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Critical Review and Rethinking of USEPA Secondary Standards for Maintaining Organoleptic Quality of Drinking Water

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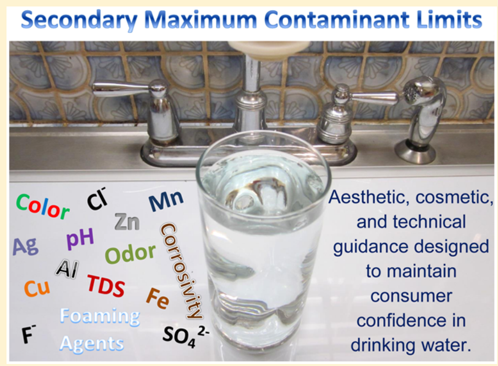
ABSTRACT: Consumers assess their tap water primarily by its taste, odor, and appearance. Starting in 1979, USEPA promulgated Secondary Maximum Contaminant Levels (SMCLs) as guidance for contaminants with organoleptic effects and also to maintain consumers' confidence in tap water. This review assesses the basis for the 15 SMCLs (aluminum, chloride, color, copper, corrosivity, fluoride, foaming agents, iron, manganese, odor, pH, silver, sulfate, total dissolved solids, zinc) and summarizes advances in scientific knowledge since their promulgation. SMCLs for aluminum, color, pH, silver, sulfate, total dissolved solids, and zinc are appropriate at current values and remain consistent with sensory science literature. Recent advances in sensory and health sciences indicate that SMCLs for chloride, copper, fluoride, iron, and manganese are too high to minimize organoleptic effects. The SMCLs for corrosivity and foaming agents may be outdated. The SMCL for odor requires rethinking as the test does not correlate with consumer complaints. Since current stresses on source and treated waters include chemical spills, algal blooms, and increased salinization, organoleptic episodes that negatively impact consumer confidence and perception of tap water still occur and may increase. Thus, adherence to SMCLs can help maintain production of palatable water along with consumers' confidence in their water providers.



■ INTRODUCTION

Most of the Secondary Maximum Contaminant Levels (SMCLs) have been in existence for over 50 years as the USEPA[1] implemented existing USPHS[2] regulations from 1962. During this period, environmental water availability and treatment practices changed, advances occurred in sensory science, and consumer perceptions/attitudes/health expectations toward drinking water transformed. This critical review responds to the compelling need to 1) assess the current 15 SMCLs within their historical and contemporary alignments with scientific knowledge and consumer perception for tap water as a beverage and 2) identify information gaps and research needs.

Water is an environmental resource that when treated and distributed becomes a beverage that is essential for and promotes good physical health, mental health, and wellbeing.[3] In the United States, quality distributed tap water is publically available, calorie-free, low-cost, regulated, and monitored for safety. Like other foods and beverages, consumers assess tap water primarily by its sensory qualities.

Supplying acceptable water is a large determinant of public trust and confidence in water providers.[4−7] The lack of producing organoleptically acceptable water and the associated loss of public trust can be exemplified by events that occurred during and after the 2014 chemical spill of odorous (4-methylcyclohexyl)methanol that disrupted the lives of over 300,000 West Virginians. Even after the "do not drink the water" order was lifted and officials acknowledged that the water was safe to drink, odors persisted in the tap water and made residents fearful.[8,9]

The role of consumer acceptance of drinking water quality has been acknowledged in practices, policies, and regulations throughout the 20th and into the 21st centuries.[1,2,4,7,10] The USEPA recognized the critical nature of the organoleptic characteristics of tap water when it incorporated nonenforceable SMCLs (Table 1) into the Safe Drinking Water Act to control contaminants that cause taste, odor, appearance, or cosmetic effects in community water systems (CWSs) and to "*maintain the consumer's confidence in the quality of their drinking water*".[1] Such contaminants can lower consumer satisfaction with drinking water even when no health-threat is present. For example, the CDC's "*Increasing Access to Drinking Water in Schools*" emphasizes that students are concerned about poor tasting tap water in their schools and suggests that schools conduct taste surveys.[11]

Water quality in the 21st century is changing across the USA and worldwide in ways that are and will continue to be recognized by the human senses. One critical change is an increase in inorganic total dissolved solids (TDS)[12] that can result in salty and other adverse tastes.[13−16] This increase is caused by drought;[17] direct and indirect water reuse that

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Table 1. USEPA Secondary Maximum Contaminant Levels[a]

contaminant	secondary MCL	USEPA SMCL category and noticeable sensory effects[b]	consistency with the current state of science
aluminum	0.05–0.2 mg/L	Aesthetic: colored water. Technical: scaling, sedimentation	SMCL consistent with current literature.
chloride	250 mg/L	Aesthetic: salty taste. Technical: corrosion	A lower chloride SMCL could benefit taste and corrosion control. Sodium is the primary cause of the salty taste and chloride only modifies it. An SMCL for sodium should be considered.
color	15 color units	Aesthetic: color, visible tint	SMCL for true color consistent with current literature.
copper	1.0 mg/L	Aesthetic: metallic taste, *odor*[c], color. Technical: corrosion, blue-green staining	Copper SMCL is not consistent with 0.4–0.8 mg Cu/L population threshold for metallic flavor.
corrosivity	noncorrosive	Aesthetic: metallic taste. Technical: corrosion, corroded pipes/fixtures staining	SMCL should be reconsidered as no direct method exists to monitor corrosivity. Corrosivity could be substituted with SMCLs for chloride, copper, iron, manganese, pH, total dissolved solids, and zinc for metal and cement materials. Consider aesthetic SMCL for polymeric materials, especially for odor.
fluoride	2.0 mg/L	Cosmetic: tooth discoloration or pitting	SMCL may be lowered to be consistent with 2011 USEPA and HHS joint proposed recommendation of 0.7 mg F/L.
foaming agents	0.5 mg/L	Aesthetic: odor; bitter taste; color - frothy, cloudy	SMCL may be outdated. Biodegradable surfactants have replaced the nonbiodegradable ones that initiated the SMCL.
iron	0.3 mg/L	Aesthetic: metallic taste, *odor*[c], color. Technical: corrosion, reddish or orange staining, scaling, sedimentation	SMCL exceeds the population threshold range for metallic flavor of 0.03–0.17 mg Fe^{2+}/L. Detectable color/particulates as Fe^{2+}/Fe^{3+} oxides can be visually perceived at and below the SMCL.
manganese	0.05 mg/L	Aesthetic:[d]-black to brown color. Technical: corrosion, black staining	SMCL value is above the Mn levels causing staining, color, and consumer complaints at 0.01–0.02 mg Mn/L. Neither Mn(II) nor Mn(IV) cause a bitter or metallic taste; this statement is outdated.
odor	3 TON[e]	Aesthetic: odor, such as, "rotten-egg", musty, or chemical smell	Odors in tap water are a continuous nuisance problem. TON has been in use since the 1940s; it measures the number of dilutions required to eliminate odor. It is acknowledged to lack correlation with consumer complaints or acceptability and may be outdated. More recent sensory methods could be used for the SMCL to measure total odor or specific odorants such as geosmin and 2-methylisoborneol.
pH	6.5–8.5	Aesthetic: low pH: bitter, metallic taste; high pH: slippery feel, soda taste; influences odor. Technical: corrosion, staining, scaling, sedimentation	pH 6.5–8.5 is consistent with good taste directly related to H^+ and OH^- but may be limited for controlling corrosion as corrosion control for select metals is better achieved at pH >8.5.
silver	0.1 mg/L	Cosmetic: skin discoloration, graying of white part of the eye	SMCL consistent with current literature; use of silver nanoparticles a possible concern.
sulfate	250 mg/L	Aesthetic: salty taste	SMCL consistent with current literature.
total dissolved solids (TDS)	500 mg/L	Aesthetic: salty taste, odor, colored water. Technical: corrosion, staining, scaling-hardness, sedimentation	The overall SMCL of 500 mg TDS/L is consistent with current literature for taste and corrosion effects. Consider guidance for effects of changing TDS or relating TDS to other taste causing ions, e.g., sodium, chloride, sulfate, and hardness.
zinc	5 mg/L	Aesthetic: metallic taste. Technical: corrosion	SMCL consistent with current literature.
ammonia	*no SMCL*	*Aesthetic: pungent taste and odor*	*Consider developing SMCL.*
hardness	*no SMCL*	*Aesthetic: bitter taste. Technical: scaling*	*Consider developing SMCL. Data needed for taste of calcium and magnesium. The value of <150 mg/L as $CaCO_3$ is targeted to avoid scaling.*
sodium	*no SMCL*	*Aesthetic: salty taste*	*Consider developing SMCL in conjunction with USEPA Drinking Water Advisory recommendation that 30 to 60 mg Na/L affects taste.*
specific odorants	*no SMCL*	*Aesthetic: odors*	*Consider developing odorant-specific SMCL based on prevalence and concentrations at which consumers complain.*

[a]USEPA.[1] [b]SMCL.[64] Specific concerns are stated by USEPA. [c]1979 USEPA did not indicate odor; recent literature confirms retronasal odor for copper and iron.[70,71] [d]Recent literature indicates that Mn(II) and Mn(IV) do not cause bitter, metallic tastes.[84] [e]TON = threshold odor number.

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converts wastewaters into potable water;[18] agriculture;[19] and potentially by hydraulic fracturing with brines, which contain >50,000 mg/L TDS.[20−22] Another problem is the aging infrastructure that leads to visually detected rusty water from degraded pipes.[23,24] Alterations to sensory properties of tap water also occur from inputs of odorous organic and inorganic chemicals from new piping materials;[25−29] chemical spills; proliferation of taste-and-odor causing cyanobacteria and algae whose odorous metabolites include terpenoids, polyunsaturated fatty acids, and organo-sulfur compounds.[30−32] Concurrent with the increased stress on water supplies and water quality, our scientific understanding of the human senses, human perception, and sensory variability have greatly expanded since 1979 when the SMCLs were first promulgated.[33] Also, the value of consuming water for improving health has been acknowledged, such as for managing weight-loss[34−36] and controlling obesity.[37] As succinctly stated by Michele Obama: *"I've come to realize that if we were going to take just one step to make ourselves and our families healthier, probably the single best thing we could do is to simply drink more water"*.[38]

This critical review addresses these topics: the basis for the SMCLs along with advances in scientific knowledge since they were promulgated; consumer perception for assessing safe tap water; and finally, information gaps and recommendations to consider for maintaining or updating the SMCLs to be a viable assessment of consumer acceptability and satisfaction with tap water.

■ OVERVIEW OF THE USEPA SECONDARY MAXIMUM CONTAMINANT LEVELS

The SMCLs complement the Primary Maximum Contaminant Levels (PMCLs). The PMCLs are health-based enforceable standards designed to protect consumer health[39] which have been updated many times since their inception in 1974.[40] Like the PMCLs, the SMCLs focus on safe water quality for consumers. The secondary contaminants are organized into three major categories that affect consumers: aesthetic (taste, odor, color, and foaming), cosmetic (bodily discolorations), and technical (corrosion and related staining, scaling, sedimentation) (Figure 1, Table 1). Individual contaminants may be placed in more than one category; over half of the contaminants have a taste, odor, or color effect, and over a third have a technical effect.

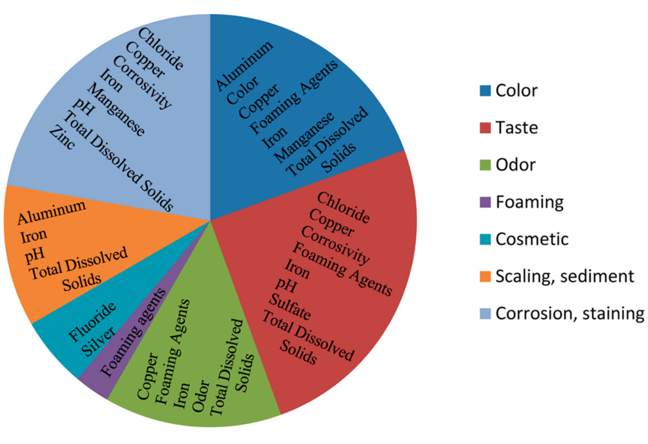

Figure 1. Distribution of the specific water quality concerns that occur for the 15 contaminants with SMCL values.

Most of the current SMCLs were derived from 1962 USPHS guidance and implemented into the Safe Drinking Water Act in 1979, although the SMCL for odor predates 1962. In 1986, a guide for fluoride was implemented, followed by aluminum and silver in 1991. The individual US States have the flexibility to adopt the SMCLs provided by the USEPA or implement specific adjustments such as

- selectively enforcing certain SMCLs in a similar manner as PMCLs (e.g., California[41] and Florida[42]);
- establishing SMCLs for additional constituents, such as methyl tert-butyl ether (e.g., California) or sodium (e.g., New Jersey[43]);
- establishing a different contaminant level for a constituent than USEPA;
- not adopting USEPA SMCLs, such as for corrosivity in California,[41] Florida,[42] New Jersey,[43] and Tennessee.[44]

The SMCLs encompass both organic and inorganic species that are either individual contaminants or aggregate categories (Table 1). SMCLs were established individually for the taste of chloride and sulfate. These two anions are also addressed in the SMCL for TDS. TDS is an aggregate measure of anions and cations in water and includes both ions with individual SMCLs and ions for which no individual SMCL exists. TDS is composed of major ions, e.g., those which typically have concentrations >10 mg/L in water such as calcium, sodium, bicarbonate, chloride, and sulfate, and also includes minor ions, e.g., those which typically have concentrations <1 mg/L, such as aluminum, copper, fluoride, iron, manganese, and zinc. The remaining SMCLs focus on properties derived from a single contaminant or by multiple contaminants depending on the situation. These include odor, corrosivity, color, foaming agents, and pH.

■ BASIS FOR THE 15 SMCLS AND SCIENTIFIC KNOWLEDGE SINCE THEY WERE PROMULGATED

The sensory data in this section were determined at room temperature, unless otherwise noted. The organization is to present the individual SMCLs in alphabetical order as was done by USEPA.[45]

Aluminum. In order to minimize technical effects related to precipitation or aesthetic effects related to color in tap water, the SMCL of 0.05−0.2 mg Al/L was issued in 1991.[45] The 0.05 mg Al/L value relates to a water treatment goal,[46] while 0.2 mg AL/L avoids discolored water.[47,48] The primary source of aluminum in distributed water is from aluminum-based coagulants; a secondary source is from dissolution of aluminosilicates present in cement lined-pipe.[49] The SMCL was set below the taste threshold which ranges from 4 to 10 mg Al/L.[50] No substantial research has been performed related to the SMCL since it was passed in 1991. No reports of organoleptic problems related to aluminum were found in the literature since 1991. The aluminum SMCL appears consistent with controlling particulate and color effects in tap water.

Chloride (*and Sodium*). The taste of chloride presents a conundrum as single anions or cations cannot be tasted since they occur as salts. Chloride is commonly assessed as sodium chloride. In 1979, the aesthetic SMCL was established at 250 mg Cl/L to prevent salty taste.[1] USEPA acknowledged that the value could be lower, but the limiting factor was that conventional treatment could not remove chloride and membrane treatment was too costly in 1979. The taste threshold range is 200−300 mg Cl/L as taste is affected by the anion(s) present (e.g., taste intensity varies according to Na> K> Ca).[48]

In the 1980s, the sodium cation, and not the chloride anion, was demonstrated to be primarily responsible for salty taste.[51,52] While sodium does not have an established USEPA SMCL, in 1996 USEPA set a health guidance level of 20 mg Na/L to protect individuals on restricted sodium diets. In 2003, 30−60 mg Na/L was suggested as guidance to avoid a salty taste.[53] New Jersey has an aesthetic guideline of 50 mg Na/L.[43] Thus, regulatory agencies are aware that sodium can contribute a salty taste to tap water.

Chloride and sodium typically occur in freshwaters at <10 mg Cl^-/L[54] and <20 mg Na/L.[46] Their natural sources can vary. Their anthropogenic sources tend to be similar and are expected to increase due to the use of deicing agents for roads,[55] estuarine or seawater that is processed by desalination into tap water,[15,56] release of brine from hydraulic fracturing fluids,[20,21] and water reuse.[18]

Both chloride and sodium ions are associated with a negative impression of tap water taste, indicating that consumers do not prefer these ions.[57] The taste detection thresholds of NaCl were found to be 150, 220, and 310 mg NaCl/L in distilled water for people with high, medium, and low NaCl intake, respectively.[58] Age also has a role in NaCl taste. For younger subjects aged 18−29 years, their overall threshold was 76 mg NaCl/L, while older subjects, 66−90 years, had a higher threshold of 333 mg NaCl/L.[59] These values translate to 30 mg Na/L for the 18−29 year age group, and 131 mg Na/L for the 66−90 year olds.[59] For subjects 23−88 years of age, the overall taste threshold for detection was reported to be 57 mg Na/L.[60] A concentration of 175 mg Na/L was reported as objectionable; this value is above the concentrations at which most people report detecting the taste of sodium.[61] The USEPA Drinking Water Advisory recommendation of 30 to 60 mg Na/L to avoid possible taste is at or below the concentration at which people detect a salty taste associated with sodium in water. The USEPA taste-based recommendation is above the health guidance level of 20 mg Na/L designed to protect individuals on sodium restricted diets; when this value is exceeded, notification of health officials is necessary.[45]

The data suggest that the aesthetic guideline of 250 mg Cl/L could be reduced and aesthetic guidance for sodium be considered as it is the major ion associated with salty taste. The use of deicing agents produces concern that surface waters may become too salty for human consumption.[55] High concentration of deicing salt causing a salty taste was acknowledged by CWS to have potentially caused aesthetic problems, as exemplified by this statement on the Web site for the CWS in Columbus, Ohio: "***Salty Taste:*** *Currently there is no treatment alternative in Columbus to remove increased concentrations of sodium from road salt. This can lead to spikes in taste and odor calls that include briny or salty concerns; occasionally for some palettes, soapy or slippery textures are also noted. Due to the higher flow rates of our river systems, such occurrences spike, and then quickly subside after the snow melts and is carried away past our plants. It is important to note this taste and odor poses no health concern but one of aesthetic quality*".[62]

Color. In 1979, the aesthetic SMCL of 15 color units was established to control color from natural organic matter and also from industrial inputs. The value represents where consumers find color objectionable[1] and where most consumers detect color in a glass of water.[48] Color can cause an emotional response that leads to a judgment of psychologically unacceptable tap water. Sources include tannins, humic and fulvic substances, iron, manganese, copper, dissolved oxygen which at cold temperatures can cause bubbles and cloudy water, colored industrial contaminants particularly those involving dyes for textiles, petrochemicals, personal care products, cleaning agents, paper, foods, beverages, and pharmaceuticals. The current SMCL of 15 color units appears appropriate to avoid colored tap water.

Color is measured as true color for soluble constituents or apparent color for turbidity from both scattered and adsorbed light in an unfiltered sample.[63] Turbidity is associated with unacceptable water quality by consumers.[64] While a treatment technique standard for turbidity is applied during the treatment of water, turbidity can increase during distribution to the tap and this is not regulated. Distribution system water quality models apply a measure of apparent color to assess the release of iron and sediment.[65] Thus, the color SMCL has value for controlling both true color and also turbidity.

Copper. The SMCL of 1 mg Cu/L was designed to prevent aesthetic effects of metallic taste and the technical effects of blue-green staining.[1] Copper is typically present at low μg/L concentrations in natural waters; corrosion of copper pipe is the major source in tap water.[66−68]

Research since 1990 has demonstrated that copper primarily causes a metallic flavor that is a combination of a slight taste and a substantial retronasal odor.[69−71] The odor results from oxidation of lipids in the human mouth to form odorous organic molecules including aldehydes, ketones, and alcohols that enter the olfactory bulb when a person swallows.[69−73] Copper also produces a bitter taste and an astringent mouth feel that develops 1−2 min after ingestion.[74] The human flavor threshold for copper is 0.4−0.8 mg soluble Cu/L in distilled water or tap water.[75] While soluble copper is readily detected, particulate or precipitated copper has little or no flavor and cannot be perceived by taste or flavor up to concentrations of 8 mg Cu/L.[75,76] A technical effect of copper is blue or blue-green staining of plumbing fixtures which can occur at concentrations <0.5 mg Cu/L.[1]

The SMCL of 1 mg Cu/L is above the flavor threshold as well as the concentration causing staining; reducing it would minimize the occurrence of metallic flavor or colored plumbing fixtures. An SMCL of 1 mg Cu/L is less than the Lead and Copper Rule's Action Level (AL) of 1.3 mg Cu/L and thus consistent with protecting human health.[45]

Corrosivity. USEPA[1] explained that corrosivity was a "complex characteristic of water primarily related to pH, alkalinity, dissolved oxygen, total dissolved solids, and hardness". Corrosive water affects the acceptability of a tap water's flavor, color, turbidity, and metal content when metal pipes are corroded. The SMCL sets a guideline of "noncorrosive" and lacks a numerical value or monitoring method associated with corrosivity. These features preclude direct measurement of corrosivity, and some states have eliminated it as an SMCL.[41−44] Related SMCLs for chloride, copper, iron, manganese, odor, pH, total dissolved solids, and zinc already mitigate corrosion effects; these SMCLs could substitute for the corrosivity SMCL. The current corrosivity SMCL is difficult to monitor and therefore enforce; it should be reconsidered as it may be outdated.

Fluoride. The fluoride SMCL was established at 2.0 mg F/L for cosmetic reasons to prevent tooth enamel discoloration and pitting (fluorosis).[77] There is no evidence that enamel discoloration affects tooth health or susceptibility to caries,

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and thus, the concern with fluoride is primarily cosmetic.[78] Fluoride is routinely added to drinking water to prevent tooth decay; the current recommended range is 0.7 to 1.2 mg F/L, although USEPA and HHS jointly proposed that it be lowered to 0.7 mg F/L.[79] The SMCL value is above the level suggested for controlling tooth decay and it is lower than the health-based PMCL 4.0 mg F/L.[45] Fluoride is naturally occurring in surface waters and ground waters in the range of 0–6.5 mg F/L; in some regions levels can exceed the SMCL and/or PMCL.[46] While the 2.0 mg F/L avoids severe fluorosis, it does not completely prevent milder cases of fluorosis.[78] Since the target concentration added to water for control of tooth decay may be lowered to 0.7 mg F/L, lowering the fluoride SMCL could be considered. For CWSs adding fluoride, it would be practical to have an operating range for dosing fluoride rather than a single value.

Foaming Agents. The current aesthetic SMCL is 0.5 mg/L to control foaming agents.[1] It was directly adopted from regulations to control foaming from nonbiodegradable, nonionic alkyl benzenesulfonates and also undesirable taste.[2] Since implementation in 1979, surfactants were redesigned to be biodegradable. In the 21st century, millions of metric tons of primarily synthetic and some natural surfactants are used annually in consumer and industrial products,[80] although no 21st century reports of foaming in tap water were found in the literature. Thus, the foaming SMCL appears appropriate for minimizing aesthetic effects but may be outdated as foaming was mitigated by redesign of surfactants. There is no standard test to measure foam formation. Instead, specific foaming agents are measured indirectly; the most common test is methylene blue active substances which determine "only" anionic surfactants.[63] The lack of a foam-based measurement may be problematic if new synthetic or natural surfactants enter tap water and cause aesthetic problems.

Iron. The aesthetic and technical SMCL of 0.3 mg Fe/L was promulgated to prevent metallic taste, rusty color, sediment, and reddish/orange staining of plumbing and laundry.[1] Concentrations of ≥0.05 mg Fe/L cause staining of plumbing fixtures and laundry.[1] Ferric iron [Fe(III)] is associated with rust, which consist of iron oxides that cause color and turbidity.[24,81,82]

Soluble ferrous iron (Fe^{2+}) is common in groundwater and stratified lakes/reservoirs.[46] Recent research indicates that the SMCL of 0.3 mg Fe/L will not prevent consumers from perceiving the metallic flavor of Fe^{2+}. Like copper, ferrous iron flavor is a combination of a slight taste and substantial retronasal metallic odor resulting from odorous volatiles released by oral lipid oxidation.[71,73,83] A population's flavor threshold is between 0.03–0.17 mg Fe^{2+}/L, while individual thresholds range from 0.007 to >14 mg Fe^{2+}/L and are age-dependent.[83] People over 50 years of age are less sensitive to the flavor of iron due to a reduced sense of smell; their group threshold was found to be 0.5 mg Fe^{2+}/L.[71,83] Fe^{3+} produces no or little taste or odor because it does not oxidize lipid.[71] The current iron SMCL of 0.3 mg Fe/L does not prevent consumers from perceiving the flavor of ferrous iron and is also above levels at which consumers can visually perceive rust and iron staining.

Manganese. The SMCL is 0.05 mg Mn/L, reportedly due to an aesthetic bitter taste and a technical brown-black color with staining of plumbing fixtures and laundry.[1] The values for aesthetic guidance are below the 0.3 mg Mn/L lifetime health advisory.[45] Manganese occurs in source water at concentrations typically between 0.1 and 1 mg Mn/L. Reduced Mn(II) is soluble and occurs in groundwater, stratified reservoirs, and lakes. Oxidized Mn(IV) is highly insoluble and forms MnO_2 precipitates that cause yellow-colored water at low concentrations and black-colored water at higher concentrations.[46,48]

A bitter taste is incorrectly assigned to Mn[84] and may have been a carry-over from the 1946 USPHS regulation of 0.3 mg/L for combined Fe and Mn due to staining, colored-water, and bitter taste.[10] A taste threshold was reported as 45 mg Mn(II)/L in 1960.[85] A recent study found a comparable threshold range of 75–160 mg Mn(II)/L with diverse descriptors of sweet, salty, astringent, yuck, bitter, and metallic.[84] Concentration ranges of 45–160 mg Mn(II)/L will contain substantial concentrations of counteranions; thus, the taste is likely caused by TDS and not Mn(II) alone.[84,86] Therefore, soluble Mn(II) produces no bitter or metallic taste and is colorless at typical concentrations found in tap water and even 100-fold higher than the taste threshold.

Insoluble Mn(IV) particles as MnO_2 have no detectable taste at either 0.05 or 0.5 mg Mn/L but can readily be seen at 0.005 mg/L in a glass of tap water.[84] Mn(II) and Mn(IV) do not cause lipid oxidation, which is the mechanism responsible for metallic flavor in the oral cavity caused by iron and copper.[86] In 1962, the Public Health Service[2] originally suggested a 0.01–0.02 mg Mn/L limit because particulate manganese (as MnO_2) and colored water are noticeable by consumers at these Mn concentrations, resulting in consumer complaints.[87−89] In the 1960s and 1979, limited ability to treat and remove Mn from water resulted in a practical value of 0.05 mg Mn/L. In the 21st century, control of Mn in water can be achieved at concentrations below 0.05 mg Mn/L.[89]

The current 0.05 mg Mn/L SMCL does not protect consumers from observing visual effects from MnO_2 as concentrations of ≤0.02 mg/L are known to produce consumer complaints. Neither Mn(II) nor Mn(IV) cause a bitter taste, and this information should be updated.

Odor. Odors result from a myriad of causes including biofilm growth, algae and cyanobacteria, distribution materials, chemical contaminants, wildfire/smoke compounds, and disinfectants, with chlorinous odors being the most common consumer complaint worldwide.[5] Particularly troublesome is that many unwanted odorants have human thresholds in the part per quadrillion or trillion making them difficult to identify and treat although readily perceived.[26,50,90−92] The USEPA[1] SMCL established an upper limit of Threshold Odor Number (TON) of 3. TON is measured by the Threshold Odor Test, which is a widely used dilution procedure that has existed since the 1940s. TON was the only standard method available in 1979 when the SMCL was promulgated.[4,93] At a TON of 3, a 1:3 mixture of tap water to odor free water at 60 °C should have no perceptible odor; TON values ≥3 indicate an odor concern, but TON has many documented disadvantages. These include the following: neither consumers or CWSs are readily able to dilute their tap water to remove odors, thus TON is not representative of most treatment options; TON does not correlate with consumer complaints; TON measures persistence of an odor upon dilution and not intensity; the odor description is not recorded; only one person usually performs the test.[4,93]

Recent methods can replace TON to evaluate odor characteristics of a water sample, such as Flavor Profile Analysis (FPA).[63] FPA uses a panel to assess the intensities of individual odors that are identified in the water sample. Another approach

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to managing odors is to establish odorant-specific concentration guidelines as has been done for the tastants chloride, sulfate, and zinc. USEPA has an odor-based drinking water advisory of 20 μg/L for methyl tert-butyl ether (MTBE),[45] which is a common groundwater contaminant from gasoline and also a chemical that migrates through polyethylene pipe into tap water.[94] In California[41] an enforceable standard of 0.005 mg MTBE/L is based on human perception of its sweet solvent odor. Florida[42] has odor-based guidelines for groundwater remediation of ethylbenzene, toluene, and xylene. Global nuisance cyanobacteria odorants geosmin (earthy) and 2-MIB (musty) have odor thresholds from 1 to 10 ng/L.[92] Australia,[95] Japan,[96] and USA cities[97−99] each have odorant-specific guidelines for geosmin and 2-MIB at 10 ng/L based on feedback from their consumers. The Metropolitan Water District of Southern California requires notification when the geosmin or MIB concentrations exceed a certain level.[97] In May 2014, the Metropolitan Water District of Southern California made this press release to explain the situation to their consumers: "*Consumers in southwest Riverside County have joined residents in San Diego County dealing with a musty taste and odor in their tap water. Officials at the Metropolitan Water District of Southern California reiterated today that the issue - an aesthetic problem caused by algae blooms in the district's water system and not a health hazard - is expected to improve in a week*".[100]

Environmental odors, such as those from tap water, can be both annoying and cause psychological effects that can be either emotional or cognitive. Hydrogen sulfide, a common groundwater contaminant causing a "rotten egg" odor[1] can also cause anxiety.[101] Aversions to odors can result in psychological discomfort when unusual environmental odors are present.[102] The malodors from swine operations, which are dominated by hydrogen sulfide, ammonia, and volatile organic chemicals, are known to cause stress, mood changes, and increased blood pressure.[103] Consumers impacted by land application of wastewater sludge reported that odors interfere with daily activities and caused eye-ear-throat irritation and breathing difficulties.[104]

Odorants from tap water can cause similar unhealthy and annoying environmental effects, and the sporadic nature and complex descriptions of odors in tap water can make them a challenge to locate and identify; thus more research is needed in this area. A good example of the complexity is odors from materials used to construct distribution systems and premise plumbing. Odorants and volatile organic compounds (VOCs) migrate from polymer materials in distribution system pipes and premise plumbing to cause odors in tap water.[25,27−29,94,105,106] Odors may occur in some sections of the distribution system or some premises and not others. Odors associated with PEX-B, a polyethylene-based pipe material, include chemical/solvent-like odors with overtones of sweet, bitter, plastic, burnt, and mechanical/motor oil. Ethyl tert-butyl ether is one VOC from PEX-B pipe that contributes to the chemical/solvent odor.[107] High density polyethylene pipe is widely used and is known to cause solvent, plastic, sweet, and glue-odors that are associated with esters, aldehydes, ketones, and aromatic compounds that migrate from the pipe into water.[29,94] Other pipe, valves, and fittings used to distribute water can cause plastic, chemical, medicinal, bitter, and rubber odors which can change in the presence of chlorine, which further complicates identifying the cause of an odor at the tap.[105]

In summary, odors in tap water are a major concern for consumers and CWSs. The current SMCL of TON of 3 is not adequately serving the water industry or consumers. Another more appropriate test or approach should be implemented to control odors in tap water. For consistently occurring odors of known origin (e.g., geosmin and 2-MIB), odorant specific guidance could be considered. Additional research and knowledge is required to more fully understand the impact on consumers from many of the odors that can occur in tap water.

pH. The SMCL of maintaining drinking water pH to between 6.5 and 8.5 is designed to provide aesthetically pleasing tap water and to control the technical effect of corrosion, particularly for metal and cement-lined pipes.[1] The pH range of 6.5−8.5 encompasses the typical pH of saliva.[108] A bitter, metallic taste can be perceived below pH 6.5, while a slippery feel and soda taste can be perceived above pH 8.5.[14] The pH range of 6.5−8.5 appears reasonable to control taste and mouthfeel of H^+ and OH^-.

pH is complicated as pH is a master variable that directly and indirectly controls dissolved chemical speciation and consequently exerts both subtle and blatant effects on tastes, odors, mouthfeel, color/particles, and corrosion at any pH value. For example, when chloramines are applied as a secondary disinfectant, then pH 8−9 is desired to maximize the production of less odorous monochloramine; pH ≤6.5 should be avoided to minimize the strong "swimming pool" odor of dichloramine.[109] Corrosion is strongly dependent on pH with both acidic and basic pH values affecting corrosion. Values of pH >8.5 are recommended to minimize corrosion of copper and lead. Thus, the pH range of the SMCL may require modification to be more appropriate when used with select metals or to control specific odorants.

Silver. In 1991, the SMCL for silver was established at 0.1 mg Ag/L to prevent argyria, which is the cosmetic blue-gray discoloration of skin or whites of eyes.[64,110] Silver concentrations are naturally low in surface and ground waters; concentrations of 0.001−0.04 mg Ag/L are typical.[46] The SMCL was motivated by its use for aqueous disinfection, avoidance of objectionable tastes, odors, and color and the fact that silver will remain indefinitely in the human body after absorption.[110]

While 0.1 mg Ag/L avoids argyria and is consistent with the historical, direct application of silver to disinfect drinking water, new sources of silver could enter drinking water in the future. In the 21st century, the USEPA approved and manufacturers began to incorporate silver nanoparticles as a biocide in consumer products such as soaps and laundry detergents, laundry machines, personal care products (toothpaste, shampoo, cosmetics), cooking utensils, water purifiers, clothing, and humidifiers.[111] Water reuse may increase silver and silver nanoparticles in drinking water.[18] Thus, the need for a cosmetic SMCL for silver still exists.

Sulfate. The aesthetic SMCL for sulfate is 250 mg SO_4^{2-}/L to avoid a salty taste,[1] although the taste threshold may be as low as 200 mg SO_4^{2-}/L.[1,46] Similar to chloride, the cation composition will affect the taste of sulfate, with calcium producing less taste and a higher taste threshold than sodium.[48,112] Whereas chloride is negatively perceived in drinking water and has more taste than sulfate, the presence of sulfate in water is positively perceived by consumers.[62] The aesthetic guideline of 250 mg SO_4^{2-} /L is lower than the health advisory of 500 mg SO_4^{2-}/L for avoiding diarrhea.[45] Natural

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sulfate concentrations in surface and ground waters range from 1 to 770 mg SO_4^{2-}/L with a median concentration of 46 mg/L.[46] The SMCL of 250 mg SO_4^{2-}/L is reasonable for taste and is also well below the sulfate level associated with diarrhea.

The SMCL directly addresses sulfate concentrations in drinking water. Indirectly, sulfate can relate to the odor SMCL. The presence of sulfate in water allows sulfate-reducing bacteria to produce hydrogen sulfide and volatile organic sulfur compounds in source water,[113] distribution systems,[114] and groundwater.[115] The addition of aluminum sulfate for drinking water treatment has been associated with the production of odors, sulfide, and corrosion in wastewater systems.[116] While wastewater is not the focus of the SMCLs, the need to limit sulfate in the entire water-wastewater cycle would suggest reconsidering the SMCL.

Total Dissolved Solids (TDS). TDS is an aggregate measure of all dissolved cations and anions in water and is also the major determinant of the taste of water.[14,56] The SMCL of 500 mg/L[1] controls for hardness, deposits, colored water, staining, and salty taste. TDS can vary widely in source waters; for the 100 largest US cities, the median was 86 mg TDS/L and the range was 22−1,589 mg TDS/L.[54] While the SMCL is designed to avoid "salty" or "mineral" tastes, the right amount and types of minerals in drinking water are associated with good taste. Water with either low mineral content or high mineral content is undesirable.[14,57] Californians generally prefer waters with a low TDS of ∼80 mg TDS/L.[13] A recent study revealed that 200−400 mg TDS/L is preferred by Europeans, and tap waters with <30 mg TDS/L or >800 mg TDS/L have low acceptance.[57] That same study found that bicarbonate, calcium, and sulfate concentrations were associated with desirable tasting water, while carbonate, chloride, and sodium had negative associations with taste. Thus, the overall taste of water is a combination of both TDS and concentrations of individual ions. The taste of TDS is substantially affected by temperature with a more intense taste perceived at room temperature and less taste for chilled or hot water.[112]

The need for minerals to be present for "good" tasting tap water creates the issue of perceiving changes in the concentration of TDS. Desalination/remineralization/blending/reuse treatments[15,18,68] and natural droughts/floods[17] can substantially alter TDS in ways that consumers will notice. Industrial activities can alter TDS if brine fluids directly or indirectly impact water, such as if hydraulic fracturing produced waters (which can contain 5,000−336,000 mg TDS/L) entered source waters.[20] When consumers in Pittsburgh, PA experienced an increase in TDS to greater than 500 mg/L, there were many complaints of salty and poor tasting tap water. The Pennsylvania Department of Environmental Protection tested the source, the Monongahela River, to confirm that concentrations exceeded the TDS SMCL, although the cause was not found.[117]

The amount of fluctuation in TDS that consumers can notice depends on the concentrations of TDS and the direction of change.[16] Consumers required TDS ≈ 185 mg/L to taste a difference at room temperature when contrasting low TDS (26 mg TDS/L) to higher TDS values (up to 524 mg/L); a change of TDS ≈ 380 mg/L was needed when a 524 mg TDS/L was compared to lower TDS values. This study was performed for a water that had a high concentration of bicarbonate, which is an anion known to be associated with good tasting water.[14,57] Drinking water with high concentrations of sodium or chloride, which are negatively associated with the taste of water, may produce different results. TDS and fluctuations in TDS are major contributors to corrosion.[68] Chloride, sodium, and sulfate are positively associated with iron corrosion, while bicarbonate mitigates corrosion. The existing models for predicting corrosion incorporate chloride, sulfate, and bicarbonate/alkalinity into the predictive equations.[46,65,82]

Aesthetics is among the top ten concerns for desalinated tap waters.[68] Desalinated water is remineralized before distribution primarily for corrosion control, but taste should also be considered. Improvement of tap water flavor can be achieved through blending desalinated water with water of a higher TDS.[15,56] In Tucson, AZ, consumers preferred 450 mg TDS/L over 650 mg TDS/L for a blend of surface and groundwater, thus confirming that an SMCL of 500 mg TDS/L is appropriate.[118]

In summary, the 500 mg TDS/L SMCL appears reasonable. Because different anions and cations contribute to TDS in various tap waters, the 500 mg/L value may prevent taste, staining, corrosion, or scaling associated with TDS. Additionally, fluctuations in TDS levels could be detectable by many consumers even if the TDS does not exceed 500 mg/L. Increased attention should be focused on the TDS SMCL due to an acknowledged nationwide trend of increasing TDS in source waters and, ultimately, tap waters. Ground waters have increased their TDS over the past two decades.[12] The increased use of deicing agents results in increased TDS and produces concerns that surface waters in the Northeastern US may become too salty and unsuitable for human consumption.[55] Increased water use for agriculture leads directly to increased TDS and deteriorating water quality due to mobilizations of minerals.[19] Industrial activities from reuse[18] and hydraulic fracturing[22] will also increase TDS in source waters and potentially tap waters. The trend toward increased TDS is not likely to mitigate.

Zinc. The zinc SMCL is 5 mg Zn/L to avoid metallic taste.[1] Zinc imparts an astringent taste at concentrations >5 mg/L.[46] At concentrations of 5−30 mg Zn/L, tap water may develop a milky appearance from Zn precipitation or a greasy scum when boiled, such as for making tea.[46] Dissolution of galvanized pipe or corrosion of brass are the primary sources of zinc in tap water.[66] One study found that the minimum concentrations detected by 5 and 50% of the population were 4.3−6.8 and 18−33 mg/L in distilled and in spring water, respectively.[85] The astringency of zinc likely results from binding to salivary proteins responsible for oral lubrication.[119] The zinc SMCL of 5 mg Zn/L appears consistent with minimizing taste in drinking water and also avoiding a milky appearance or zinc precipitate.

Role of Consumers Perception for Assessing Safe Tap Water. Many organoleptic events in tap water are temporary nuisances that are usually not harmful to human health even though they deter consumers from drinking tap water.[7] Consumer identification of changes in tap water quality may be early warnings of serious water quality problems. Consumer detection of tastes, odors, colors, or particles in their tap water has been instrumental in identifying contamination and improving water treatment.[120] Overlooking consumer feedback on sensory water quality has also been detrimental, such as when consumer complaints of turbidity were not investigated in the weeks before the 1993 *Cryptosporidium* outbreak in Milwaukee that eventually resulted in a number of deaths.[121] The USEPA promotes consumer feedback on sensory properties of tap water as a rapid-response early warning of possible contamination because consumers can detect and report

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sensory changes in a matter of minutes.[122] Consumers were essential to identifying the odorous and potentially health threatening crude (4-methylcyclohexyl)methanol (MCHM) spill that occurred on January 9, 2014 in West Virginia. Residents of Charleston and surrounding counties used their sense of smell to be the first to identify licorice smelling crude MCHM in their drinking water. The governor issued a "do not drink the water" message that lasted for many days. Months after the spill, residents were still smelling licorice and still avoiding drinking tap water.[8,9]

While there is a tendency to treat "taste and odor" separately, when humans eat and drink they experience "flavor" which is a combination of taste and odor. The five tastes are sweet, salty, sour, bitter, and umami, each of which is associated with specific chemoreceptors in the taste buds.[123] Odor is a more complicated sense.[124] Advances in understanding odor are fairly recent, as illustrated by awarding the 2004 Nobel Prize in Physiology or Medicine to Linda Buck and Richard Axel "for their discoveries of odorant receptors and the organization of the olfactory system".[125] There are hundreds of types of odor receptors in humans that can detect thousands of odors. Odorants interact with many receptors; the combination of which receptors and the intensity of interaction with the odorant determines the odor.[124,126] Orthonasal odors are those that are inhaled through the external nose. Retronasal odors result from vapors that rise from the mouth to the olfactory bulb when a person swallows; these contribute substantially to flavor.[124] Often consumers will say it 'tastes" good when referring to foods and beverages, such as chocolate, but there is no chocolate taste. The chocolate flavor is a combination of volatile odorants with sweet and bitter tastants.

Taste and odor thresholds are measured values based on groups or populations of human subjects. A detection threshold may be the concentration at which 50% of the test subjects can detect that a contaminant is present,[33] although, "it is recognized that some sensitive individuals may detect a chemical at levels below this threshold".[45] A single value is usually reported for thresholds although a statistical range is more appropriate,[127−129] especially since thresholds are affected by factors such as prior exposure, acclimation, test method, test location, time of day, age, gender, health, hunger, satiety, mood, genetics, temperature, and background matrix for the contaminant.[33,130] Threshold concentrations for individuals typically vary by factors of 100 or more. The human sensory response is proportional to the log of the concentration; this relationship is the Weber-Fechner Law. For tastants and odorants, a small change in concentration may produce either a small or large change in sensory response as the response is odorant specific.

While humans can readily detect countless odors, describing and naming an odor is a very complex and difficult multidimensional neuroactivity.[126,131] Training and experience allow individuals to be more accurate and precise in their lexicon for describing odors; this is why experts are better than typical consumers in describing beverages such as wine.[29,132] Naïve tap water consumers usually do not possess a developed lexicon for describing drinking water-related odors. Thus, consumers have trouble accurately describing odors that they do not expect to be in their tap water and often use diverse and misrepresentative descriptors which can make interpretation of consumer feedback by CWSs challenging.[133] Likewise, CWS personnel require experience and training to accurately describe odors. Therefore, a desirable approach for CWSs is to train personnel in FPA and also to consider training consumers or recruiting consumers to participate in FPA panels.

Water temperature is acknowledged to affect human perception of taste and odors. Warmer temperatures will enhance most odors as the increased temperature is usually associated with an increased concentration of the volatile odorant in the gas phase due to Henry's Law. Likewise, warmer temperatures are acknowledged to enhance the taste of minerals.[16,112] While temperature is not an SMCL, water temperature impacts perception and therefore must be considered in relationship to consumer complaints and satisfaction.

■ INFORMATION GAPS AND RECOMMENDATIONS

The SMCLs promote good flavored tap water, which when ingested, will promote health and wellbeing. As with any area of evolving environmental and health science, the SMCLs require updating. Key gaps and needs are presented below.

SMCLs. Table 1 summarizes current SMCL guidance along with recent scientific data for the 15 contaminants that possess SMCL values and select other contaminants that cause organoleptic concerns in water.

National Systematic Surveillance of Consumer Feedback. Since SMCLs are guidelines that are not monitored or enforced nationally, there is no systematic collection and interpretation of consumer feedback (e.g., consumer complaints) like what exists for PMCLs. Research is necessary to develop standardized procedures for syndromic surveillance of consumer feedback on aesthetic/cosmetic/technical concerns at individual CWSs and centralizing in a national database. Statistical data analysis procedures would be developed to identify background levels and determine unusual water quality situations at individual CWSs, regionally, and nationally.

The tap water producers, regulatory community, CWSs, and consumers would benefit from using a common language to describe organoleptic issues in a surveillance program. The Drinking Water Taste and Odor Wheel (*Standard Method #2170*)[63] is suggested as it includes four tastes (sweet, salty, sour, bitter), eight basic odor categories (earthy-musty, chlorinous, grassy-woody, swampy-sulfurous, fragrant, fishy, medicinal, chemical), and mouthfeel. A color scheme for dissolved and particulate matter is also required and could build upon that presented by Booth and Brazos.[134]

Candidate Contaminants for SMCLs. Since USEPA SMCLs have a goal "to maintain the consumer's confidence", guidance should be developed for tastants and odorants that were less problematic or unknown when the SMCLs were developed in 1979. Contaminants to be considered include the following.

Ammonia. As chloramine use becomes more widespread, ammonia may become an aesthetic concern. Overall, taste and odor data for ammonia in water are both lacking and poorly explained as ammonia species (NH_3, NH_4^+, or total) are infrequently provided. The ammonia threshold odor concentration is reported as 1.5 mg/L.[90] The drinking water advisory concentration is 30 mg/L as ammonia nitrogen for taste.[45] Since the distribution of ammonia species, and therefore the odor, will vary with pH, research is likely needed in this area.

Hardness. Aesthetic effects of taste are also caused by calcium and magnesium, the two main ions that contribute to hardness. Interestingly, hardness is associated with good tasting tap water when the concentration is appropriate[46] and is well-known to have cardiovascular and osteopathic health

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benefits.[135] Calcium is generally preferred by consumers and contributes to good tasting tap water,[57] although at concentrations >100 mg Ca/L it can be objectionable.[61] The reported taste thresholds are from 100−300 mg Ca/L in water.[48] Magnesium concentrations above 10 mg/L in water caused an offensive and bitter taste.[61] Research is required to further investigate the threshold ranges for calcium, magnesium, and combinations of these two ions. Such research is especially relevant as remineralization with limestone is a common practice following drinking water desalinization.[15,68]

Sodium. As discussed earlier, sodium was shown in the 1980s to be the major aqueous ion associated with a salty taste. USEPA[53] acknowledges that 30−60 mg Na/L can cause a salty taste; thus, a sodium SMCL would benefit consumers. Research is required to determine the threshold range for sodium and when changes in sodium concentration can be noticed, such as when deicing agents increase the NaCl content of drinking water during winter months.

Specific Odorants. Nuisance odorants that are common and result in consumer complaints should have acceptable levels established for aesthetic guidance. Select contaminants include geosmin, 2-MIB, and MTBE that were previously discussed and for which the odor threshold ranges are known. Other odorants that are identified in tap water but do not have odor threshold ranges should have thresholds determined.

Consumer Communications. Consumers would benefit by having public education materials that explain the SMCLs and their role in acceptable tap water quality. Water Quality Reports, which are reports required to be provided to tap water consumers by their CWSs under the USEPA Consumer Confidence Report Rule,[136] should be updated to include statements related to SMCLs that are written in a language understandable to the typical consumer. Analyses of Water Quality Reports demonstrated that many consumers find them poorly understandable and not responsive to consumers' needs.[137] They are typically written at a 12th grade level instead of the 7−8th grade level recommended for effective communication to the general public.[138] The recent regulatory change to allow Water Quality Reports to be published online with consumers being able to request paper copies[139] should enhance the ability of CWSs to include a color version of the Drinking Water Taste and Odor Wheel[63] as well as use other colored illustrations to present information related to the SMCLs.

Corrosion Control Regulations. Corrosion and aesthetic problems are caused by many of the same water quality parameters, including chloride, sulfate, and pH. Corrosion releases aluminum, copper, iron, and zinc, all of which cause aesthetic effects plus staining or particulates. The interrelationship of corrosion and aesthetics should be investigated and emphasized in regulations or best practices for corrosion control.

Assessing Aesthetics of New Materials. Installation of newly designed polymer and metal materials is underway in tap water distribution systems and premise plumbing. Consideration should be given to the impacts of these materials on the taste, odor, or appearance of tap water before they are installed in the distribution system and impact consumers. A testing program to assess aesthetic effects of materials in contact with water should be implemented.

Human Perception of Changes in Water Quality. The human senses are designed to detect changes and then notify individuals that the situation is not the same as previous, which may be a warning that the situation is not safe. The ability to identify when consumers can readily detect changes in sensory properties of tap water is a contemporary research need because water quality is fluctuating from desalination/remineralization, blending of water from different sources, droughts, and floods. All of these factors will affect the day-to-day taste, odor, and appearance of tap water and potentially cause consumers to have a negative perception of tap water.

Name Change. The phrase "Secondary Maximum Contaminant Level (SMCL)" does not convey to consumers that these USEPA values are nonenforceable guidelines related to aesthetic, cosmetic, and technical concerns. SMCL is too similar to PMCL, which are enforceable, health-based regulations. This can be confusing as consumers and professionals outside the water industry expect SMCLs to be similar to PMCLs. Consideration should be given to phrases such as "Guidelines for Consumer Acceptance (GCAs)" or "Consumer Quality Guidelines (CQGs)" which would better represent their intended purpose.

■ SUMMARY

The SMCLs are designed to be a viable assessment of consumer acceptability and a means to instill consumer confidence in tap water. The literature indicates that the SMCLs for aluminum, color, pH, silver, sulfate, total dissolved solids, and zinc can be considered appropriate at their current values as they are consistent with the sensory literature. The SMCLs for chloride, copper, fluoride, iron, and manganese have values that are too high to minimize organoleptic effects and should be reviewed and reassessed. The SMCL for corrosivity is a challenge to implement and interpret as there is no method to measure corrosivity; this SMCL may be outdated. In recent years foaming agents have not been an issue in tap water as modern surfactants are biodegradable; thus, this SMCL may no longer be necessary. The pH range appropriate for corrosion control extends to more basic values than pH 8.5 for the current SMCL; this indicates that the SMCL should be evaluated to consider higher pH values used to minimize corrosion. The SMCL for odor requires rethinking as the TON test does not correlate with consumer complaints or acceptability and thus is not a good test for consumer satisfaction. New SMCLs should be considered for ammonia, hardness, sodium, and specific odorants.

Consumers need to drink water to stay healthy. Producing a tap water that is palatable and that meet consumers' desire to drink water will benefit the health of individuals and society. SMCLs provide important guidance for acceptable levels of contaminants with organoleptic properties, and consequently, aid in maintaining the consumer's confidence in tap water. The scientific understanding of sensory function and human perception has evolved since most of the SMCLS were promulgated. Likewise, water treatment and source water quality has also changed. Thus, it is appropriate to reassess the SMCLs by considering both scientific advancements and the 21st century tap water consumer.

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Notes

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