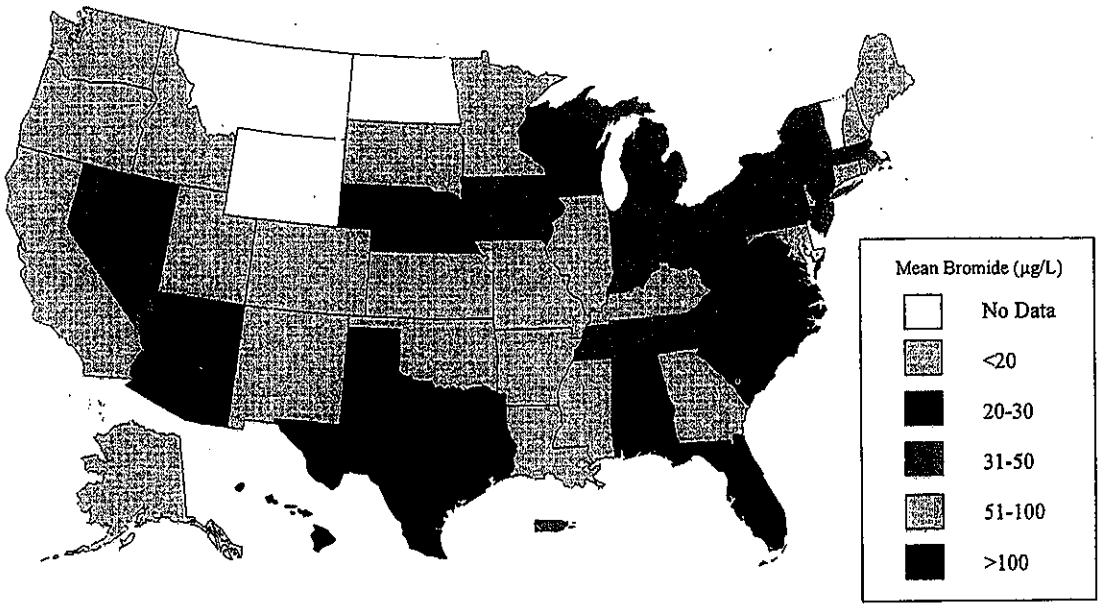

Figure 12.2 National distribution of bromide occurrence in surface water and groundwater

A comparison of Figures 12.1 and 12.2 illustrates the co-occurrence of high bromide and high TOC concentrations in Florida, Texas, Oklahoma, Kansas, Nebraska, and South Dakota. The lowest bromide and TOC concentrations co-occurred in the Pacific Northwest and Alaska.

Figure 12.3 plots paired concentrations of bromide versus TOC in all ICR plant influents. Several patterns are immediately apparent. The very high TOC concentrations (>10 mg/L) do not co-occur with very high bromide concentrations (>0.50 mg/L), but dozens of ICR influent samples had either very high bromide (up to 2 mg/L) or very high TOC (27 mg/L) values. If very high TOC and bromide concentrations did co-occur in a plant's influent, it would be extremely difficult for that plant to use any free chlorine for any appreciable contact time and still meet the 1979 TTHM maximum contaminant level (MCL) of 0.10 mg/L. In most of the paired data shown in Figure 12.3, bromide concentrations ranged from less than the minimum reporting level (MRL) to 0.50 mg/L, and TOC concentrations ranged from <MRL to 10 mg/L (16% and 27%, respectively).

The broad ranges in water quality parameters measured under the ICR indicate the challenges confronting U.S. water utility managers, who must comply with the D/DBP Rule.

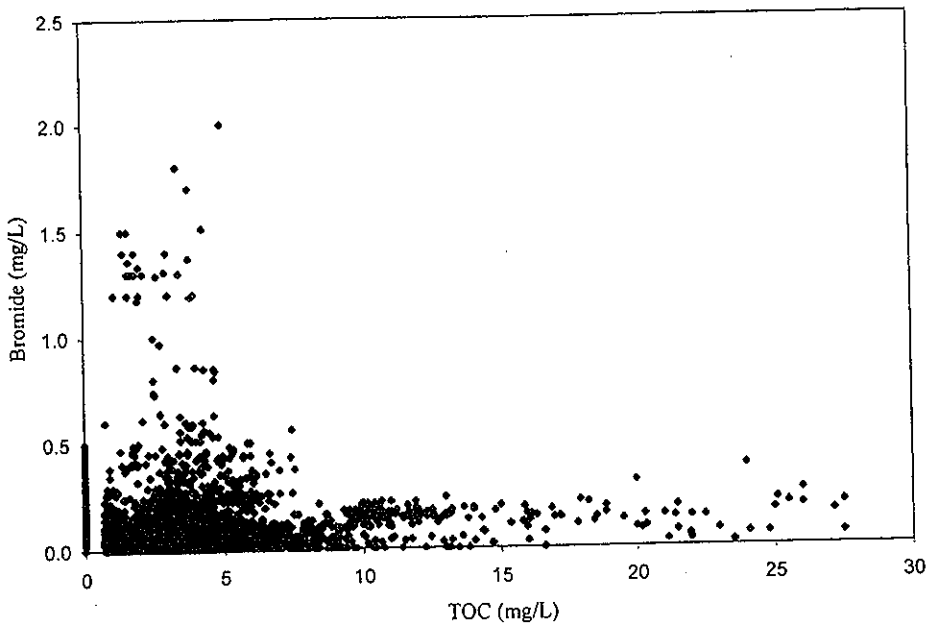

Figure 12.3 Relationship between TOC concentrations and bromide concentrations in the influent of ICR plants (based on plant-months)

DISINFECTION AND TREATMENT TECHNOLOGIES

Figure 12.4 summarizes the water treatment technologies used by 431 of the 500 plants involved in ICR monitoring. Both groundwater and surface water plants are included in the data shown in Figure 12.4; ICR plants not included in this figure were classified in other treatment categories. Conventional treatment (CONV), generally characterized as coagulation–sedimentation–filtration, was by far the most common treatment technology used at ICR plants. A smaller percentage of plants used direct filtration and in-line filtration, described as unconventional treatment (UNCONV). Plants applying only disinfection to unfiltered surface water (UNFILT/SW) constituted a small portion of ICR plants. Disinfection only (DIS/GW) was the most common treatment used for groundwater supplies. The softening category (SOFT) represents a variety of simple, two-stage, split-treatment and other complex softening processes used to reduce hardness (see Chapter 22 [Clark, James, and Lawler 2002] for a detailed discussion of softening at ICR plants). Disinfection of wholesale supplies (DIS/WHSALE), membrane treatment (MEMBRANE), and other groundwater treatment techniques (OTHER/GW) account for the remaining treatment categories represented in Figure 12.4.

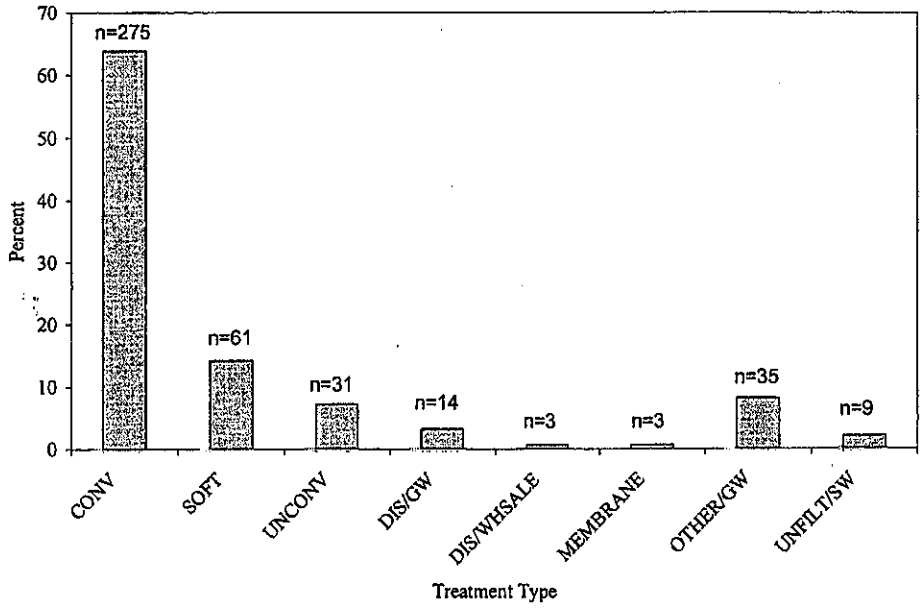

Figure 12.4 ICR plants classified by treatment technology

Attempts were made to segment the treatment technologies shown in Figure 12.4 into "bins" of influent TOC and bromide concentrations (not shown). The purpose of this effort was to determine if these influent water quality parameters drove the selection of treatment processes. No relationship was found between influent TOC and bromide concentrations and treatment plant type, possibly because ICR utilities had chosen treatment technologies for a variety of reasons that were unrelated to TOC and bromide (e.g., the need to filter surface water, high hardness concentrations, high source water concentrations of pathogens, and treatment costs).

Primary and secondary disinfectants are of principal importance in the formation of DBPs, and the distribution of their use among ICR plants is described in Figures 12.5 and 12.6. Free chlorine was the most prevalent primary disinfectant used by ICR utilities. Alternative primary disinfectants such as ozone, chlorine dioxide, and chloramines were used in about 13% of plant-months (months of data collected by ICR treatment plants). Theoretically, ICR sampling could have produced a maximum of 9,000 plant-months of data (i.e., 500 plants times 18 months). Plant-months were calculated and graphed in Figures 12.5 and 12.6 because some treatment plants changed primary and secondary disinfectants from month to month over the 18-month monitoring period.

Figure 12.6 shows that 69% of ICR plants used free chlorine as a secondary disinfectant in their distribution systems. The number of utilities that changed their distribution system disinfectant to chloramines prior to ICR monitoring increased between 1979, when the TTHM MCL was promulgated, and 1987 (McGuire and Meadow 1988).

Although overall statistics on the types of treatment and disinfectants used at ICR plants are of general interest, it is more important to understand which plants with specific influent water qualities were using free chlorine or alternative disinfectants during ICR monitoring. The FACA negotiators in 1999–2000 were interested in understanding the effects of technology and the capacity for installing additional treatment at a relatively low cost in order to achieve better control of DBPs (for example, switching to alternative disinfectants).

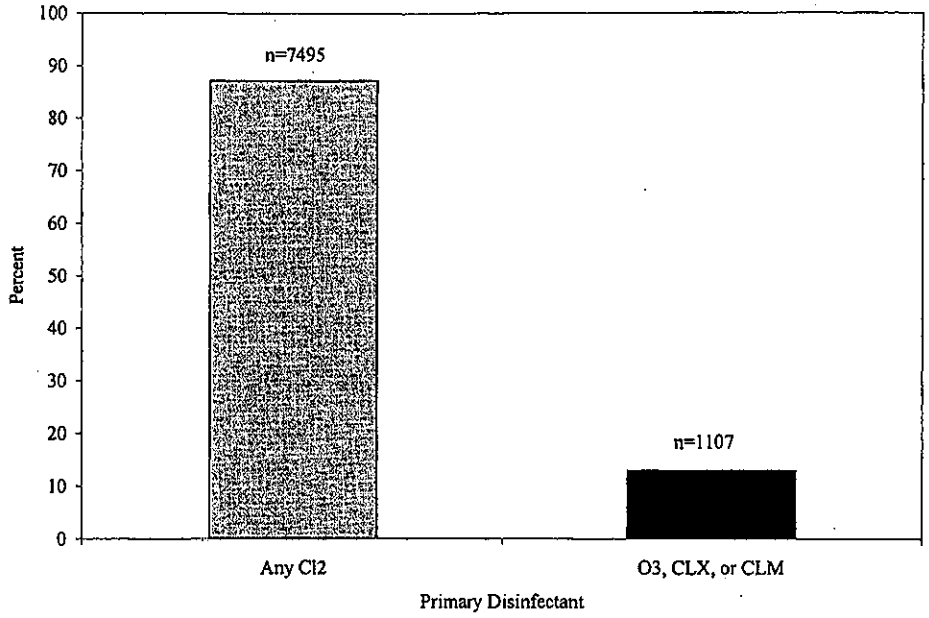

Figure 12.5 Primary disinfectants used by ICR treatment plants (based on plant-months)

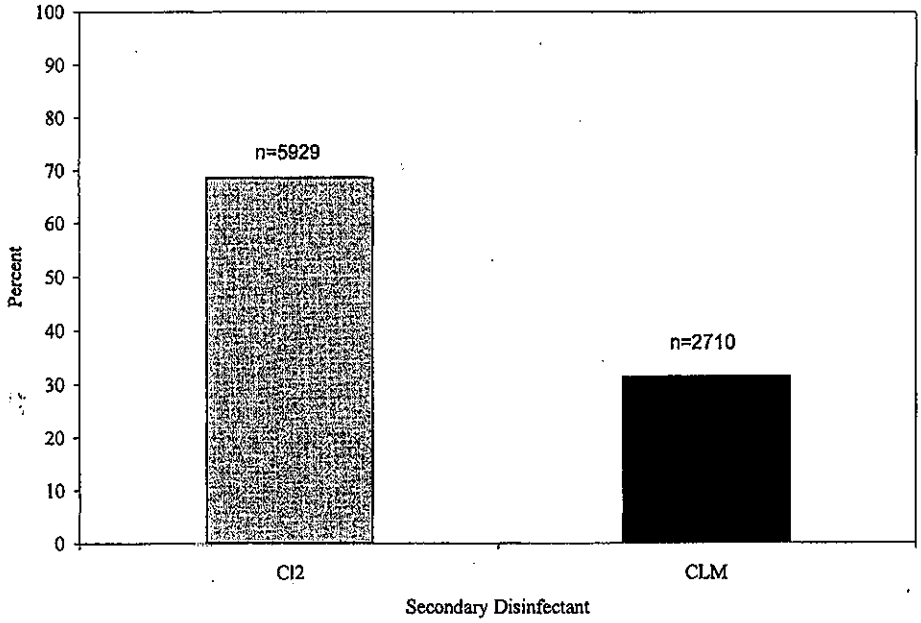

Figure 12.6 Secondary disinfectants used by ICR treatment plants (based on plant-months)

DISINFECTION AND SOURCE WATER QUALITY RELATIONSHIPS

Primary Disinfectants

Figures 12.7, 12.8, and 12.9 synthesize ICR information on source water quality and choice of primary disinfectant. Each graph plots the percentage of plant-months in which ICR plants used free chlorine or an alternative disinfectant as the primary disinfectant. Plant-month percentages are organized into five bins of TOC values representing approximate quintiles, or ranges, each comprising 20% of the TOC values. For example, in the bin for TOC concentrations ranging from 0.9 to 1.95 mg/L, free chlorine was used as the primary disinfectant in 97% of the plant-months, and an alternative disinfectant (such as ozone, chlorine dioxide, or chloramines) was used as the primary disinfectant in 3% of the plant months.

Overall, Figure 12.7 shows that increasing concentrations of TOC in source water supplies required a higher percentage of ICR plants to change to a primary disinfectant other than free chlorine. In other words, if a treatment plant with high concentrations of natural organic matter in its source of supply used free chlorine, the utility would risk violating the existing TTHM MCL of 0.10 mg/L. Chapter 4 discusses the relationship between influent TOC concentrations and TTHM produced at ICR plants (McGuire and Graziano 2002).

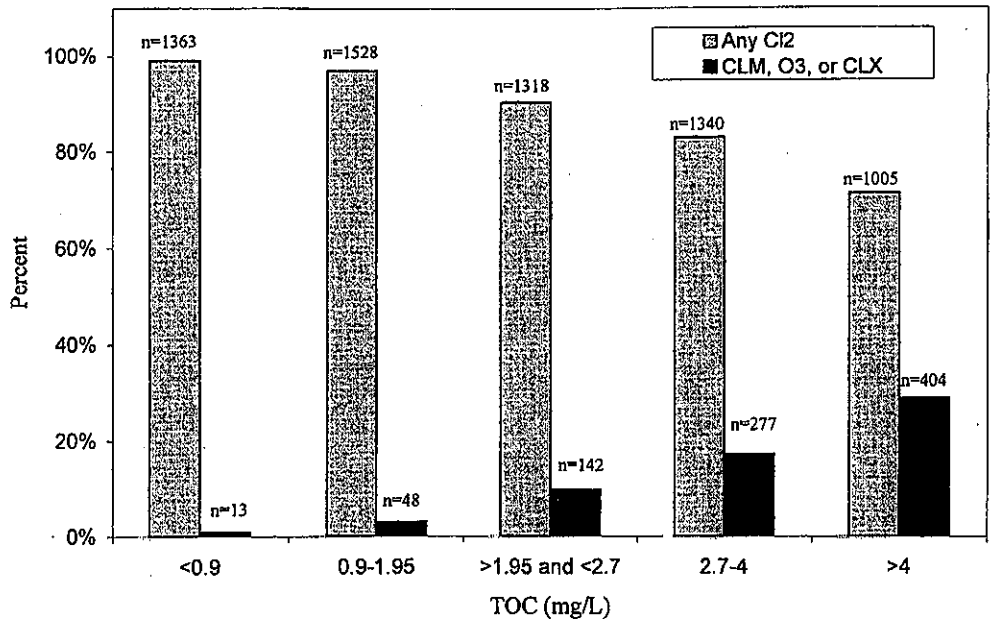

Figure 12.7 Primary disinfectants used by ICR treatment plants and binned according to influent TOC data (based on plant-months)

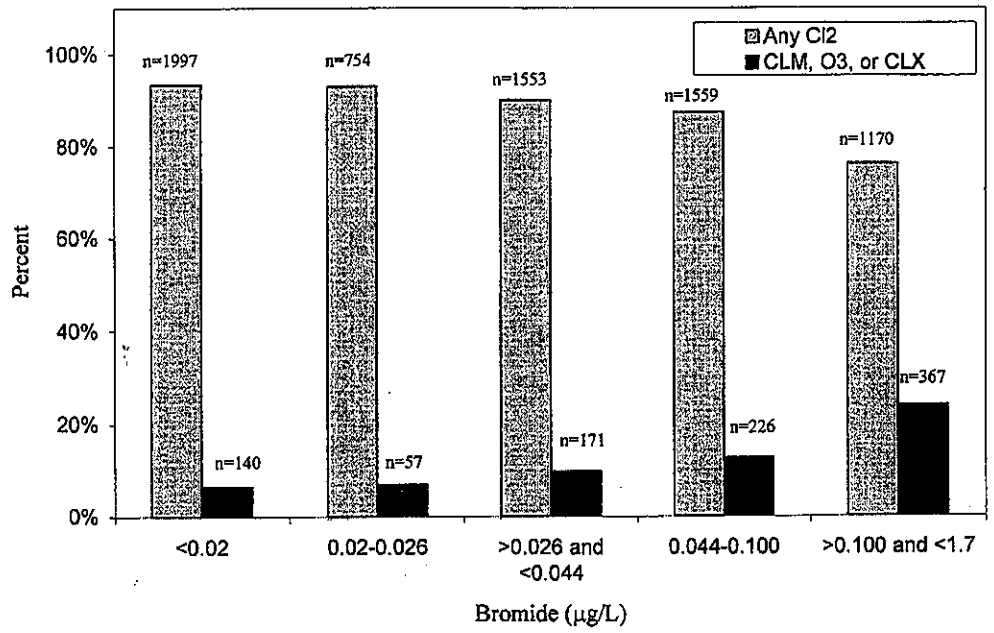

Figure 12.8 Primary disinfectants used by ICR treatment plants and binned according to influent bromide data (based on plant-months)

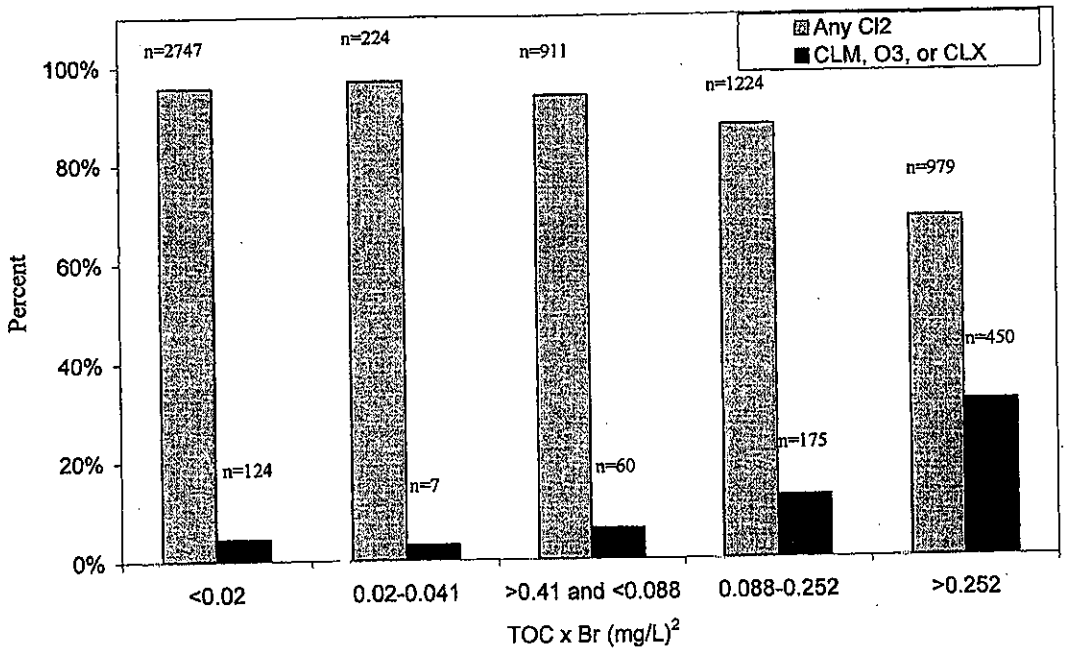

Figure 12.9 Primary disinfectants used by ICR treatment plants and binned according to the product of influent TOC × bromide (based on plant-months; units = milligrams per liter, squared)

Figure 12.8 shows that ICR treatment facilities also appear to have chosen primary disinfectants on the basis of influent bromide concentrations. This finding is somewhat surprising, because national distributions of bromide were not widely known before ICR sampling was conducted. Without data on bromide concentrations, utilities were probably choosing primary disinfectants on the basis of some other parameter that likely had some type of relationship with bromide in source water supplies. In the 1980s and 1990s, water utilities were modifying their primary disinfectant based on the occurrence of THMs in their distribution systems. Utilities that had high TTHM concentrations and were uncomfortably close to the 0.10 mg/L MCL probably switched to alternative primary disinfectants to avoid the effect of high bromide concentrations on THM formation. Under laboratory conditions, increasing bromide concentrations while maintaining constant concentrations of TOC and free chlorine produced higher concentrations of THMs (Pourmoghaddas et al. 1993, Symons et al. 1987).

Figure 12.9 plots the product of TOC and bromide concentrations (in units of milligrams per liter, squared) to illustrate the combined effects of these two DBP precursors on the choice of

primary disinfectant. In the bin containing the highest concentrations of TOC × bromide (>0.252 $[mg/L]^2$), alternative primary disinfectants were used in 31% of plant-months, whereas in the bins containing the highest concentrations of TOC and bromide alone, alternative primary disinfectants were used in 29% and 24% of plant-months, respectively. Thus, when the two precursors were considered together, the highest TOC and bromide product in the influent seemed to influence almost one third of the plants in that category to change to an alternative primary disinfectant.

Secondary Disinfectants

Figures 12.10, 12.11, and 12.12 synthesize ICR information on source water quality and choice of secondary disinfectant. These figures show that poor source water quality resulted in more choices of alternative secondary disinfectants than alternative primary disinfectants. For example, in the bin containing the highest TOC concentrations (>4 mg/L) alternative primary disinfectants were used in 29% of plant-months, whereas alternative secondary disinfectants were used in 66% of plant-months. This is not surprising, because one of the first things utilities did upon realizing that they might have trouble meeting the 1979 TTHM MCL was to change their distribution system disinfectant from free chlorine to chloramines (McGuire and Meadow 1988, Kreft et al. 1985). Using chloramines in the distribution system was a lot less expensive for utilities than implementing an alternative primary disinfectant such as ozone or chlorine dioxide.

Figure 12.12 shows that the impact of considering both TOC and bromide in selecting a secondary disinfectant was greater than the impact of considering either precursor separately, as was the case with selection of a primary disinfectant. In the bin containing the highest concentrations of TOC × bromide (>0.252 $[mg/L]^2$), chloramines were used in 74% of plant-months, whereas in the bins containing the highest concentrations of TOC and bromide alone, chloramines were used in 66% and 57% of plant-months, respectively.

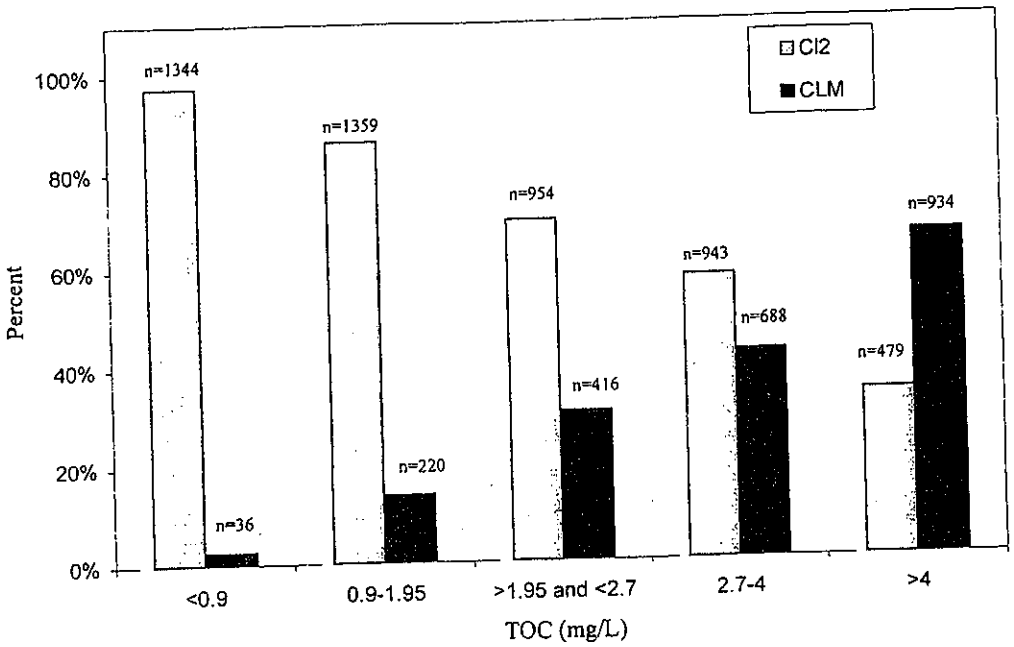

Figure 12.10 Secondary disinfectants used by ICR treatment plants and binned according to influent TOC data (based on plant-months)

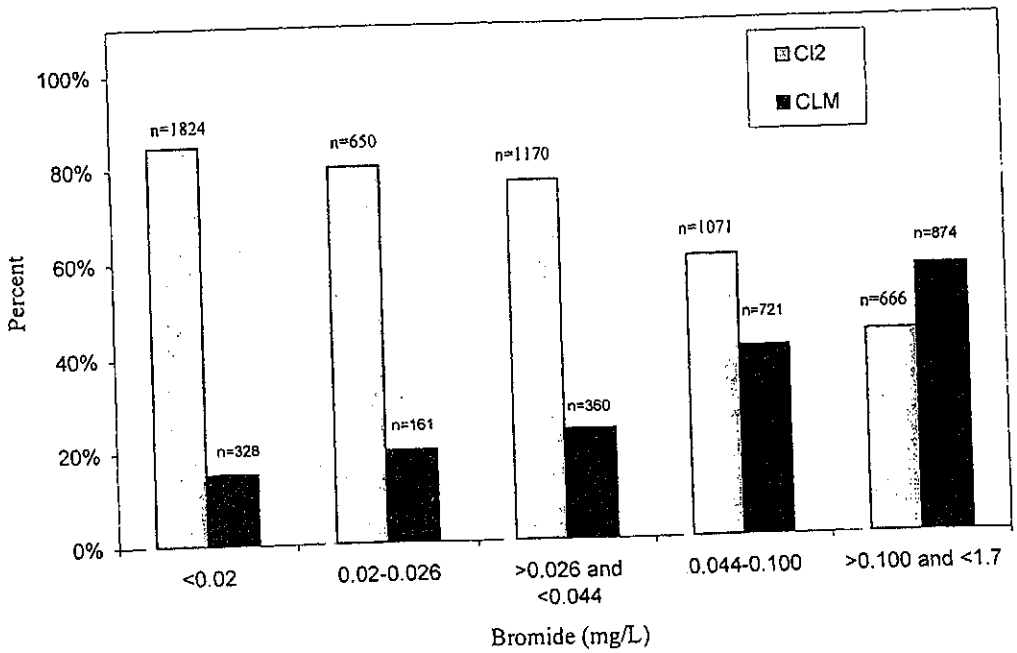

Figure 12.11 Secondary disinfectants used by ICR treatment plants and binned according to influent bromide data (based on plant-months)

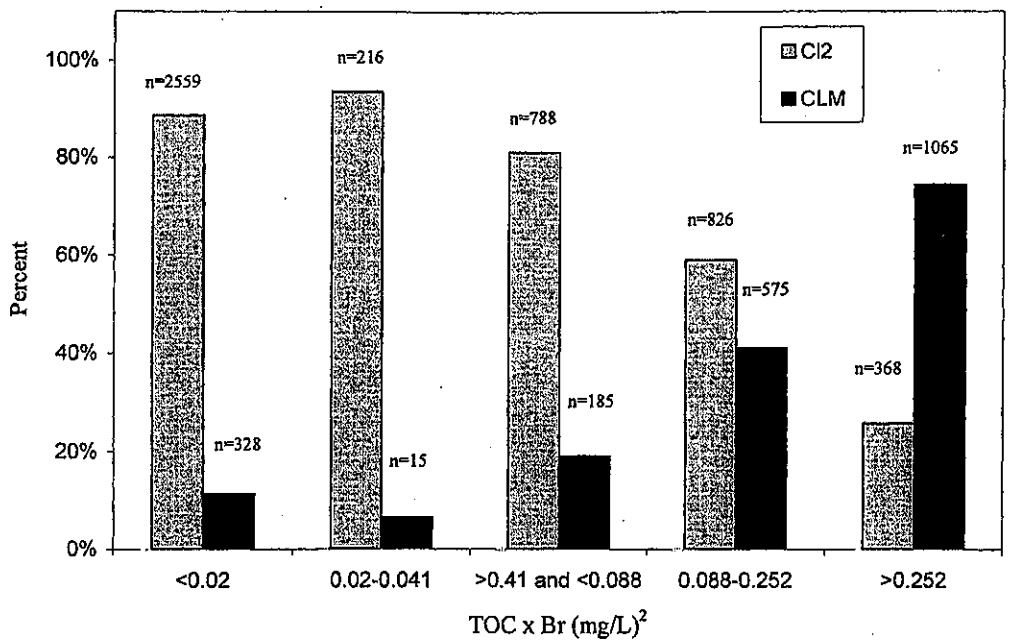

Figure 12.12 Secondary disinfectants used by ICR treatment plants and binned according to the product of influent TOC × bromide (based on plant-months; units = milligrams per liter, squared)

The data shown in Figures 12.7–12.12 indicate that many ICR plants with relatively high TOC and bromide concentrations have continued to use free chlorine. To achieve further reductions in DBP formation, the obvious choice for these plants would be to change either or both of their primary and secondary disinfectants to something other than free chlorine.

SUMMARY AND CONCLUSIONS

Influent inorganic and organic water quality at ICR treatment plants was highly variable. High TOC and bromide concentrations co-occurred in the influent of ICR plants in Florida, Texas, Oklahoma, Kansas, Nebraska, and South Dakota. Fortunately for ICR utilities, a scatter plot of TOC and bromide data pairs illustrated that very high levels of TOC (>10 mg/L) did not co-occur with very high bromide levels (>0.50 mg/L) in any treatment plant influent.

The results presented in this chapter show that ICR plants were more likely to apply primary and secondary disinfectants other than free chlorine if their influent contained high concentrations of TOC and bromide. This conclusion is in agreement with the findings presented

in Chapter 4 (McGuire and Graziano 2002), which showed that source water TOC and bromide concentrations exerted an influence on TTHM concentrations in distribution system samples. As stated in Chapter 4, water treatment plants have adjusted their treatment schemes by modifying the single most important factor in THM production—contact with free chlorine used as either a primary or secondary disinfectant. The data in this chapter confirm that many treatment plants adjusted their primary and secondary disinfectants if their source water contained high concentrations of organic and inorganic precursors. By converting to the use of alternative disinfectants, ICR utilities have complied with the 1979 TTHM MCL. Utilities still using free chlorine will be faced with similar choices as they try to comply with the D/DBP and Stage 2 DBP rules.

ACKNOWLEDGMENT

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Use of flavour profile and consumer panels to determine differences between local water supplies and desalinated seawater

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Abstract The San Diego County Water Authority of California has initiated planning for coastal desalination facilities to augment their water supplies. Integration of the different water qualities from these facilities into existing pipelines must be achieved. This investigation determined whether, and to what degree, consumers can discriminate between desalinated seawater and imported water supplies and how these investigations can contribute to decision making regarding the need for construction of facilities to blend such supplies prior to delivery. Based upon the results of the flavour profile analysis panel and the consumer evaluation sessions, it was concluded that free chlorine versus chloramine disinfection or different concentrations of disinfectants did not significantly affect consumer perception of the taste and odour of desalinated seawater or blends with Colorado River water and State project water. Consumers were able to discern between desalinated seawater and imported water, preferring imported water when forced to make a choice. However, the investigators did not believe that the difference in consumer perception was significant enough to warrant special blending facilities to mitigate the relatively minor aesthetic quality differences between imported water supplies and desalinated seawater.

Keywords Chloramine; chlorine; consumer panel; desalination; flavour profile analysis; seawater

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Introduction

Coastal desalination facilities are in the planning stages for the San Diego County Water Authority (SDCWA) in southern California to augment their water supplies. Integration of the water from these facilities into existing pipelines must be achieved. Absent extraordinary measures and costs, the Desalinated Water Conveyance Facility could result in a cycle where a proportion of customers might receive pure desalinated water one day and pure imported water the next day. If consumers can discern substantial differences between the two water supplies, SDCWA may wish to take actions to reduce these water quality differences. The management options include blending supplies, treatment options and post-treatment conditions to determine, and if necessary narrow, the flavour difference of the two waters.

The objective of this project was to determine whether, and to what degree, consumers can discriminate between desalinated seawater and imported water supplies and how these investigations can contribute to decision making regarding the need for construction of facilities to blend such supplies prior to delivery. Potential consumer reactions were modelled using a professional panel and a consumer panel comprising of participants from the area potentially impacted by the different water supplies. There were very few examples of consumer panel testing in the literature to guide this project experimental design (de Greef *et al.*, 1983). Consumer panels have been recently shown to provide valuable insight into preferences and sensitivities of water utility customers (Aciukewicz *et al.*, 1999). This investigation also sought to define the effect of disinfectant residual

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and alkalinity on human perception of taste and odour of desalinated seawater and blends. Alkalinity adjustments to desalinated seawater will be necessary to stabilise the water with respect to corrosivity and it was important to determine whether alkalinity adjustment of desalinated water affected odour or flavour.

Materials and methods

Seawater and other water samples

Seawater was collected from the Encina Power Plant outfall near Carlsbad, California. The samples were collected on the ocean side of Pacific Coast Highway and stored in five-gallon polycarbonate bottles and returned to the test laboratory. Field measurements of the raw seawater included:

- TDS = 30,000 mg/L field measurement (laboratory measurements showed TDS of 35,300 mg/L)
- Temperature = 32.1°C
- pH = 7.8

The water samples were processed through an Applied Membranes dual Hydranautics 2.5″ element reverse osmosis (RO) system. To ensure that the water was safe to drink during the flavour profile analysis (FPA) panel and consumer sessions, a UV disinfection unit was used as the final polishing step. As a control measure, FPA of one set of pre- and post-UV samples as conducted to ensure UV had no effect on the aesthetic qualities of the water.

Treated Colorado River water (CRW) was collected from the effluent of the undisinfected microfiltration treatment plant serving the domestic water system at the Metropolitan Water District of Southern California's (Metropolitan's) Hinds Pumping Plant. State Project water (SPW) was collected from the disinfected filter effluent of Metropolitan's H.G. Mills treatment plant.

Table 1 summarises the results of general mineral analyses of the three waters examined including the unadjusted RO permeate. There are significant chemistry differences between the waters, particularly regarding alkalinity, hardness, sulphate and chloride concentrations.

Table 1 Water quality in raw seawater and the three waters examined in this study

Constituent	Units	Raw seawater	State project water–mills	Colorado River Water–Hinds	Unadjusted RO permeate
Alkalinity	mg/L	109	65.6	129	2.07
Bicarbonate alkalinity	mg/L	133	79.6	156	2.54
Total hardness	mg/L	5,920	106	304	34.2
mg/LTDS	mg/L	35,300	280	680	280
Calcium	mg/L	390	21	74	2.3
CO_2	mg/L	2.66	1	1.24	1.28
CO_3	mg/L	0.864	0.82	2.55	
Sulfate	mg/L	2,400	44	260	8.7
Chloride	mg/L	19,000	76	91	160
Bromide	µg/L	63,000	20	11	580
Arsenic	µg/L		1.3	2.9	1
Copper	µg/L		2.1		
Iron	mg/L				
Magnesium	mg/L	1,200	13	29	6.9
Potassium	mg/L	350	2.6	4.5	3.5
Sodium	mg/L	10,000	53	97	87
Nitrate	mg/L		0.67		
Lab pH	Units	8	8.2	8.4	6.6

Adjustments were made to chemistries of the source waters and blends. Alkalinity and pH in the RO permeate were adjusted by adding dissolved pharmaceutical grade calcium hydroxide in water and adjusting the pH with carbon dioxide gas. Figure 1 shows the experimental conditions and water qualities of the blends presented to the consumer panelists. The original plan was to actually sample water from the Skinner treatment plant effluent and use it in the consumer panel studies. However, an algae bloom that contributed 8 ng/L of geosmin to the plant effluent meant that a 50:50 blend of Colorado River water and State Project water needed to be made to represent the typical Skinner plant effluent.

Analytical methods

FPA is an analytical method that evaluates the sensory characteristics of water. Originally developed for evaluation of food products by Cairncross and Sjostrom (1950), FPA was adapted for drinking water off-flavour assessment by Krasner *et al.* (1985). FPA is described in Standard Methods for the Analysis of Water and Wastewater as Standard Method 2170. FPA determines the strength or intensity of each perceived odour or flavour (on a scale of 0–12) without dilution or treatment of the sample. Flavour characteristics are determined by taking water samples into the mouth; odour characteristics are determined by sniffing the sample.

Seawater samples were collected and RO permeate generated as described above. Typically, FPA samples were stored in 500 mL amber glass bottles with PTFE-lined caps. For odour and flavour determinations, samples were presented in non-odourous plastic cups (Solo Cup Company Highland Part, IL, USA) covered by watch glasses. Samples were allowed to adjust to room temperature and then analysed by the panel immediately after preparation.

Consumer panel selection and operation

Consumers were recruited by telephone by Taylor Research, Inc. (San Diego, CA, USA) which maintains a list of over 50,000 participants for consumer studies. Consumers who passed screening criteria were assigned one of three appointment sessions (72 consumers were ultimately recruited for three sessions). Participants were informed that they would

Skinner Water Treatment Plant Treated Water	◻ 50:50 blend of Colorado River Water (Hinds) and State Project Water (Mills) Calculated TDS based upon Lab analysis = 480 mg/L ◻ Chloramine residual: 2.5 mg/L adjusted with sodium hypochlorite (5%) ◻ Temperature: Room temperature
Desalinated Seawater	◻ Total dissolved solids = 350 mg/L ◻ Alkalinity Targets: 50, 75 & 100 mg/L ◻ Chloramine residual: 2.5 mg/L adjusted with sodium hypochlorite (5%) ◻ Temperature: Room temperature
Blend	◻ Alkalinity Targets: 50, 75 & 100 mg/L ◻ Chloramine residual ; 2.5 mg/L adjusted with sodium hypochlorite (5%) ◻ Temperature: Room temperature ◻ 75% desalinated seawater/25% Skinner water; 50%:50% & 25% desalinated seawater/75% Skinner water blends generated

Residual chlorine measurements were made before and after both sessions to ensure sample consistency

Figure 1 Experimental conditions for samples presented to consumer panel

receive $50 for their involvement in this study. No indications of the study's scope, instructions or objectives were given to the screened panelists prior to the panel sessions.

The 72 panelists broadly reflected the demographics of the service area of the SDCWA. The split along gender lines was approximately 50:50 and there was a broad representation of ethnicities, ages and household incomes.

Eight sets of samples were presented to consumer panelists at room temperature (approximately 22.5°C) in non-odourous plastic cups. For the first seven sets of samples presented to panelists, the test was conducted by providing each participant three cups of samples to compare. Two samples were the same water and the third sample was the test water. The participant was asked to determine which of the three was "different". This type of flavour evaluation is called "forced-choice" triangle testing and is widely accepted in the field of off-flavour investigations (ASTM, 1991). The placement of the "different" cup was randomised in each presentation so that panelists would not be tempted to learn from their neighbours. The eighth set presented to the participants consisted of only two cups and the panelists were asked: "Are these two water samples different? Is the difference between these two objectionable? Which sample do you prefer?"

Results and discussion

Professional panel evaluations

Figure 2 shows that the odour and flavour intensities of the RO permeate samples were generally rated as odour free or flavour free. Generally, the increases in alkalinity did not affect odour or flavour characteristics of the RO permeate samples. An adjusted alkalinity of approximately 50 mg/L as $CaCO_3$ was chosen for most of the subsequent experiments with RO permeate.

Figures 3 and 4 show FPA results for free and total chlorine disinfectants used in RO-treated seawater. There were few consensus odour or flavour characteristics except for chlorine; chlorine intensities were low and would not generally elicit complaints from the public. Results showed a higher prevalence for chlorine odour as compared with chlorine flavour which may be a function of sample presentation: volatilisation of chlorine from the water, concentration in the headspace under the watch glass and low-level detection after removal of the watch glass covering the plastic cup. No dramatic increases in intensity

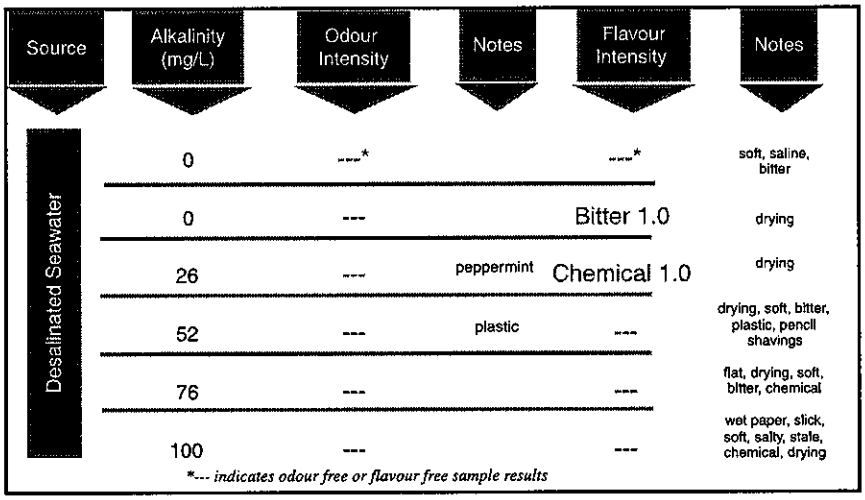

Figure 2 FPA panel results for RO permeate at increasing alkalinity concentrations (mg/L as $CaCO_3$); temperature = 22.5°C

Source	Free Chlorine (mg/L)	Odour Intensity	Notes	Flavour Intensity	Notes
Desalinated Seawater	0.2	Chlorine 1.0		---	drying, wet cardboard, chlorine, bitter
	0.6	Chlorine 0.5	sour, sweet, plastic	---	plastic, drying, chlorine, bitter, slick, wet cardboard
	0.8	Chlorine 0.5		Chlorine 1.0	drying, bitter, salty, plastic/chemical, wet cardboard
	1.0	Chlorine 1.5	sweet	---	stale, drying, wet paper, metallic, astringent, drying
	1.3	Chlorine 0.5		---	bitter, slick, stale, drying, chlorine, mineral/old pipe
	1.6	Chlorine 1.0		Chlorine 1.0	bitter, slick, salty, sweet, mineral/old pipe

Figure 3 FPA panel results for RO permeate at increasing free chlorine concentrations (mg/L as Cl_2); temperature = 22.5°C

were noted for higher free and total chlorine residuals. Based on these results, subsequent experiments with RO permeate and blends were conducted with free chlorine residuals of approximately 1.0 mg/L and total chlorine residuals of 2.5 mg/L.

Figure 5 shows results from the FPA panels that were typical of a number of blends and water qualities studied. Similar results were obtained for total chlorine residuals of approximately 2.5 mg/L. No consensus panel results for odour or flavour were determined except for chlorine. In general, the FPA panels did not discern any significant off-flavour characteristics in either desalinated seawater or in blends of desalinated seawater and local water supplies.

Consumer panel evaluations

Figures 6 and 7 show the results of the first seven comparisons conducted by the 72 consumer panelists. For the first comparison, a statistical test showed that the panelist selection of cups containing the same water was no different from selection by chance. For comparisons 2, 3 and 4, selection of the "desal" water by the panelists was far greater

Source	Chloramines (mg/L)	Odour Intensity	Notes	Flavour Intensity	Notes
Desalinated Seawater	0	Chlorine 0.5	sweet	---	bitter, drying, soft, slick, chlorine
	0.8	Chlorine 0.5	resin, citrus peal	---	wet paper, chlorine, slick, bitter
	1.3	Chlorine 0.5	citrus peel	---	wet paper, slick, chemical, bitter
	2.3	Chlorine 1.0		Chlorine 0.5	soft, slick, chalky, drying, bitter, wet paper
	3.5	Chlorine 1.0	chemical resin	---	wet paper, chlorine, chemical, bitter
	4.4	Chlorine 1.0		---	wet paper, chlorine, bitter/acrid, soft, astringent

Figure 4 FPA panel results for RO permeate at increasing total chlorine concentrations (mg/L as Cl_2); temperature = 22.5°C

Source	Free Chlorine (mg/L)	Odour Intensity	Notes	Flavour Intensity	Notes
RO Permeate	0	---	Swampy, sweet	---	Drying, soft, salty
75% RO/ 25% SPW	0.9	Chlorine 1.0	butter, peppermint	Chlorine 0.5	drying, salty, slick
50% RO/ 50% SPW	1.0	Chlorine 1.0		---	salty, plastic, drying, slick, chlorine
25% RO/ 75% SPW	1.0	Chlorine 1.0		---	salty, drying, slick, bitter
75% RO/ 25% CRW	0.9	Chlorine 1.0	plastic, rubber	---	Stale, plastic, slick, bitter, drying, salty, chlorine
50% RO/ 50% CRW	0.9	Chlorine 0.5	sweet	---	Drying, wet paper, salty, stale, chlorine
25% RO/ 75% CRW	1.0	Chlorine 0.5	sweet	---	drying, wet paper, salty, stale, chlorine

Figure 5 FPA panel results for RO permeate and blends with CRW and SPW; free chlorine; temperature = 22.5°C

than by chance alone. Therefore, they could clearly tell the difference between Skinner and desal. For the same three comparisons, increasing alkalinity of the desal water did not make the selection of the desal water any more likely. In other words, alkalinity levels in this range did not appear to impact the panelists' ability to notice differences between the two types of water.

In Figure 7, comparisons 5, 6 and 7 indicate that the consumer panel members could identify differences between Skinner water and blends of desal and Skinner water at statistically significant levels. The panelists noted a slight decrease in ability to discern desal water as different from Skinner water at higher percent blends of Skinner water. However, this slight decrease was calculated as not statistically significant.

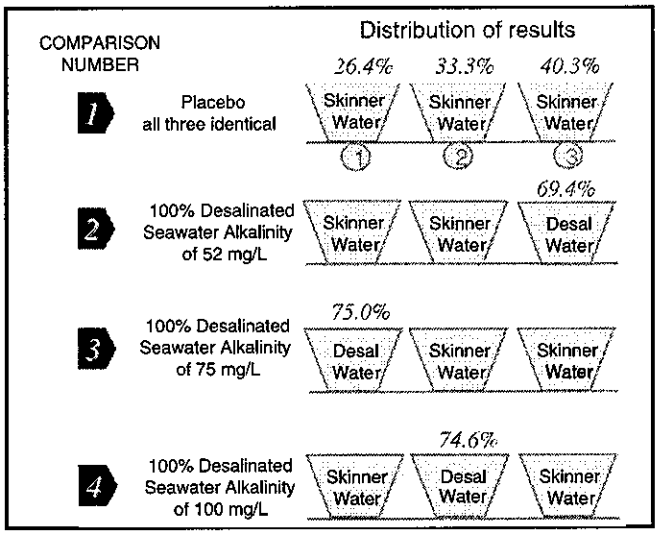

Figure 6 Consumer panel results: forced-choice comparisons 1 to 4

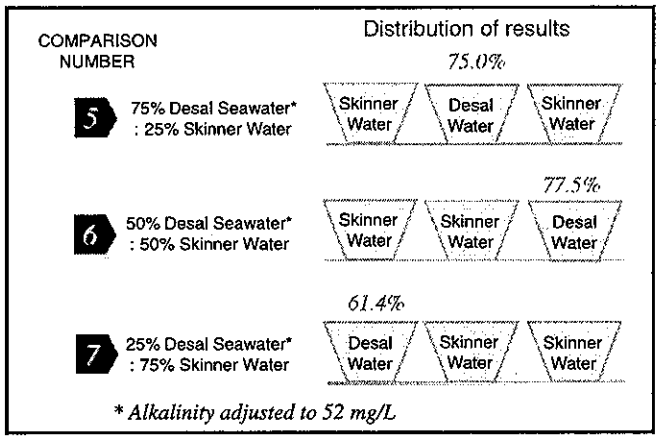

Figure 7 Consumer panel results: forced-choice comparisons 5 to 7

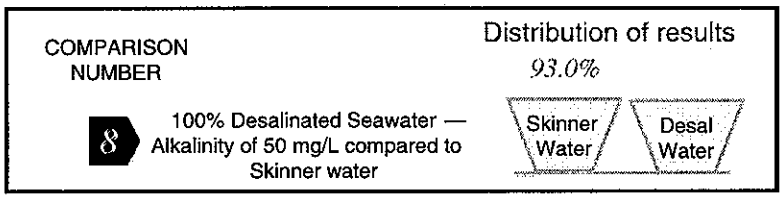

Figure 8 Consumer panel results for RO permeate Skinner water

Figure 8 presents the results of the last comparison test conducted by the consumer panel. The consumer panelists noted overwhelmingly (97.2%) that the two waters were different. However, only 62.0% noted that the difference was objectionable. Of those panelists that noted a difference in the two waters, 93.0% of them selected Skinner water as the water they preferred when compared with 100% desal.

Summary and conclusions

Based upon the results of the FPA panel and the consumer sessions:

- Alkalinity adjustment did not affect expert or consumer perception of the taste and odour of desalinated seawater. Selection of the appropriate alkalinity for treated desalinated seawater should be driven by corrosion control, not consumer aesthetics.
- Free chlorine or chloramine disinfection or concentration did not significantly affect consumer perception of the taste and odour of desalinated seawater or blends with Colorado River water and State Project water.
- The FPA panel did not note any significant off-flavour problems in desalinated seawater; no significant off-flavours were found in blends of desalinated seawater with either State Project water or Colorado River water.
- Consumers panelists were able to discern between desalinated seawater and imported water preferring imported water when forced to make a choice. Consumer panel sessions compared the two waters "side by side". This would not occur in practice because an area may get imported water in the morning and desalinated water at night (or less frequent changes).

- The reason for the preference of Skinner water is unknown but may involve disinfection chemistry in desalinated seawater and the formation of short-lived but odorous bromamines.
- Even though consumer panelists were able to determine with a high degree of certainty the differences between desalinated seawater and imported water, the findings of no significant off-flavours by the professional panel suggests that the differences that the consumers found were detectable but small. The authors do not believe the differences in consumer panel perceptions noted in this study were significant enough to warrant special blending facilities to mitigate the aesthetic quality differences between imported water supplies and desalinated seawater.

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