RESOLVING WATER QUALITY ISSUES IN PREMISE PLUMBING SYSTEMS WITH ADVANCED WATER CONSERVATION FEATURES

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ABSTRACT. New buildings increasingly incorporate advanced water conservation features and use of grey water and recycled water for non-potable purposes. Recent experiences highlight the negative impact of these sustainable practices on water quality at the tap. Water residence time in building plumbing can increase markedly, causing microbial growth, taste and odor problems, and elevated lead. In our experience, at some locations as much as 40 minutes of continuous flushing were needed before chloramine levels in the water main were observed at building taps. Remedial actions, including supplemental flushing, were developed and implemented.

INTRODUCTION

Sustainable construction has led to increasing use of advanced water conservation features (e.g., metered and sensor faucets, low-flow showerheads and toilets, waterless urinals) in buildings. The University of North Carolina at Chapel Hill (UNC) is a leader in implementing such practices in the United States. One consequence of reducing the volume of potable water use within buildings without also making corresponding reductions in pipe diameters and stored water volumes is a marked increase in the water “residence time, ” the period of time potable water is held in the building plumbing system before it flows through the tap for its intended use.

Excessive residence time is known to cause problems with microbial growth in water distribution systems (U.S. EPA, 2002). This is expected to be particularly acute in “premise plumbing” characterized by a large pipe surface area to water volume ratio (Table 1), regular periods of stagnation, and variable temperature and redox. Plumbing codes make every building a “dead end." Water can stagnate in the pipes of conventional plumbing systems for hours or days before use. The result is ecological niches for a wide diversity of microorganisms (Edwards et al., 2004a, 2003; Snoeyink et al., 2006).

Table 1. Characteristics of U.S. Public and Private Transmission Systems
(after M. Edwards, D. Bosch, G.V. Loganathan, A. M. Dietrich, 2003; Snoeyink et al, 2006)

Characteristic	**Public Infrastructure**	**Private Infrastructure (Premise Plumbing)**
Replacement value	0.6 trillion $US	> 0.6 trillion $US
Pipe material	Cement, ductile iron, plastic, cast iron	Copper, plastics, galvanized iron, stainless steel, brass
Total pipe length (US)	0.97 million miles	> 6 million miles
Approx. pipe surface per volume of water*	0.26 cm^2/mL*	2.1 cm^2/mL*
Complete stagnation	Relatively rare	Frequent
Disinfectant residual	Usually present	Often completely absent after stagnation
Flow	Relatively consistent	On/off
Temperature	0-30° C	0-100° C
Maximum cost over 30 yrs per consumer	$500-7,000 US	Easily up to $25,000 per homeowner or millions for buildings
Advocacy	Water industry (WIN)#	None

#Water infrastructure network
*Assumed 15.2 cm diameter for mains and 1.9 cm diameter for home plumbing

Regulation historically has not crossed the line between the main distribution system and the building plumbing system. The notable exception in the U.S. is the lead and copper rule (LCR) which targets reduced corrosivity in the public water supply to diminish leaching of lead or copper in buildings. That sample requires that the water sit at least 6 hours in the premise plumbing before collection. In contrast, most standard protocols, such as those for bacterial monitoring by utilities at taps within buildings require flushing for 3-5 minutes before sampling. These regulatory compliance samples are not representative of the bacterial concentration in the building but rather, in the distribution system.

Prior research on bacterial regrowth in water mains can be expressed simplistically as:

Organic Carbon + Nitrogen + Phosphate + Trace Nutrients + O_2 → Heterotrophic Bacterial Regrowth (1)

High levels of disinfectants, such as free chlorine or chloramines, can control regrowth even if all nutrients shown in Equation 1 are not growth limiting. However, loss of disinfectant triggers regrowth if all key nutrients are available. The first nutrient reduced to relatively low levels somewhat limits the extent of regrowth and is termed the limiting nutrient.

A water is microbiologically stable if nutrient concentrations are low enough to prevent growth to undesirable levels (Rittmann et al., 1984; Sathasivan et al, 1999). Many European countries successfully limit nutrients to distribute safely drinking water with little or no disinfectant (Van der Kooij, 1992). In the U.S., nutrient requirements among bacteria of interest are believed to be far too variable to select a specific control value (e.g., Rice et al., 1991); thus, disinfection is widely accepted as a more effective strategy (LeChevallier et al., 1991). Moreover, the argument for relying upon disinfectants is strengthened by the broadly held view that chloramine is more chemically stable than free chlorine, without formation of many currently regulated disinfection byproducts. This paper documents problems encountered with reliance on chloramine disinfection as a control strategy for buildings with very low water usage.

PROBLEM IDENTIFICATION AND REMEDIATION

Initial Identification of a Problem. UNC administrators received taste and odor complaints soon after occupancy of two buildings with water conservation features. A systematic evaluation was conducted to identify and resolve the complaints, including study of the disinfectant (chloramine) loss rate and measurements of microbes and related chemical parameters. Testing at representative taps in each building showed the first water withdrawn had undetectable disinfectant. Some distal taps in the buildings had to be flushed up to 40 minutes before the disinfectant levels approached those known to be present in the water main (Figure 1).

The lack of chloramine residual may be due to several factors. The calculated water residence times in the building plumbing exceeded several days even during full occupancy due to overdesign of the plumbing system (e.g., pipe diameters larger than needed) and reduced potable water demand by use of non-potable water. Additionally, the remote chiller water fountain arrangement produced relatively high water temperatures (18-30°C) within sections of the premise plumbing that could accelerate both regrowth and chloramine decay. Finally, new copper piping can accelerate chloramine decay rates (Nguyen, 2005).

To quantify the rate of chloramine decay, extensive flushing was conducted until water with a high chloramine residual (> 2 mg/L as Cl_2) was drawn from the main into each line. Thereafter, the water was allowed to sit in the pipes, with small aliquots removed from each tap after a specified holding time to measure chlorine residuals. In all cases the disinfectant mostly disappeared in 6 hours and completely disappeared within about 12-18 hours (Figure 2). This observation counters the widely held view that chloramine residual is very stable and persistant. The only constraint on microbial regrowth after the disinfectant disappears is nutrient limitations.

Characterization of Bacteria Levels. Extensive testing revealed very high levels (> 308,000 cfu/mL) of heterotrophic plate counts (HPC) in several first draw water samples, which is not unexpected given the warm conditions, lack of chloramine residuals, and long residence times. These levels were much higher than the threshold concentration of 500 cfu/mL often used to indicate excessive microbial regrowth in distribution mains. A fairly strong negative correlation was found between the logarithm of HPC and the chloramine concentration (Figure 3).

Human pathogens including *P. Aeriginosa* and *Legionella* were not detected in any of the samples despite the absence of disinfectant. However, concentrations of heterotrophic aerobic bacteria (HAB) in a suspended growth mode (liquid culture), denitrifying bacteria, and acid producing bacteria (APB) were sometimes very high (Figure 4). While of concern, high HPC counts do not violate health standards. Their direct contribution to the co-occurring taste and odor complaints is unknown. There is also potential for some types of the bacteria (Figure 4) to induce corrosion, which can explain the high levels of lead also detected in the water from brass plumbing devices. Given all of these possible negative consequences, remedial actions to reduce the bacteria levels were proposed.

Remediation. An automated flushing system was installed in one location, bringing fresh water regularly into the plumbing to maintain higher chloramine residuals and prevent build-up of bacteria, tastes, and odors during stagnation. While automated flushing seems directly incompatible with water conservation, only a relatively small amount of water was needed to increase disinfectant residuals (less than 1% of total daily water use). In other situations, manual flushing was conducted when triggered by taste and odor complaints. Water fountains were replaced with models having integrated chillers to lower water temperatures to the accepted range.

The automated flushing every 6 hours reduced water residence time, thereby increasing the disinfectant residual in the water system. Given the baseline pattern of infrequent water use, 7 minutes of flushing was required to bring the chloramines to 2 mg/L (Figure 5). In contrast, only about 3 minutes was required to reach the same residual at each tap after implementation of automated flushing. Microbial levels declined sharply after flushing was implemented, although HPC remained somewhat above the accepted target threshold of 500 cfu/mL at a few taps (Figure 6).

Tests of chloramine residuals and microbial counts in premise plumbing of much older buildings on-campus revealed very stable chloramine residuals and low HPC counts, even with copper pipe and very long stagnation times. These results suggest that some combination of new copper piping and water conservation features contribute to problems observed in new buildings.

DISCUSSION

Microbial regrowth is considered inevitable albeit undesirable in potable water systems. Although useful indicators of aesthetic issues, HPC and other standard microbial measurements are insufficient as indicators of health concerns. This philosophy is reflected in a consensus opinion from a 2002 World Health Organization (WHO) workshop in Geneva:

> ***"There is no evidence that HPC values alone directly relate to health risk either from epidemiological studies or from correlation with occurrence of waterborne pathogens. They are therefore unsuitable for public health target setting, or as sole justification for issuing "boil water" advisories….HPC testing may be used in investigating aesthetic quality and it is used by some authorities as a marker for some of the underlying causes of some aesthetic problems."***
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> Accessed 11/20/2007 at:
> http://www.who.int/docstore/water_sanitation_health/Documents/HeterotrophicPC/HPCconcl2.htm

On the other hand, recent evidence points to deficiencies in plumbing system design as contributors to waterborne disease (Borella et al., 2004; CDC, 2008). For instance, legionella bacteria are now believed responsible for a majority of waterborne disease outbreaks in the U.S. These bacteria can be amplified in premise plumbing in the absence of disinfectant residual (CDC, 2008). Other opportunistic pathogens found in premise plumbing that are of human health concern include *Pseudomonas Aeruginosa*, certain *mycobacterium*, and *acanthamoebae*.

CONCLUSIONS

Current construction practices that incorporate advanced water conservation features in premise plumbing can contribute, at the very least, to a loss in aesthetic quality of potable water. While no adverse health consequences have been documented thus far, prudence suggests that steps should be taken to mitigate microbial regrowth. More research is needed on premise plumbing system designs and remedial measures to prevent deterioration of water quality. Two key goals are to reduce water residence times in buildings by improving the design and operation of premise plumbing, and to implement nutrient-limiting strategies at water treatment plants for control of regrowth after disinfectants dissipate. Process engineering tools from the distribution system field, such as computer models to determine water residence time and loss of disinfectant residual (e.g. EPANET, 2008), could be readily adapted to premise plumbing systems and would be useful in design.

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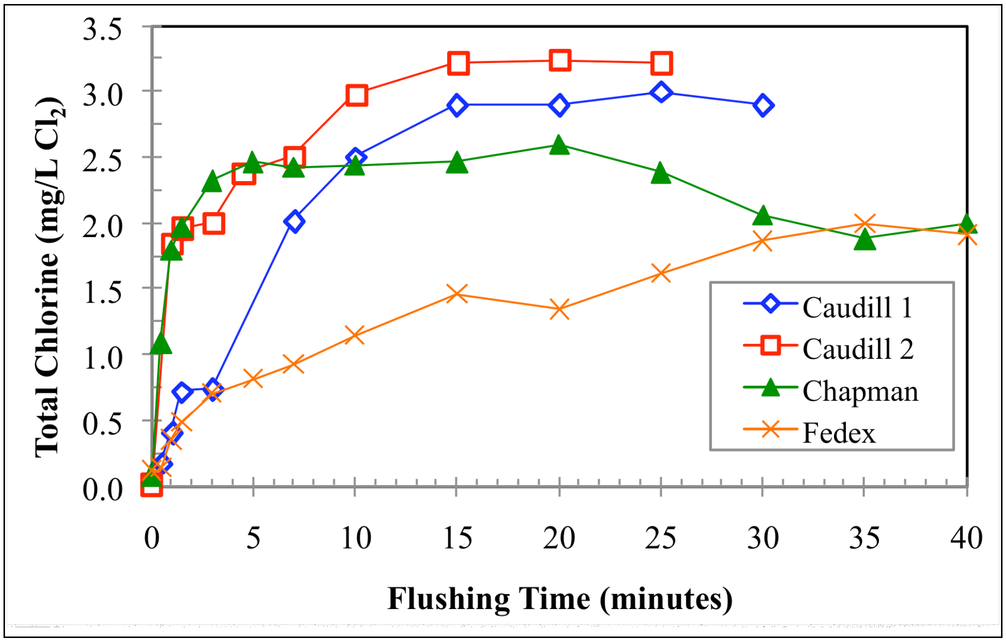

Figure 1. Chloramine concentration during flushing for four sites.

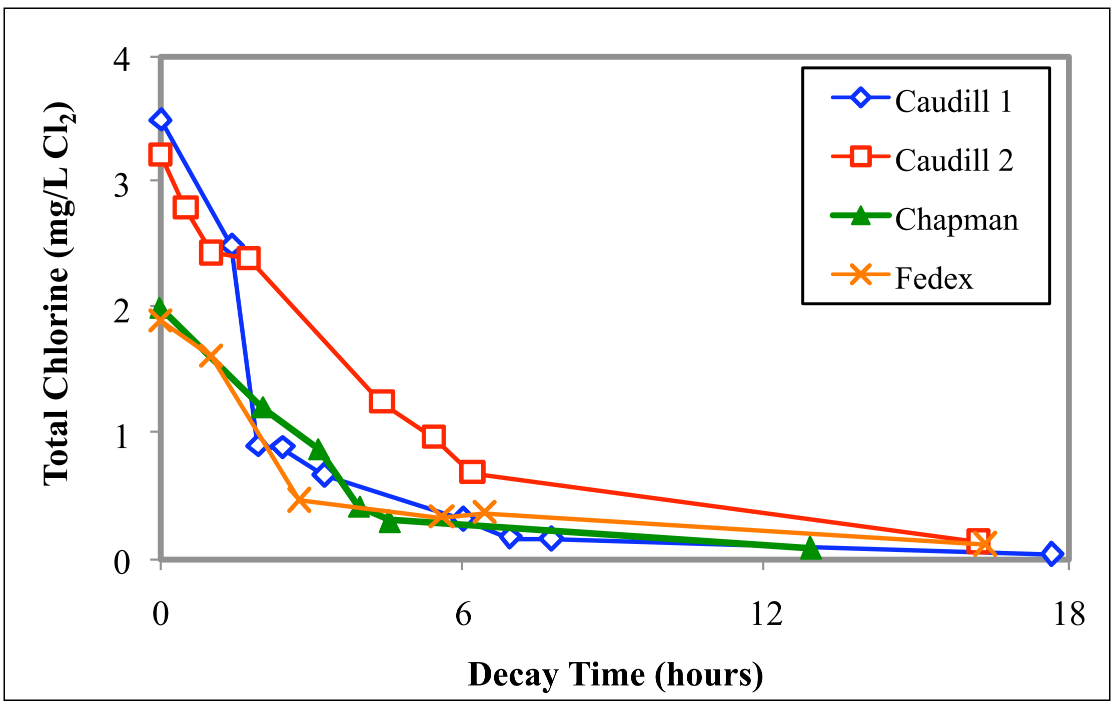

Figure 2. Chloramine decay for four sampling sites.

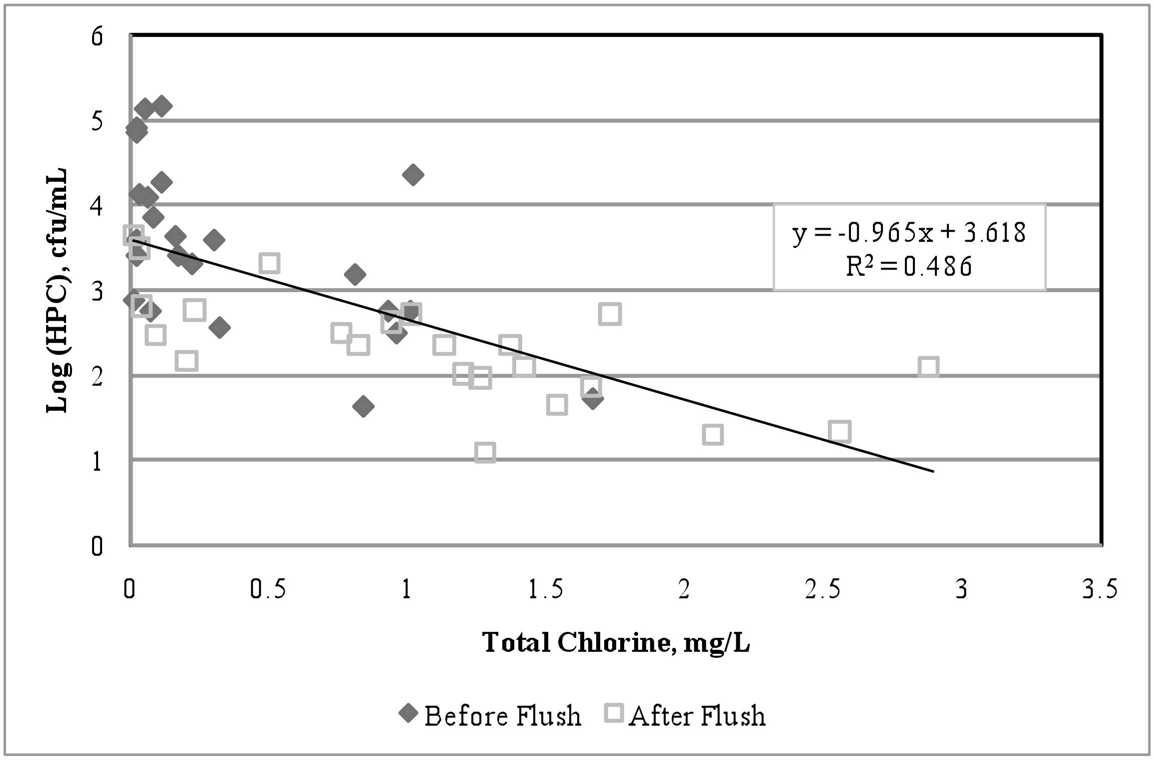

Figure 3. HPC and total chlorine concentration before and after flushing in Caudill building.

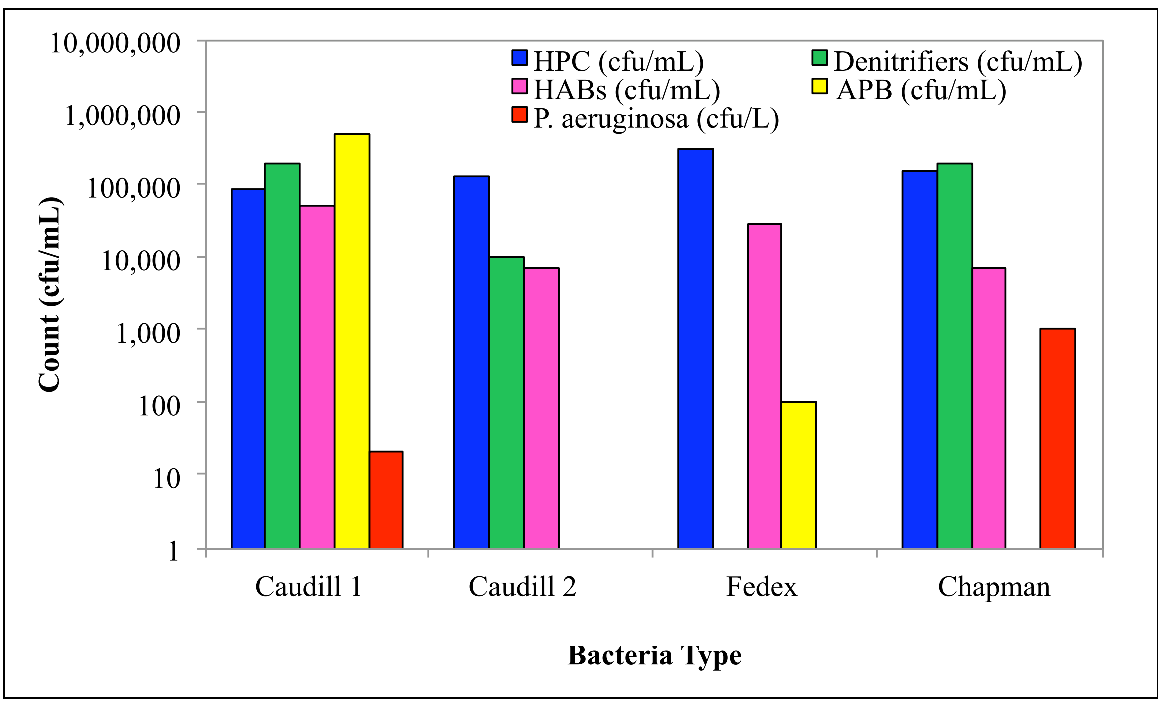

Figure 4. Bacteria test results for the four sites.

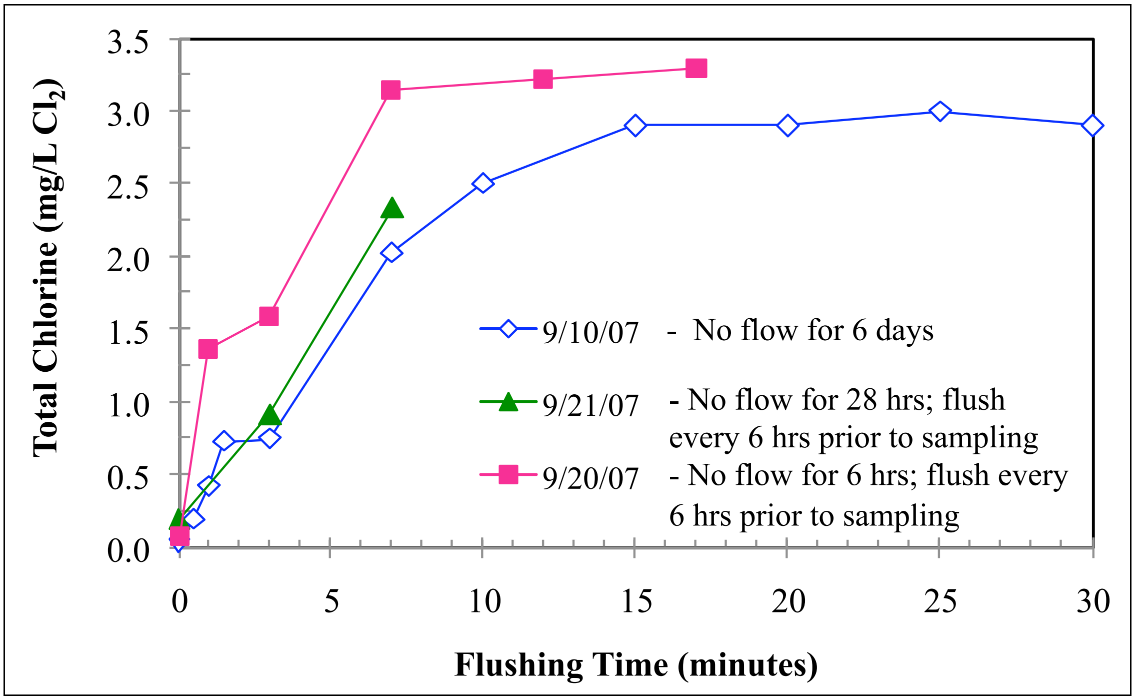

Figure 5. Influence of stagnation time and flushing frequency on chloramine concentration during flushing.

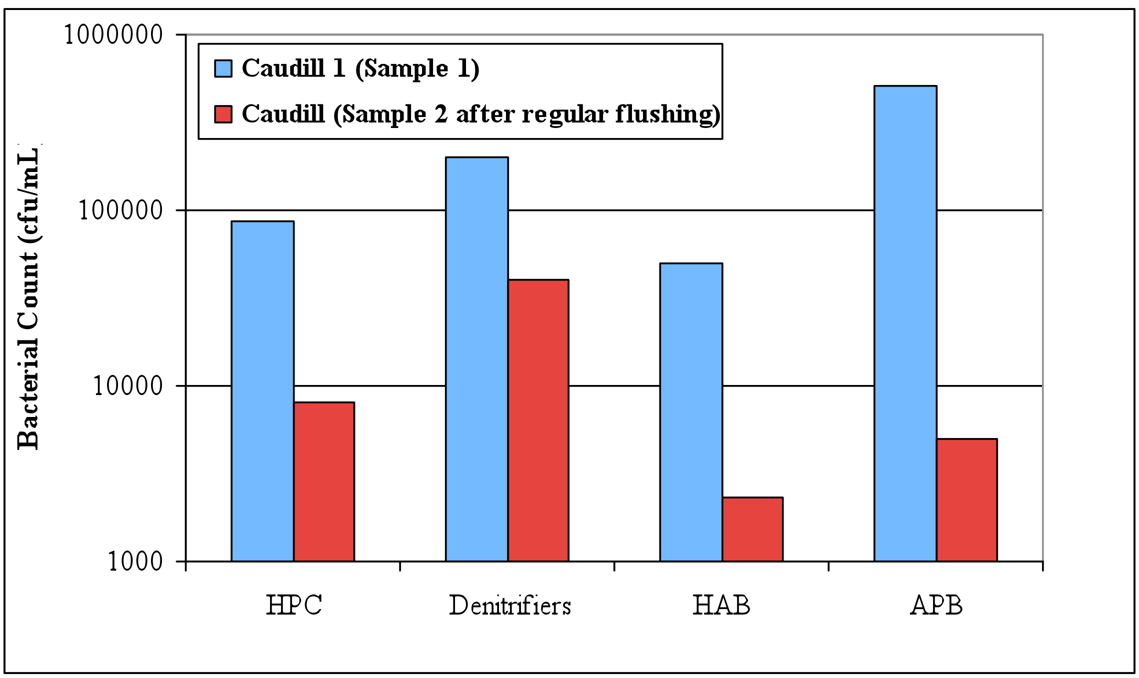

Figure 6. Testing of bacteria before and after implementation of regular flushing in one building with microbial re-growth problems.