Proactive Management of Aesthetic Quality to Maintain Customer Confidence

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Key Takeaways

"Water quality aesthetics" describes various customer concerns, such as taste and odor, color, turbidity, and effects of pipe corrosion.

As end users, customers are on the front lines of emergent water issues and can indicate aesthetic quality changes for water suppliers.

Managing aesthetic quality in a proactive manner not only can save a water supplier money but also build public confidence.

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AWWA's Aesthetic Quality and Perception Committee (AQPC) is a long-standing group of volunteers that organized in 1965 as the Taste and Odor Committee (Khiari 2004, Rosen 1970). By 2020, the AQPC's scope included water quality aesthetics and customer perceptions such as these (Adams et al. 2022a):

- Taste
- Odor
- Color
- Staining
- Particles and turbidity
- Rust
- Corrosion byproducts
- Iron and manganese
- Customer complaints

As presented in the following sections, water quality aesthetics cover a wide range of contaminants. However, utilities should focus on a common theme, namely proactive management of aesthetic quality. Potential aesthetic quality issues must be addressed proactively to maintain customer confidence.

Aesthetic Issues and Secondary Maximum Contaminant Levels

As shown in Table 1, the US Environmental Protection Agency has set secondary maximum contaminant levels (SMCLs) for contaminants that cause aesthetic issues, including cosmetic effects (skin/tooth discoloration), aesthetic effects (taste, odor, color), and technical effects (corrosion and scaling). Individual states may choose to adopt them as enforceable standards. The need to revise the SMCLs for the contaminants listed in Table 1 has been discussed (Burlingame & Dietrich 2022, Dietrich & Burlingame 2015). For example, the SMCL for copper is 1.0 mg/L, which is not consistent with the 0.4–0.8 mg/L threshold for the metallic flavor that copper contributes. Similarly, the SMCLs for fluoride, iron, manganese, and odor itself are all considered to be outdated according to data from more recent sensory methods.

It is important to train operators and plant staff to recognize the causes of aesthetic quality complaints. The most common complaints and reasons, illustrated in Figure 1, are summarized in the next sections.

Color

Most of the issues surrounding colored water occur as a result of crossflow and backflow between interconnects or household plumbing. An example is blue-colored water appearing in a customer's home as a result of a backflow from a cross connection with a toilet water with blue-colored cleaner. Sometimes customers can also see small soap bubbles, either in the water or when a sample is shaken, and this can confirm a cross-connection with a nearby toilet.

In another example, water that is green and tastes sweet could be caused by ethylene glycol, which is frequently used as an anti-freezing agent to winterize nonpotable irrigation systems. Without a backflow preventer or check valve, a potable water could lose pressure and draw antifreeze into the plumbing. There have also been complaints about pink-colored water, which is less common but can happen because of the excessive use of potassium permanganate, an oxidant commonly used for drinking water treatment.

Turbidity

Customers sometimes see "milky" or "cloudy" water that is turbid immediately after filling a glass with tap water. Most of the time, the milky or cloudy water is caused by dissolution of air, which causes formation of bubbles in the water when the air is released. The bubbles rise from the bottom to the top and then dissipate, leaving clear water behind. Another example is residue that appears after distilling tap water—it is usually calcium and magnesium carbonate, which can form a visible cream-colored or tan scale on sinks, faucets, pots, and kettles. The carbonate residues precipitate in hot water, but they don't pose human health risks.

Slime

Sometimes a pink-, orange-, or black-colored slime can grow in bathrooms and other wetted areas. This growth, which comes off surfaces when scraped, is usually caused by bacteria and molds that grow on wet surfaces. It may be referred to as "bio-slime," and it can be many colors, including yellow, pink, green, brown, and black. These bio-slimes are either single species or multispecies growth.

> **A wide range of factors can affect the aesthetic quality of water, including its taste, odor, and appearance.**

Pipe Corrosion

Copper pipes can corrode with time and produce blue–green colored water or stains on sinks and toilets. Copper

EPA National Secondary Drinking Water Standards[a]

Contaminant	Secondary MCL	Noticeable Effects Above the Secondary MCL
Aluminum	0.05–0.2 mg/L[b]	Colored water
Chloride	250 mg/L	Salty taste
Color	15 color units	Visible tint
Copper	1.0 mg/L	Metallic taste; blue–green staining
Corrosivity	Noncorrosive	Metallic taste; corroded pipes/fixtures staining
Fluoride	2.0 mg/L	Tooth discoloration
Foaming agents	0.5 mg/L	Frothy, cloudy; bitter taste; odor
Iron	0.3 mg/L	Rusty color; sediment; metallic taste; reddish or orange staining
Manganese	0.05 mg/L	Black to brown color; black staining; bitter metallic taste
Odor	3 TON	"Rotten-egg," musty, or chemical smell
pH	6.5–8.5	Low pH: bitter metallic taste, corrosion High pH: slippery feel, soda taste, deposits
Silver	0.1 mg/L	Skin discoloration; graying of the white part of the eye
Sulfate	250 mg/L	Salty taste
Total dissolved solids	500 mg/L	Hardness; deposits; colored water; staining; salty taste
Zinc	5 mg/L	Metallic taste

EPA—US Environmental Protection Agency, MCL—maximum contaminant level, TON—threshold odor number

[a]Secondary Drinking Water Standards: Guidance for Nuisance Chemicals. https://bit.ly/EPA-SDW-Stds

[b]mg/L is milligrams of substance per liter of water; 1 mg/L is approximately 1 ppm, and the two terms are often used interchangeably.

Table 1

is soluble in water, where it forms a blue color and imparts a bitter, metallic taste. Alternatively, sometimes water main repairs can unintentionally release iron in soluble forms (yellow color) or oxidized insoluble forms (orange/red/brown color). Customers living in cul-de-sacs may encounter black-colored water because of release of manganese dioxide particles that can build up in the distribution system.

Cement is a common material used in water mains as the primary material or as a liner for metal pipes. Cement can break off the pipe and appear in tap water as hard particles that are sandy, cream, brown, or gray. These particles can settle out on the aerators or faucet screens, and plumbing materials such as brass, magnesium, or aluminum can release particles into tap water.

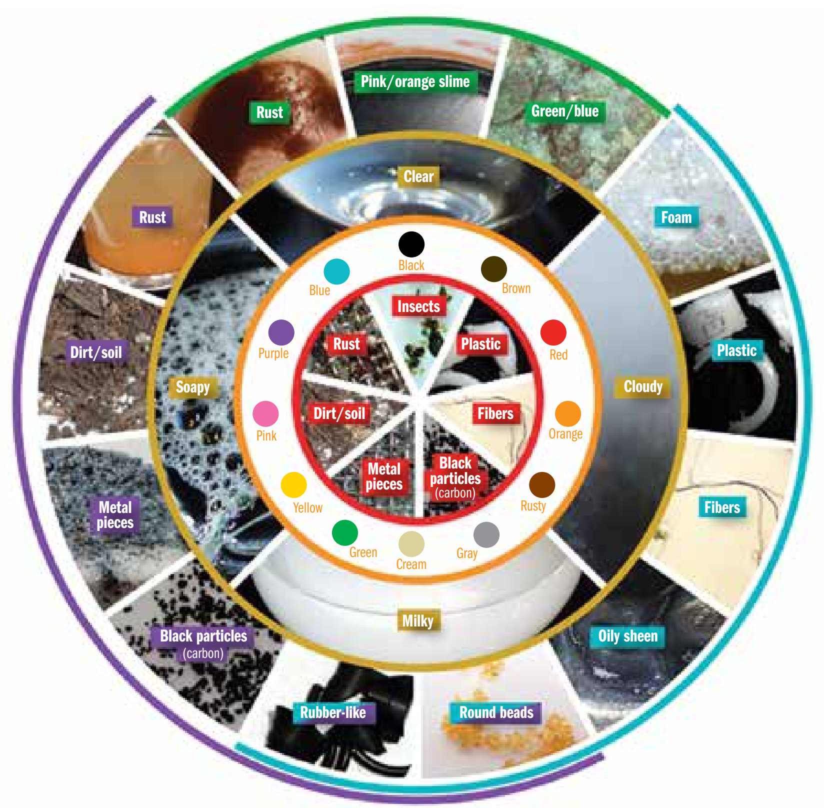
Rare occurrences of beads or resins in tap water could be a result of their release from point-of-use filters in places such as restaurants.

Can Appearance Signal a Health Threat?

The term *water appearance* refers to an aesthetic property of water, in particular the visual properties of transparency, color, and cloudiness. Problems can originate from source water, biofilm formation, water treatment processes, water distribution and storage systems, premise plumbing, and corroding pipes and plumbing fixtures (Lytle et al. 2018, 2005; Burlingame et al. 2006). While water appearance has not typically been associated with human health risks, that is not always a safe assumption.

When responding to customer complaints related to water appearance, the best approach is to avoid health-based assumptions. Timely investigations should be conducted, keeping careful records, with detailed observational notes such as location(s), nature of appearance, date/duration, photographs, and sample collection information. This should be

Guide to Particles and Color in Tap Water



Suspended or trapped on faucet screens
- Insects
- Plastic
- Fibers
- Black particles (carbon)
- Metal pieces
- Dirt/soil
- Rust

Water color
- Black
- Brown
- Red
- Orange
- Rusty
- Gray
- Cream
- Green
- Yellow
- Pink
- Purple
- Blue

Water texture
- Clear
- Cloudy
- Milky
- Soapy

Stains
Left on sinks, tubs, etc.
- Pink/orange slime
- Green/blue
- Rusty

Floaters
Matter that floats on top of water
- Foam
- Plastic
- Fibers
- Oily sheen
- Round beads
- Rubber-like

Sediment
Matter that settles at the bottom of water
- Round beads
- Rubber-like
- Black particles (carbon)
- Metal pieces
- Dirt/soil
- Rust

Source: Burlingame GA, Dietrich K, Ingram K. © Philadelphia Water Department, 2021. Permission is given to freely use this graphic if the citation is retained.

Figure 1

followed by identifying the composition of water and suspected contaminants and responses, which could include

- filtration to identify solids;
- microbiology-associated appearance problems, such as disinfectant residuals, and consultation with microbiologists;
- identification of the source;
- basic plumbing inspection; and
- historical distribution system water quality concerns.

Appearance issues can reflect broader system issues, and proactive approaches to address them can be helped with records of source and finished water quality. Systems can carry out scale and sediment analyses in areas of concern (e.g., different pressure and blend zones) to understand elemental composition and mineral formation and optimize corrosion control. With water quality data from regular monitoring, water systems are better prepared to discuss complaints and potential solutions.

Algae and Cyanobacteria-Related Taste and Odor

Taste and odor (T&O) issues in surface water have been problematic historically for warmer regions, but they are now prevalent even in temperate ones (Chowdhury 2021). Algae and cyanobacteria are microscopic, photosynthetic organisms that are similar in many aspects, so they are often lumped into the term *harmful algal blooms* (HABs). Since both can produce T&O compounds, water systems should perform routine monitoring in their source, in-plant processes, and treated water to determine whether an event is likely or already occurring.

Proactive monitoring includes integrating sensory analyses (e.g., flavor profile analysis), microbiological identification and enumeration of algae and cyanobacteria, and analytical chemistry (e.g., T&O compound analysis by gas chromatography–mass spectrometry). As shown in Figure 2 (Adams et al. 2022b), proactive monitoring can be used by utilities to drastically reduce or eliminate T&O complaints. Monitoring plans can be adapted for T&O issues produced by other organisms as well, such as halogenated anisoles in filter media, and to detect elevated levels of inorganics such as total dissolved solids (TDS) (Adams et al. 2021, Gallagher & Dietrich 2010).

Flow Imaging Microscopy

Phytoplankton monitoring provides utilities with the information required to make rapid treatment decisions. Historically, sample analysis has been performed using manual microscopy, but this can be slow, and results may take days to weeks. Timely results can affect the scale of a HAB and ultimately the cost of treatment.

In response to T&O issues caused by HABs, more utilities are using flow imaging microscopy (FIM) to provide timely phytoplankton results. FIM provides the morphological information available from microscopy at throughputs comparable to flow cytometry. Using this technique, analysts can rapidly count, image, and characterize particles in a sample. An objective lens magnifies particles within the fluid while a camera

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captures and stores thousands of particle images and measurements per second. Further analysis and sorting of images based on their fluorescent pigments provides a semi-automated overview of the concentration of cyanobacteria versus algae and diatoms in the sample, and organisms can be further classified as those that clog filters or that produce T&O or cyanotoxins.

Routine proactive monitoring using FIM allows managers to understand the phytoplankton community in their source water and over time create baseline and trigger levels for problem organisms. Time saved using

Cypress Environmental Laboratory Monitoring Workflow

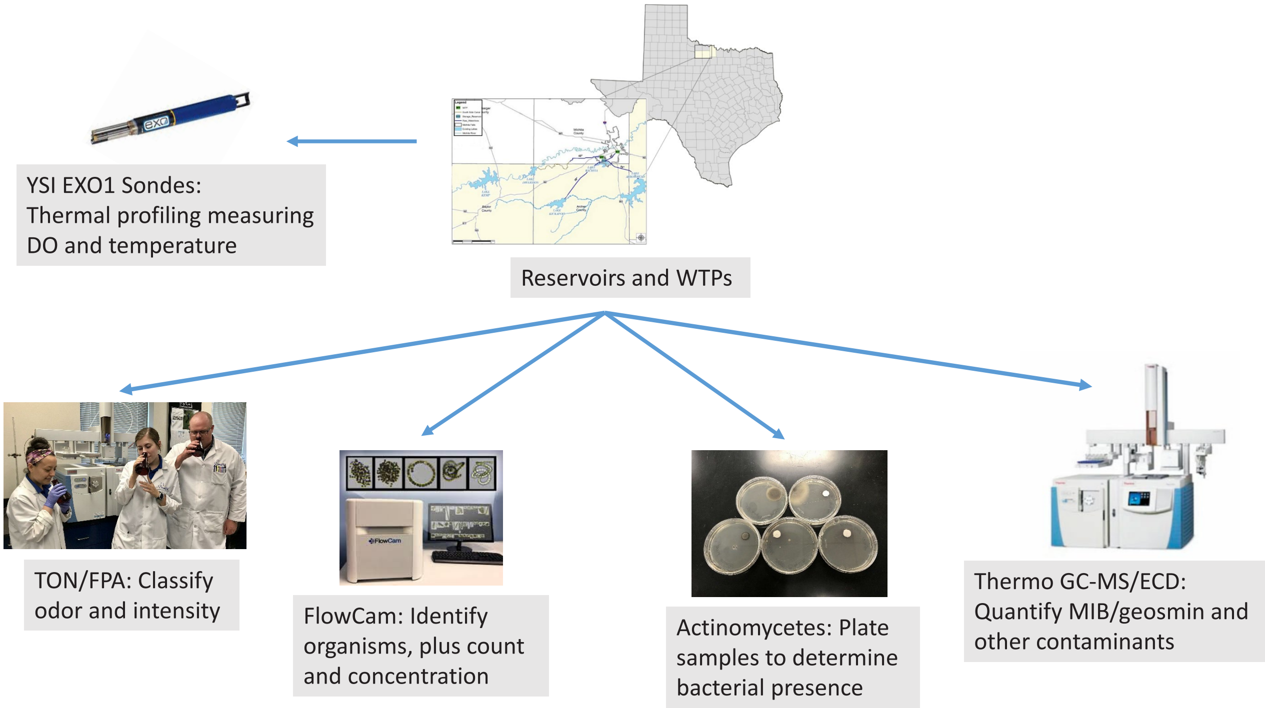

Image from City of Wichita Falls, Texas

DO—dissolved oxygen, ECD—electron capture detector, FPA—flavor profile analysis, GC-MS—gas chromatography–mass spectrometry, MIB—2-methylisoborneol, TON—threshold odor number, WTP—water treatment plant

Figure 2

FIM over traditional microscopy can be reallocated to additional sampling to span multiple depths and locations, providing a more complete picture of source water health. Changes in these baseline concentrations provide an early warning that managers should take additional samples and possibly change treatment parameters.

Expert and Consumer Panels

Tucson was a groundwater utility before the arrival of the Central Arizona Project (CAP) in 1992. Groundwater levels had plummeted 250 feet, managers wished to prevent severe consequences of subsidence downtown, and a renewable water supply was needed. At the time, the only renewable surface water supply available to Tucson was from the Colorado River through the CAP, whose surface water had huge differences in mineral quality compared with local groundwater.

Direct delivery of CAP began in November 1992. Overnight, a huge change in water quality led to issues with color, and complaints began immediately. More information on the crisis can be found in *Tucson Water Turnaround: Crisis to Success* (McGuire & Pearthree 2020, 2018). As a result of the crisis, research was conducted in the form of expert- and consumer-panel studies. In 1998, flavor profile analysis was performed by an expert panel to set consumer-panel levels.

Consumer panels composed of more than 100 participants determined the degree of acceptability at different TDS levels. Consumers were presented with eight samples with varying degrees of TDS and chlorine residuals and were asked to rate them. Experts could detect differences between the lowest and highest TDS levels, but only small differences in intensity were found. In the consumer panel, a 323-mg/L TDS blend was liked as much as the current groundwater supply and nearly as much as bottled water. While acceptance dropped to 59% as the TDS level reached 422 mg/L, this blend was still acceptable to the majority of consumers. A target TDS blend range of 350–450 mg/L was set, while the panel acknowledged that more research was needed.

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This was followed in 2006 by a consumer panel study that evaluated the acceptability for 450 mg/L and 650 mg/L TDS. Some statistically significant differences were shown between TDS levels on the basis of the degree of acceptability, while actual differences in scores were small. There was a clear trend that panelists gave lower (i.e., more negative) responses as TDS increased and statistical results mirrored the anecdotal responses of panelists, some of whom could not tell any difference between the six samples while others clearly liked lower TDS levels. Full-scale experience has shown that small changes in TDS over many years have not resulted in customer complaints in Tucson.

Helping Building Managers

The Consumer Confidence Report (CCR), delivered annually to all customers, provides information on the results of regulated water quality sampling. However, some customers may have complex building water systems (BWS), and they may not understand how water quality can change within it. CCRs could be improved for BWS managers by including more context to the data, such as their averages and ranges as well as what it means to be out of an acceptable range.

With a better understanding of how water quality can vary through their facilities, BWS managers improve their water management programs to detect, diagnose, and correct water quality upsets while communicating with local health departments, building occupants, and visitors. In their customer communications, utilities can also provide links to resources and guidance tailored to BWS managers.

Additional Tools and Resources

The US Centers for Disease Control and Prevention maintains an Emergency Water webpage that includes tools for emergencies, directed at both water systems and the general public. Subjects include household water treatment; an outbreak questionnaire; surface cleaning; preparedness and response; communication resources, guides, and toolboxes; and data, policy, and recommendations.

The Water Research Foundation (WRF) has funded more than 40 research projects related to aesthetics since 1989. T&O analysis has been regularly studied using the flavor profile analysis method; the WRF Report 55, *Taste and Odor in Drinking Water Supplies—Phase I & II*, first proposed the "T&O wheel" for characterization of organoleptic properties of drinking water (Suffet 1989). Since then, WRF's projects have studied ozone for control and treatment of geosmin and 2-methylisoborneol, public perception issues, T&O in discolored water associated with manganese and biofiltration, molecular methods, and early warning techniques.

Proactively Managing Aesthetic Challenges

As this article has shown, water quality aesthetics is a broad field and encompasses a gamut of conditions and concerns; if unaddressed, such issues can undermine the

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relationship between supplier and customer. Aesthetic challenges must be well understood by water systems so they can proactively manage them and maintain confidence that the water is safe. The industry must pay attention to customers because they are on the front lines of experiencing changes in water quality that can indicate aesthetic issues (Burlingame et al. 2017). If you are interested in joining the AQPC, please contact Trevor Voegele (tvoegele@cristengineers.com) or Julie Kurzawa (jkurzawa@awwa.org).

Acknowledgment

The authors would like to thank Darren Lytle with the US Environmental Protection Agency and Jonathan Yoder with the US Centers for Disease Control and Prevention. The sections titled “Can Appearance Signal a Health Threat?” and “Additional Tools and Resources” were based on their respective ACE22 presentations.

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https://doi.org/10.1002/awwa.2162

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