

## **BIOSTABILITY OF MEMBRANE-TREATED FINISHED WATERS IN DISTRIBUTION SYSTEM: STUDY AT PILOT-SCALE.**

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### **ABSTRACT**

The study described in this paper is part of an AWWARF and Tampa Bay Water Tailored Collaboration Project to determine the effect of blending different source waters on distribution systems water quality. Seven different finished waters have been analyzed and are further described in this paper. The water processes included high pressure reverse osmosis (RO) (desalination), both membrane and chemical softening and ozonation – biological activated carbon (BAC). The results showed that RO produced the most biologically stable water source, i.e. exerted lowest AOC influent, lowest changes in AOC, and lowest effluent heterotrophic plate counts. Nanofiltration treatment did not significantly improve bulk liquid biostability (sources G4 and S2) as compared to other treatments of the same source water (respectively chemical softening of a blend for G3 and ozone-BAC of surface water for S1). The effect of hydraulic residence time on residual maintenance and biostability has been observed. Increasing HRT resulted in greater residual consumption and poorer biostability.

Key words: Biostability, membrane treatment, AOC

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## INTRODUCTION

Bacterial numbers tend to increase during distribution and are influenced by a number of factors including the microbiological quality of the finished water entering the system: temperature, hydraulic residence time, presence or absence of a disinfectant residual, construction materials, and availability of nutrients for growth (Geldreich et al., 1972; LeChevallier et al., 1987). If the disinfectant residual is sufficient, bacterial regrowth is significantly reduced in bulk water. Conventional water treatment in North America has traditionally added a secondary disinfectant (chlorine and /or chloramines) to achieve biological stability. The strong trend toward replacing free chlorine with chloramines (i.e., combined chlorine) in drinking water treatment in order to meet more stringent regulations on disinfectant byproducts may also have an impact on bacterial regrowth in distribution systems. Chloramine is generally thought to produce a more stable secondary residual than free chlorine and thus provide lasting protection against bacterial regrowth. In addition, chloramine is believed to penetrate more deeply than chlorine within biofilm (LeChevallier et al., 1990). However chloramines potentially add nutrient, ammonia, to the distribution system (Skadsen, J AWWA 1993).

Organic substrates in drinking water can be quantified by assimilable organic carbon (AOC). AOC is the part of dissolved organic carbon (DOC) that can be easily assimilated by bacteria and converted to cell mass. The biostability of drinking water may be assessed by using AOC method since heterotrophic bacterial growth is supported by biodegradable organic matter in drinking water and AOC is widely considered to be the major nutrient source for bacterial regrowth in distribution system (Van der Kooij *et al.*, 1992). Therefore choosing the treatment processes that reduce organic nutrients and yield to more biostable finished waters is critical.

University of Central Florida is conducting an AWWARF and Tampa Bay Water (TBW) tailored collaboration project to determine the effect of blending different water qualities on distribution system water quality. Several finished waters have been examined and are presented in a following section. The process treatment systems have been designed in order to produce finished waters that simulate actual or proposed finished water of TBW Member Governments.

## MATERIAL AND METHODS

### *Pilot Distribution Systems Experimental Design*

Waters produced from seven different treatment systems (aeration (G1), softening (G2), Blended softening (G3), Blended NF (G4), CSF-O<sub>3</sub>-BAC (S1), IMS (CSF-NF or S2) and high pressure RO were blended and distributed into 18 different pilot distribution systems (PDSs). The preceding acronyms are defined accordingly: G: ground water; S: surface water; NF; nanofiltration; CSF: coagulation-sedimentation-filtration; BAC: biological activated carbon; IMS: integrated membrane system; RO: reverse osmosis. G1, G2, and RO finished waters were produced from the same groundwater (Cypress Creek Water Treatment Plant, Polk County, Florida, USA). Salts were added in RO permeate to simulate typical finished water from a desalination process. G3 and G4 originated from identical blends of G1, S1 and RO. The S1 and S2 finished waters were produced from the same surface water (Hillsborough River Water Treatment Plant, Hillsborough County, Florida, USA). The PDS consisted of combined PVC, lined ductile iron, unlined cast iron and galvanized steel pipes taken from actual distribution

systems, connected in series in that order and were operated at a 5-day hydraulic residence time (HRT). Only the PDS fed by single water sources G1, G2, G3, G4, S1, S2 or RO are considered in this paper. The results presented further correspond to operational phases 1, 2 and 4 of the project. Data from phase 3 is omitted in this analysis due to occurrence of nitrification in the PDS. Due to this event, it had been decided to operate the PDS at a 2-days hydraulic residence time (HRT) in phase 4, instead of 5 days in phase 1 and 2, in order to maintain combined residual levels throughout the PDS (Table 1). Chloramines were used as secondary disinfectant in all the PDS.

Table 1. Hydraulic residence time per sampling period.

Sampling period	HRT
From 12/13/01 to 5/16/02 – Phases 1&2	5 days
From 9/20/02 to 11/28/02 – Phase 4	2 days

*Heterotrophic Plate Count (HPC).*

HPC were performed by plate spreading on R2A agar incubated at 22°C for 7 days, according to Standard Method 9215B (1995). Results were expressed in colony-forming units per milliliter (cfu/mL). The procedure was performed entirely inside a laminar flow hood (model 62674, Enviroco Cooperation, Albuquerque, NM, USA) equipped with a HEPA filter.

*Assimilable Organic Carbon (AOC).*

AOC was measured using the rapid method of LeChevallier et al. (1993), except that plate counts were used to enumerate bacteria rather than ATP fluorescence, in conjunction with Standard Methods 9217 (1995) and the method of van der Kooij (1982). The procedure used a temperature of 25°C for sample incubation and is outlined in great detail in an article (Escobar and Randall, 1999).

*Chemical Water Quality.*

Dissolved oxygen and total chlorine residuals (DPD assay) have been measured according to Standard Methods (USEPA, 1995).

**RESULTS AND DISCUSSION**

This paper describes differences between single water sources, i.e. 7 finished waters, with respect to biostability in distribution systems. Table 2 shows average values of water quality parameters for the water sources of concern. In average, results showed that RO produced the most biologically stable water source. Table 2 shows that nanofiltration of the blend (G4) and the surface water (S2) did slightly improve the bulk liquid biostability (lower influent AOC). However HPC were higher for G4 and S2 than for G3 and S1 (0.2 and 1.3 log difference, respectively).

Table 2. Water quality parameters for single water sources - averages

Blend	Influent AOC (µg C/L)	Absolute Delta AOC (µg C/L)	Effluent Total Cl <sub>2</sub> (mg Cl <sub>2</sub> /L)	Effluent HPC (cfu/mL)	Delta DO (mg O <sub>2</sub> /L)
G1	96	24	1.9	3483	0.7
G2	88	11	2.0	1371	0.8
G3	103	20	1.7	775	1.5
G4	82	37	1.7	17754	1.6
S1	69	13	1.7	1095	1.5
S2	53	5	1.6	1614	1.7
RO	35	6	1.5	299	1.8

Delta AOC = influent AOC – effluent AOC  
 Delta DO = influent DO – effluent DO

In order to better understand these observations, it is important to examine the evolution of the water quality parameters with time. The data in all the PDSs showed a consistent trend as influent AOC decreased with time (Figure 1). However the relative differences between blends was very consistent. Figure 1 shows that RO had consistently lower influent AOC. S2 has lower influent AOC than S1. It can be noted that among the 7 finished waters, S2 and RO are in the lower end of the observed range of values, which promotes biostability. In terms of changes in AOC (absolute values of delta AOC, i.e. any increase or decrease in AOC through the PDS), it appears that S2, RO and G3 were more biostable than the other finished waters (Figure 2). The switch of HRT from 5 days to 2 days between phase 2 and phase 4 improved the stability of AOC (i.e. lowering absolute delta AOC), for all waters. Figure 3 presents total chlorine residual levels, sorted by water source. It appears that similar levels were observed for every water source and that they followed the same trend during the period of the study. A gradual decrease of combined residual was observed for all PDS during phases 1 and 2, leading to total depletion in phase 3 during which the systems nitrified (data not shown since this paper focuses on heterotrophic biostability). An increase of residual levels was observed in phase 4, when HRT was switched from 5 to 2 days. Dissolved oxygen consumption (i.e. delta DO) and total chlorine demand correlated with each other, following the same trends in response to changes in water quality. Loss of residual in a PDS promotes bacterial regrowth and bioinstability and therefore higher dissolved oxygen demand. However other factors can affect DO consumption like corrosiveness of the water. RO, S1 and S2 yielded higher dissolved oxygen consumption (delta DO) than the other sources. G4 and G3 had higher delta DO than G1 and G2. It can be noted that corrosiveness of these waters is as follows, based on influent chloride concentration:

$$RO > S2 > G4 > G3 > S1 > G1 > G2$$

Given the fact that corrosive waters probably result in higher oxidation of the corrodible parts of the PDS (unlined cast iron and galvanized steel sections), they also had higher oxygen demand,

which explains the trends observed in Figure 4. Depletion of oxygen was also a good indicator for nitrification occurrence in other phases of this study. However the data in this paper is confined to phases where nitrification was not occurring, and no total depletion of DO was observed in phases without nitrification.

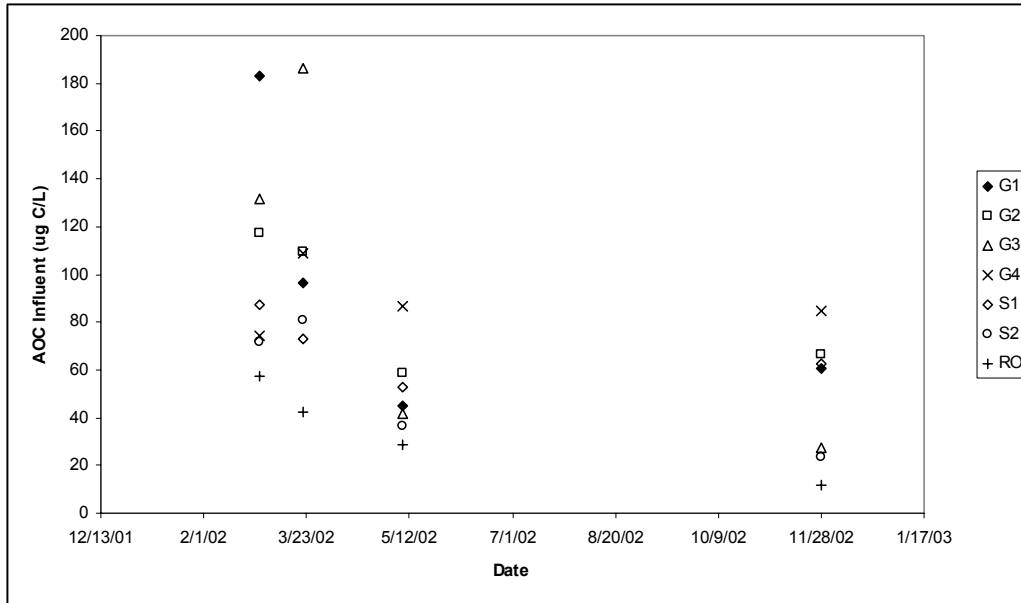


Figure 1. AOC Influent vs Time, sort by water source.

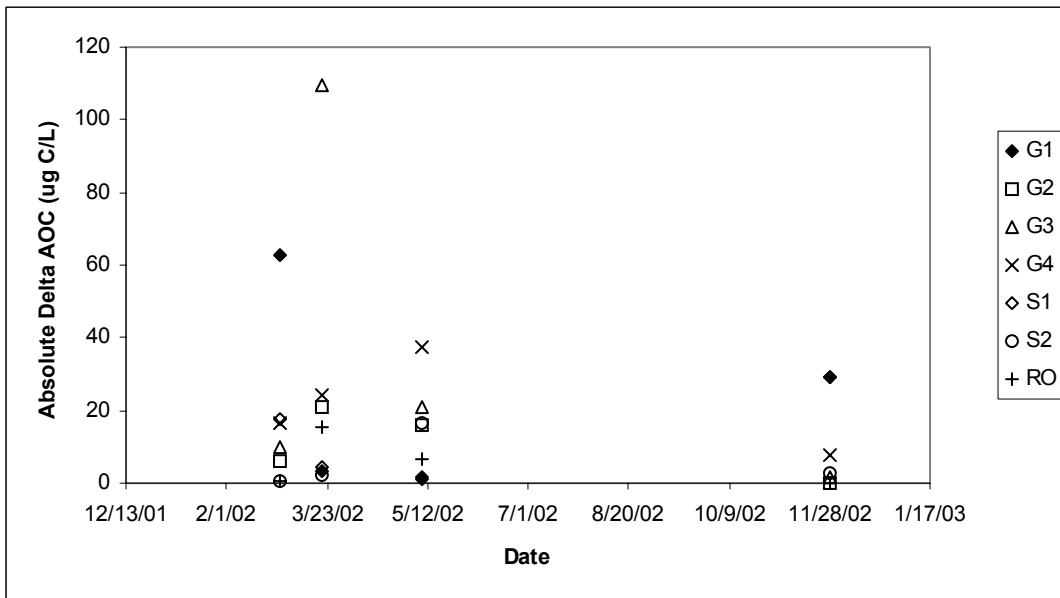


Figure 2. Absolute Delta AOC vs Time, sort by water source.

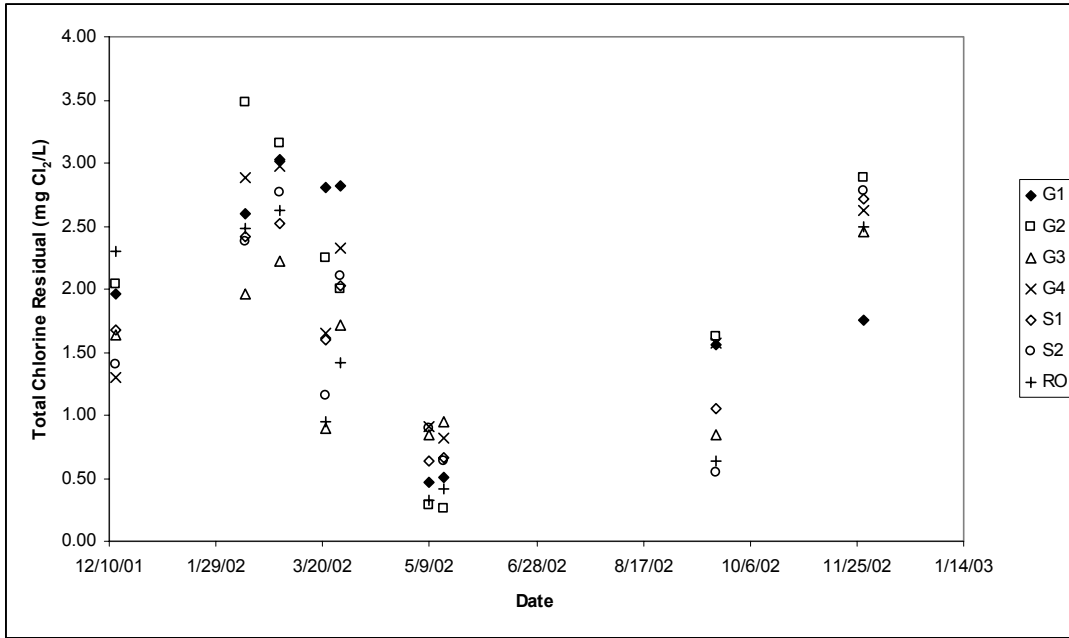


Figure 3. Total Chlorine Residual vs Time, sort by water source.

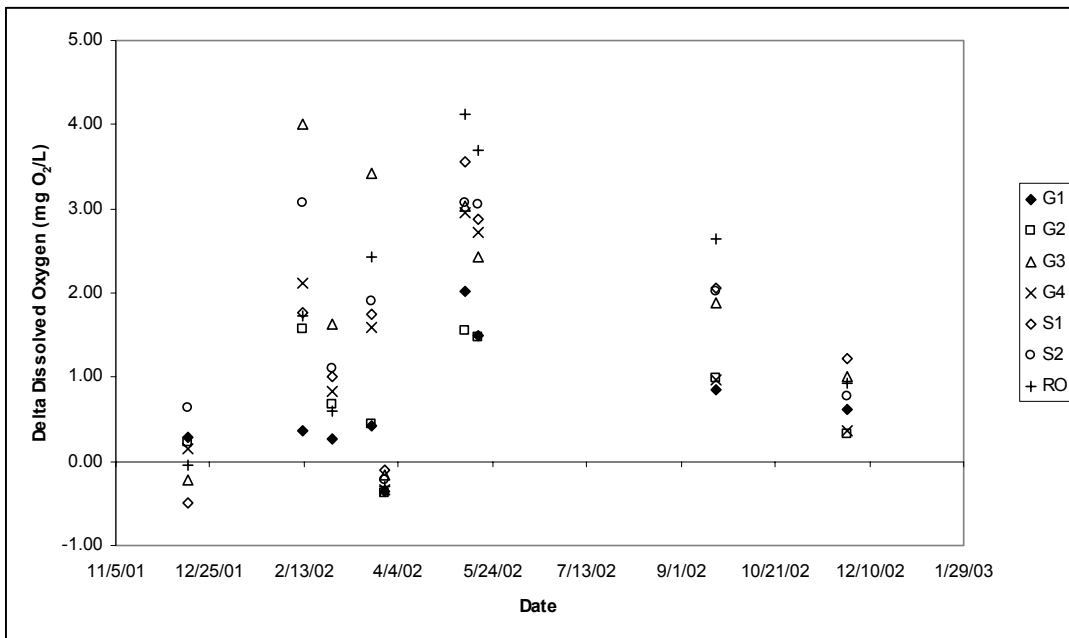


Figure 4. Delta Dissolved Oxygen vs Time, sort by water source.

RO had a lower average HPC than the other waters (Figure 5), and consistently had one of the lowest HPCs in all sampling events. G4 (nanofiltered blend) also appeared to be more stable with respect to heterotrophic proliferation than its softened counterpart (G3), which occupied the higher end of the range of HPC values. S1 and S2 had similar HPC values.

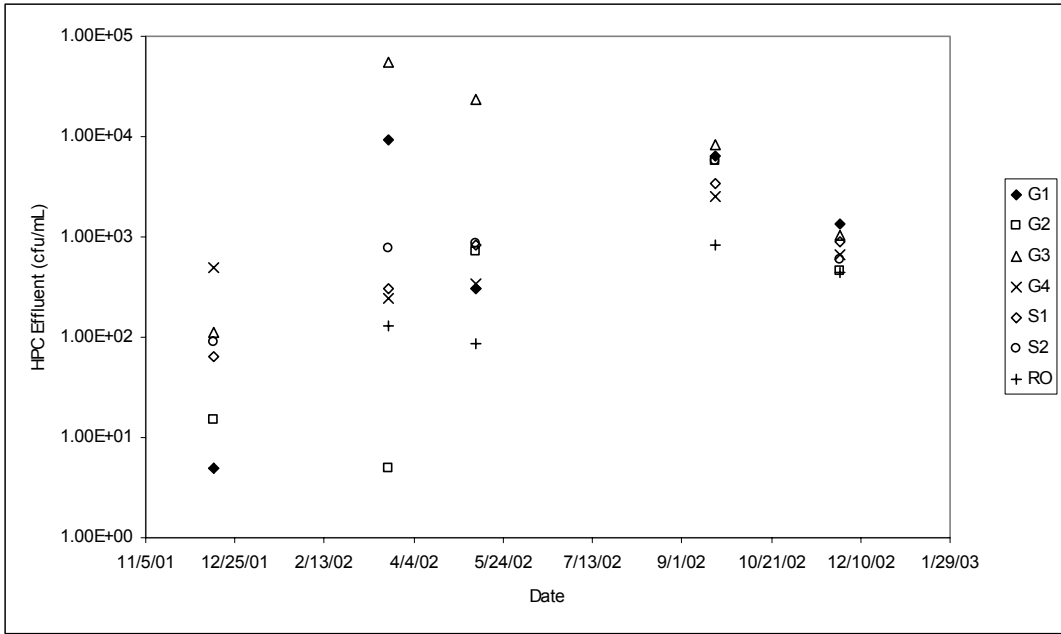


Figure 5. Effluent HPC vs Time., sort by water source.

Increased DO consumption, decreased total chlorine residual, and increased HPC occurred at a 5 day HRT (Table 1; Figures 3, 4, and 5). The increase of influent temperature (Figure 6) during this period is thought to have heavily contributed to the poor water quality. Improvement was noticed after a switch to a 2 day HRT (The September and November data points in each figure are at a 2 day HRT), mainly due to subsequent recovery of the residual in all the PDSs. Nevertheless, RO remained the most stable finished water with respect to AOC influent, changes in AOC and effluent HPC.

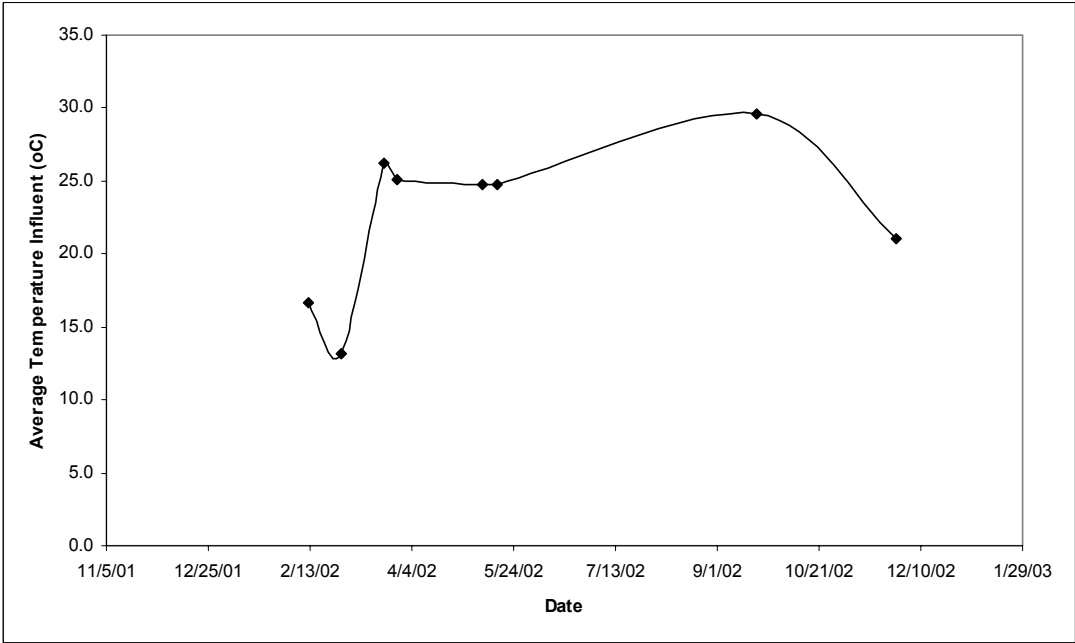


Figure 6. Influent Temperature vs Time.

## CONCLUSIONS

This paper described differences between seven finished waters generated from three different source waters (groundwater, surface water, and brackish water). The following conclusions with respect to heterotrophic biostability have been reached:

- Treatment by high pressure reverse osmosis of groundwater (RO) provided the most biostable finished water out of the 7 finished waters, with respect to AOC influent, changes in delta AOC and effluent HPC.
- Treatment by nanofiltration did not improve biostability significantly for finished waters S2 and G4 in comparison with conventional ozone-BAC treatment for S1 and with softening for G3.

The biostability of the finished waters improved with a reduced HRT, mainly due to a better maintenance of total chlorine residual in the PDSs. The suggested correlation between corrosiveness (assuming chloride ion can be used as a surrogate for corrosivity) and DO consumption needs to be further examined. It is suggested that the combination of elevated temperatures with unlined metal material provides both a source of reducing equivalents (metals) along with an acceleration of kinetic rates of reaction for corrosion and other abiotic surface reactions. Under these conditions highly oxidized electron acceptors such as residual and DO will be consumed at significant rates as they react with the zero valent metal surface, and this would explain why high residual and DO consumption typically occur simultaneously and have a strong correlation. These rates of reaction may also be accelerated by the presence of chloride ion. In addition any increased biological activity would also contribute to DO consumption.

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