TTHMs in Desalinated Seawater: A Case Study

H A Minnigh
RCAP Solutions, Inc., Lajas, PR
Remy-Martín Ramírez
Annelise Knudsen
Shawn Scotland
(all)
The Water and Power Authority of the US Virgin Islands (WAPA)
Harold Mark
USVI Division of Environmental Protection
Department of Planning and Natural Resources, St. Croix, USVI

H A Minnigh, PO Box 48, Lajas, PR 00667
hminnigh@compuserve.com  787 808 0640  FAX 787 892 2089

Abstract

Water-poor coastal regions of the world are turning increasingly to desalination of seawater for supply. Tampa, FL has a plant under construction and San Diego, CA one under consideration. In addition, the State of Texas is evaluating a large-scale desalination demonstration project for several sites along its Gulf Coast. While much of this desalination relies on membrane processes sites where electrical power is generated using steam are uniquely suited to distillation processes.

The Water and Power Authority of the USVI (WAPA) has operated hypobaric distillation desalination plants on the three major islands for over 10 years. Two major plants each provide potable water for populations of about 50,000 persons. In the last two years one of the islands experienced a sudden increase in TTHMs at the long-residence-time site (LRT). This increase was roughly concomitant with changes in passivation for corrosion control in the distribution system and a number of other distracting changes in treatment and operational regimes.

It was found that several factors contributed to the problem, including automatic disinfectant rate control, operation of storage facilities, instantaneous water supply demand changes and possibly application of mixed-oxidants generated on-site. For each contributing factor the corrective actions taken by the Authority and their results are presented. At this point, only a single, under-utilized part of the system does not comply with DBPR Stage 2 requirements and proposed corrective action for this area is also presented. (Pontius, 1999)

Keywords: TTHMs, Seawater, Desalination

Introduction

The USVI are the northern end of the Leeward Islands and are located about 1,100 miles east of Miami and between about 40 and 65 miles southeast of Puerto Rico. The three major islands are St. Croix, St. Thomas and St. John; together they aggregate to about 130 miles². Rainfall in the period 1991-2001 averaged about 100 cm/yr. There is essentially no surface water on the Islands and relatively little groundwater. Virtually all potable water is produced by the desalination
units of The Water and Power Authority of the USVI (WAPA).

WAPA examined various methods of desalination between about 1949 and 1979 with mixed, though generally poor, results, employing pilot or production units from Aqua Chem, Sterns-Rogers, Envirogenics and BLH. In 1979 WAPA ordered 3 multi-effect distillation plants from Israel Desalination Engineering (IDE) and has operated hypobaric distillation desalination plants on the three major islands since then, or for almost 25 years (Bruno-Vega & Thomas, 1994). The two major plant complexes (on St. Thomas and St. Croix) each provide potable water for populations of about 50,000 persons. In routine sampling during the summer of 2000 and subsequently, one of the islands experienced a sudden increase in THMs at the long-residence-time site (LRT). In the preceding year or so a number of changes in system treatment had occurred, including addition of a passivating chemical, some changes to intakes, installation of a new electrolytic mixed-oxidant (MO) generator and changes in send-out disinfectant concentration. WAPA immediately began sampling to verify the existence and location of THMs throughout the distribution system (DS). Results were not consistent with earlier estimates of residence time, though LRT sites were confirmed. Many samples in areas considered low residence time were higher than expected, though not in themselves worrisome. In addition, and unlike THMs in most systems, those in the WAPA system were between 50% and 70% bromoform, with up to 90% brominated species. Illustrative results are presented at Table 1, with results more typical of US experience presented at Table 2:

<table>
<thead>
<tr>
<th>RT(days)</th>
<th>BrdiClMeth</th>
<th>DiBrClMeth</th>
<th>Bromoform</th>
<th>Chloroform</th>
<th>Total THM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.01</td>
<td>1.5</td>
<td>0.17</td>
<td>1.66</td>
<td>3.1</td>
</tr>
<tr>
<td>0.2</td>
<td>2.53</td>
<td>4.74</td>
<td>4.71</td>
<td>3.41</td>
<td>14.5</td>
</tr>
<tr>
<td>1</td>
<td>10.68</td>
<td>3.91</td>
<td>7.35</td>
<td>8.32</td>
<td>29.3</td>
</tr>
<tr>
<td>2</td>
<td>6.62</td>
<td>5.33</td>
<td>7.49</td>
<td>5.85</td>
<td>24.5</td>
</tr>
<tr>
<td>5</td>
<td>15.2</td>
<td>11.33</td>
<td>16.9</td>
<td>16.98</td>
<td>60.4</td>
</tr>
<tr>
<td>7</td>
<td>4.26</td>
<td>22.4</td>
<td>3.83</td>
<td>5.59</td>
<td>35.1</td>
</tr>
<tr>
<td>12</td>
<td>26.11</td>
<td>43.67</td>
<td>30.31</td>
<td>21.11</td>
<td>121.2</td>
</tr>
</tbody>
</table>

Table 1. USVI results for TTHMs through Dec, 2003: all results in µg/L.

<table>
<thead>
<tr>
<th>time (days)</th>
<th>BrdiCl</th>
<th>DiBrCl</th>
<th>Bromoform</th>
<th>Chloroform</th>
<th>Tot THM</th>
</tr>
</thead>
<tbody>
<tr>
<td>0(warm)</td>
<td>8</td>
<td>1.7</td>
<td>0.27</td>
<td>23</td>
<td>33</td>
</tr>
<tr>
<td>2(warm)</td>
<td>8.8</td>
<td>1.9</td>
<td>0.16</td>
<td>27</td>
<td>38</td>
</tr>
<tr>
<td>&gt;3 (warm)</td>
<td>9.2</td>
<td>1.9</td>
<td>0.28</td>
<td>30</td>
<td>42</td>
</tr>
</tbody>
</table>

Table 2. Representative results for TTHMs for one year’s sampling for a surface water in New Jersey: all results in µg/L; (“warm” is >10ºC).

(Chen & Weisel, 1998)

To date HAAs have been mostly NDs in the system, even at short and mid-residence time samples and are not discussed here.

**Results and Discussion**

**Brominated species[Bromoform]**

It was believed that bromine, common in seawater, must be the reason for the preponderance of brominated species, especially bromoform (CHBr₃) in TTHMs. Concentrations of bromine in seawater are normally around 65 mg/L while in natural waters concentrations above about 50 µg/L are considered indicative of industrial pollution. The mechanism of entry was the question since the units supply distilled water. The IDE units are hypobaric, multistage distillation units, generally using waste steam from the generation process at the WAPA plants. It was found that all influent water to the units was being treated with mixed-oxidants generated by an electrolytic unit, using seawater instead of a brine from commercial salt. A series of experiments was con-
ducted by WAPA in 2002, following an initial experiment conducted by Aqua Smart Consulting Group in January, 2002. (Smart, March, 2002) Bromine and chlorine concentrations were measured in the effluent of each of the IDE units and in the combined, or plant, effluent. ANOVA showed no difference between units (one-way, (passes Levene's test) $F = 0.495 \& 0.031, \text{[sig2,24 0.616 \& 0.972]}$ for Cl and Br, respectively) nor between units in a similar study on St. Croix. Results of the WAPA studies are presented in Figure on page . It became apparent much or most of the bromine was associated with the use of electrolytically-generated MOs for disinfection in process water. Accordingly, the use of MO for all process water was suspended. Within a few days the bromoform contribution dropped dramatically, and by the end of the year was at a level more representative of other systems. See Figure 1 on page 3.

However, the concentration of bromine is not the only mediator of brominated species; numerous studies have noted that TTHMs form more rapidly and result in higher concentrations when bromine is present. Symons presents comparative TTHMs produced by various concentrations of bromine between 0 and 313 µmols (0-25 mg/L) added to the same water and incubated for the same period of time. The proportion of brominated species in this water shifted from 0% at 0 mg/L to about 90% at only 0.48 mg/L Br and bromoform dominated after about 4 mg/L. (Chen & Weisel, 1998; Chowdhury & Amy, 1999; Kirmeyer, Friedman, Martel, Noran, & Smith, July, 2001; Sung, Levenson, Toolan, & O'Day, October, 2001; Symons, 1999)

Figure 1. Cl and Br with MO on and off.

![Figure 1. Cl and Br with MO on and off.]

Figure 2. TTHMs and Bromoform over period when MO on and off.

![Figure 2. TTHMs and Bromoform over period when MO on and off.]

Chlorine concentration

WAPA on St. Thomas had operated for some years with a send-out residual of about 1 mg/L free chlorine and has regularly supplemented routine residual concentration measurements with both HPC and Pseudomonas counts to control flushing and disinfectant residuals in the DS. At about the same time as the increase in TTHMs routine residual at send-out was incremented and this was repeated several times in the next year or so. The reason reflected concern over reduced residual levels and increased HPC counts in the area of the system with the LRT site. By November, 1991, WAPA’s residual at send-out was up to 3.0 mg/L. Compounding this, residuals measured at the nearest sample site (about 30 seconds at system mean flow) were frequently much lower than measurements at send-out.

Chlorine (Ca hypochlorite) application was by means of piston pumps controlled by automatic residual monitoring equipment and the residual at send-out is recorded on circular chart recorders. It was found that those charts showed irregular excursions (see and, at the time (Feb03), send-out was normally over 2 mg/L and often >3.5 mg/L for extended periods. A number of problems were identified and addressed.

1) The feed line for the automatic residual monitoring device was found to have a residence time of over 40 minutes. The line was changed and residuals are now measured within 2 minutes of sampling.

2) To help reduce the excursions in the residual concentration the piston stroke (volume) was changed, the concentration of the slurry was reduced and the Cl application site was moved to reduce interference from high-volume withdrawals in mains feeding Charlotte Amalie. One of the mains in addition to serving the west end also provides service to several standpipes that WAPA operates for water haulers. During the enhanced sampling done to discover whether THM concentrations were elevated throughout the system it was noted that some sites in Charlotte Amalie had levels that, while not near MCLs, were higher than expected. This led to a re-evaluation of residence times in the system (this study is ongoing), but it was noted that Cl residuals excursions could, in part, be traced to elevated flows in the that main during tank filling. The application point was moved back about 50’ to improve mixing before diversions caused by higher instantaneous flows in one or other main. Excursions continue, though at much reduced scale and frequency and further study is ongoing, including consideration of alternative disinfectants and means of application.

Figure 3. Typical STT Cl residuals over one day

---

1 Many buildings in the USVI are supplied only by haulers.
3) The send-out residual was reduced slowly in increments of about 0.5 mg/L with a concentration of about 1.5 mg/L the goal. Service, or booster chlorination was not possible at the time, though at least one site was identified and equipment is on order. During the reduction additional sampling for bacteriological indicators, HPC and Cl residual was done to reduce the likelihood of the worst-case where the control of THMs by disinfectant residual reduction allowed either regrowth or occurrence of indicator species.[Murphy&Craun99]

4) Finally, one of the reasons for elevated residual concentrations at send-out concerned the storage tank, Donoe Tank, that served the LRT site with elevated THMs. Chlorine residuals were raised, in part, to supply effective residuals in the area past Donoe Tank. After the loss of the major user in that area (discussed in residence time), residuals fell to undetectable in that area. Normally, Donoe Tank had been filled daily, when the tank volume had been reduced about 10%. It was decided to allow Donoe Tank to draw down to about 50% and fill on about a 5-day schedule. This provided higher residuals in LRT area without the need for excessive residuals at send-out. Donoe Tank will also be the site where the first booster chlorination facility will be installed.

Residence time

The USVI, like all the Caribbean, is a zone both active geologically and subject to hurricanes and tropical storms and each island is, well, an island. WAPA, accordingly, must maintain a substantial quantity of potable water on hand to prevent shortfalls in the event of interruptions to supply caused by either vulcanism or weather. WAPA currently has sufficient excess production capacity to allow the operation of Donoe Tank in the manner described above and it is estimated that there is sufficient to allow considerable flexibility in storage; this is still under study at this time. However, it is clear that storage requirements will always be a major factor in residence time in this system.

Figure 4. Effect of Residence time on TTHMs.
Figure 5a-c. Modelled fit of TTHM formation vs system data; note changes in scale
As noted previously, residence time is still under study, but residence time is clearly a factor, both as described by others (Chen & Weisel, 1998; Chowdhury & Amy, 1999) and in WAPA. As may be seen in Figure 4 on page 3, WAPA TTHM concentrations closely follow residence times (F=11.359, [sig6,48 0.000]). Modeled TTHM concentrations for up to 3 mg/L are shown in Figure 5.(Chowdhury & Amy, 1999) Among the residence time factors affecting the change in TTHMs at the LRT site we studied the following:

Leak Survey and Loss Reduction
In the period 1999-2001 WAPA conducted leak surveys and a repair schedule resulted in reducing unaccounted-for water from about 28% to 12-15%. Unfortunately this had the coincident effect of increasing residence time in the system, and thereby TTHMs.

Flushing
Desalinated water is still somewhat expensive, and WAPA must use extreme care in using potable water for flushing. In part to correct for the good work in reducing UAW WAPA has:
1) Completed a tentative progressive flushing program for implementation to complement corrosivity studies throughout the system.
2) Purchased and installed a number of automatic flushing devices in dead ends or extreme low use areas. At this time these are sited utilizing data from residual, HPC and Pseudomonas analyses. Customer complaints are also considered in siting, but typically those data are the result of either routine sampling or extended monitoring initiated as a result of elevated TTHM sampling. More of these devices will be purchased and sited in 2003-2004 and an additional round of THM sampling conducted. As more data become available from the corrosivity and biofilm studies that data will be used in siting the automatic flushing devices.

Change in East End use
Usage in the east end, the area of the high TTHM LRT site, fell in 2000 from about 1.5 MGD to 0.5 MGD, around the same time as the increase at the LRT site. This increased residence time in the Donoe Tank from about 6 days to about 11 days. This was addressed as described above in Chlorine Concentration. In order to allow minimal disinfectant residual concentration at sendout a booster or service chlorination station will also be established at this site.

Storage
WAPA maintains about 30 MG in storage near the pumphouse. This water is part of the strategic reserve held to provide emergency supply in the event of production failure due to natural or operational interruptions. These tanks are flow-by, with water stored only when production exceeds system demand. At this point the estimated residence time is about 11 days in A and C and 6 days in C. Water quality changes during storage undoubtedly are responsible, in part, for varying chlorine demand.
WAPA is studying required piping changes to allow more flexible operation of this storage facility. Serial operation through the various tanks would be the ideal, but, again, considerations of security and integrity in the face of possible geologic and weather damage to the system will require thorough consideration and careful planning. In addition, WAPA is considering the installation of devices to reduce stratification and allow aeration through the tank when these tanks are rehabilitated.

Acknowledgment
An earlier version of this work was presented at WQTC in November, 2003.

References
Chen, W. J., & Weisel, C. P. (1998). Halogenated {DPB} Concentrations in a Distribu-


