CDM Smith

Memorandum

To: *CV-SALTS*

From: *Richard Meyerhoff, CDM Smith*

Date: *June 22, 2012*

Subject: *Salinity Effects on MUN-Related Uses of Water*

Background

The CV-SALTS Executive Committee identified the following focus area for policy discussion: (Focus Area #5): "Define what constitutes 'Reasonable protection of existing and probable future MUN [Municipal and Domestic Supply] uses' with respect to electrical conductivity (EC) and some specific individual ions. Determine whether and when to use secondary MCLs [maximum contaminant levels] as water quality objectives." To support the discussion, the Executive Committee requested the development of technical information in the following two areas:

- Summarize the current state of knowledge regarding the effects of elevated electrical conductivity (EC) (salinity or total dissolved solids [TDS]) and hardness concentrations on drinking water supply and other domestic purposes.
- Identify and summarize unique concerns related to specific ions (e.g. sodium, chloride, boron, etc.)

This Technical Memorandum (TM) represents the findings from research completed to date on each of these two technical areas. In addition to the specific areas of research posed above, we provide a summary of federal and California water quality standards currently applicable to MUN-related uses. For comparative purposes, information from other selected states and international sources is also provided.

All California Regional Boards define MUN as follows: "Uses of water for community, military, or individual water supply systems including, but not limited to, drinking water supply". This definition is broad, encompassing uses of public water supplies for purposes other than drinking. Accordingly, both drinking water and non-drinking water uses of potable water supplies are evaluated in subsequent sections of this memorandum.

Consistent with Westcot (2012), this review considered total dissolved solids (TDS), EC and the principal cations and anions in water salinity:

- Principal cations: Sodium, (Na^{+}), Calcium (Ca^{2+}), Potassium (K^{+}), Magnesium (Mg^{+2}); and

- Principal anions: Chloride (Cl-), Sulfate ($SO_4{}^{2-}$), Carbonate ($CO_3{}^{2-}$), Bicarbonate ($HCO3^-$).

In addition to the above, this review will also include some information on a minor cation, Boron (B^{3+}), that can be associated with dissolved solids.

Development of this memorandum relied extensively on the work completed to date by Dennis Westcot: *Recommended Water Quality Criteria for Evaluation of Water Quality Objectives* (Draft document provided on June 8, 2012, hereafter referred to as Westcot [2012]). The full draft of this document is provided as Attachment A. The information in Westcot (2012) was supplemented where appropriate, especially with regards to the use of potable water for non-drinking water purposes. References used in this TM are provided at the end of this memorandum; additional extensive references are available in Attachment A.

Summary of Findings

Insert after TAC Review and Comment

Regulations to Protect MUN-Related Uses

This section includes a summary of (a) federal requirements for the protection of waters used as a public water supply; (b) California drinking water standards; and (c) requirements from other selected states or international organizations.

Federal Requirements

State adopted surface water quality standards are typically based on Environmental Protection Agency (EPA) guidance developed under Section 304(a) of the Clean Water Act (CWA). However, for protection of waters designated as MUN the EPA has not adopted 304(a) criteria specific to the protection of MUN-related uses[1]. Instead, states typically rely on the primary maximum contaminant levels (MCLs) and secondary maximum contaminant levels (SMCL) promulgated by the EPA under the Safe Drinking Water Act (SDWA) to protect surface waters designated as a municipal or domestic water supply.

EPA has established both MCLs (enforceable) and Maximum Contaminant Level Goals (MCLGs, non-enforceable) for drinking water. MCL means the maximum permissible level of a contaminant in water which is delivered to any user of a public water system. An MCLG means the maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health of persons would occur. MCLs and MCLGs are found at 40 Code of Federal Regulations (CFR) 141, in particular parts 141.11 (MCL - inorganic compounds), 141.13 (MCL - coliform) and 141.61 (MCL - organics), and 141.50 through 141.5 (MCLGs) (or see, http://water.epa.gov/drink/contaminants/index.cfm). **No MCLs or MCLGs have been promulgated for any salinity-related constituents.**

[1] It is important to note that the EPA has developed human-health based criteria, which do protect for direct consumption of untreated water from a waterbody; however, these criteria assume direct consumption of raw water and also include protection for exposure to pollutants from other pathways, e.g., consumption of harvestable aquatic life.

EPA has also promulgated SMCLs, which are non-mandatory or voluntary water quality standards[2] (**Table 1**). Although adopted in 1979, the SMCL for TDS dates back to standards recommended by the U.S. Public Health Service in 1942 and by the National Technical Advisory Committee to the Secretary of the Interior in 1968 (aka, "Green Book").

The federal SMCLs provide guidance to public water systems for managing their drinking water to take into account aesthetic considerations, such as taste, color, and odor. The SMCLs include several salinity related constituents, e.g., chloride, sulfate, and TDS. At the SMCL threshold, none of these contaminants is considered to present a risk to human health (also, see Table 5 below regarding specific salinity-ion effects).

The EPA promulgated the first SMCLs in 1979 (after publishing proposed regulations in 1977). These standards have never been modified; the only changes since 1979 have been the addition of three more SMCLs for fluoride, aluminum and silver. The SMCLs are published at 40 CFR 143.3 or see the EPA's website: http://water.epa.gov/drink/contaminants/index.cfm#SecondaryList.

California Requirements

The federal MCL and SMCL regulatory structure is mirrored in California through the promulgation of primary and secondary drinking water standards. Two California agencies are involved in establishing standards to protect drinking water:

- *California Office of Environmental Health Hazard Assessment (OEHHA), Toxicology Unit* – Agency responsible for establishing California Public Health Goals (PHGs). A PHG is the level of a contaminant in drinking water that does not pose a significant risk to public health; it is not a regulatory standard, but instead provides guidance for the California Department of Public Health (CDPH) to consider when setting a drinking water MCL. **No PHGs have been established for salinity-related constituents.**
- *California Department of Public Health, Division of Drinking Water and Environmental Management* - CDPH drinking water-related regulations are found in Titles 22 and 17 of the California Code of Regulations (CCR) commonly known as the California Safe Drinking Water Act & Related Statutes:
    - *Primary Drinking Water Standards (PDWS)* - Under §116275, MCL means the maximum permissible level of a contaminant that may be present in water and not have an adverse effect on human health. §64431 establishes the PDWS for inorganic chemicals administered by CDPH. **No PDWS have been adopted for salinity-related compounds in California**.

[2] In the original federal promulgation of SMCLs (1979), EPA provided the following basis for SMCLs: "At considerably higher concentrations, these contaminants may also be associated with adverse health implications…they are intended as guidelines for the States. The States may establish higher or lower levels as appropriate to their particular circumstances dependent upon local conditions such as unavailability of alternate raw water sources or other compelling factors, provided that public health and welfare are adequately protected. However, odor, color and other aesthetic qualities are important factors in the public's acceptance and confidence in the public water system; thus, States are encouraged to implement these SMCLs so that the public will not be driven to obtain drinking water from potentially lower quality, higher risk sources (44 FR 42195, July 19, 1979)."

Table 1. Federally Promulgated SMCLs – All Constituents[1,2]

Constituent	SMCL	Federal Register (FR) Publication	Noticeable Effects above the SMCL[3]
Aluminum	0.05 to 0.2 mg/L	56 FR 3597, Jan 30, 1991	Colored water
Chloride	250 mg/L	44 FR 42195, Jul 19, 1979	Salty taste
Color	15 color units	44 FR 42195, Jul 19, 1979	Visible tint
Copper	1.0 mg/L	44 FR 42195, Jul 19, 1979	Metallic taste; blue-green staining
Corrosivity	Non-corrosive	44 FR 42195, Jul 19, 1979	Metallic taste; corroded pipes/ fixtures staining
Fluoride	2.0 mg/L	51 FR 11396, Apr 2, 1986	Tooth discoloration
Foaming Agents	0.5 mg/L	44 FR 42195, Jul 19, 1979	Frothy, cloudy; bitter taste; odor
Iron	0.3 mg/L	44 FR 42195, Jul 19, 1979	Rusty color; sediment; metallic taste; reddish or orange staining
Manganese	0.05 mg/L	44 FR 42195, Jul 19, 1979	Black to brown color; black staining; bitter metallic taste
Odor	3 TON (threshold odor number)	44 FR 42195, Jul 19, 1979	Rotten-egg, musty or chemical smell
pH	6.5 - 8.5	44 FR 42195, Jul 19, 1979	*Low pH:* bitter metallic taste; corrosion *High pH:* slippery feel; soda taste; deposits
Silver	0.1 mg/L	56 FR 3597, Jan 30, 1991	Skin discoloration; graying of the white part of the eye
Sulfate	250 mg/L	44 FR 42195, Jul 19, 1979	Salty taste
Total Dissolved Solids	500 mg/L	44 FR 42195, Jul 19, 1979	Hardness; deposits; colored water; staining; salty taste
Zinc	5 mg/L	56 FR 3597, Jan 30, 1991	Metallic taste

Notes:

1 Prior to publishing its 1977 rule proposal, the EPA also considered proposing SMCLs for hardness, alkalinity, phenols, sodium and standard plate count (bacteria-related measure of aesthetics, not human health-related protection). None of these constituents was included in the published rule proposal.

2 Original federal proposal (42 FR 17143, Mar 31 1977) also included a proposed SMCL for hydrogen sulfide; this constituent was removed in the final promulgation (44 FR 42195, Jul 19, 1979) based on public comment.

3 Source: http://water.epa.gov/drink/contaminants/secondarystandards.cfm

- *Secondary Drinking Water Standards (SDWS)* – These standards specify a secondary maximum contaminant level that, in the judgment of CDPH, is necessary to protect public welfare. SDWS are not enforceable but set guidance on how public water systems should be operated. An SDWS may apply to any contaminant in drinking water that may adversely affect the odor or appearance of the water and may cause a substantial number of persons served by the public water system to discontinue its use, or that may otherwise adversely affect the public welfare.

  Inorganic chemical SDWS are found in §64449 (Tables 64449-A and 64449-B). Those constituents that are salinity-related are found in Table 64449-B. For the most part, these standards are similar to the federal SMCLs; however, differences include the inclusion of upper limit and short-term/intermittent use levels for TDS, chloride, and sulfate concentrations (**Table 2**), and the inclusion of a standard and levels for specific conductance (µS/cm) (or EC), for which there is no federal SMCL. The upper limit and short-term levels reflect the lack of evidence of any health affects below these values and the findings that consumer acceptance is diminishing above these levels. **Table 3** provides a comparison between California requirements and federal requirements or international guidelines.

Table 2. Summary of California Salinity-Related Secondary Drinking Water Standards

Constituent	**Recommended**	**Upper Level**	**Short-Term or Intermittent Use**
Total Dissolved Solids mg/L)	500	1,000	1,500
or			
Specific Conductance (µS/cm)	900	1,600	2,200
Chloride (mg/L)	250	500	600
Sulfate (mg/L)	250	500	600

California Regional Board Basin Plans

As noted above, all California Regional Boards have adopted the same MUN definition. However, although the same definition applies statewide, variability exists across regions with regards to the adoption of salinity-related water quality objectives in each region's Basin Plan (**Table 4**).

Other State Requirements

Westcot (2012) prepared a brief review of selected state drinking water standards requirements with regards to salinity-related constituents. Information was originally developed for the California Urban Water Agencies (CUWA) (2007). CUWA chose states to survey based on known incidences of water quality concerns related to the constituent of interest, presence of unfiltered drinking water supplies, historically progressive regulatory arena, and presence of large number of impacted source waters for the CWA Total Maximum Daily Load program. Examples from the CUWA survey include:

- Florida has a surface water salinity criterion with a monthly average of 500 mg/L, not to exceed 1,000 mg/L. Groundwaters used for potable supplies are classified by their TDS levels, either Class G-1 less than 3,000 mg/L or Glass G-II less than 10,000 mg/L;

Table 3. Comparison of U.S. Federal, California and International Standards or Guidelines to Protect MUN-Related Uses (NA – no standard or guideline established)

Constituent	Federal MCL and MCLGs (40 CFR §141)	Federal SMCLs (40 CFR §143.3)	California Primary Drinking Water Standards (CCR §64431)	California Secondary Drinking Water Standards (CCR §64449)	WHO International Drinking Water Guidelines	Canadian Guidelines (MAC or AO/AG)[8]	Australia/New Zealand (HB or AeB)[9]
Total Dissolved Solids	*NA*	*500 mg/L*	*NA*	*500 mg/L (1)*	*(2)*	*500 mg/L (AO/AG)*	*600 mg/L (AeB)*
Electrical Conductivity	*NA*	*NA*	*NA*	*900 µS/cm (3)*	*NA*	*NA*	*NA*
Bicarbonate (HCO_3^-)	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
Boron (B)	*NA*	*NA*	*NA*	*1.0 mg/L (4)*	*2.4 mg/L*	*5 mg/L (MAC)*	*4 mg/L (HB)*
Calcium (Ca^{2+})	*NA*	*NA*	*NA*	*NA*	*(2)*	*(5)*	*NA*
Carbonate (CO_3^{2-})	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*	*NA*
Chloride (Cl^-)	*NA*	*250 mg/L*	*NA*	*250 mg/L (6)*	*(2)*	*250 mg/L (AO/AG)*	*250 mg/L (AeB)*
Magnesium (Mg^{2+})	*NA*	*NA*	*NA*	*NA*	*(2)*	*(5)*	*NA*
Potassium (K^+)	*NA*	*NA*	*NA*	*NA*	*(2)*	*NA*	*NA*
Sodium (Na^-)	*NA*	*NA*	*NA*	*NA*	*(2)*	*200 mg/L (AO/AG)*	*180 mg/L (AeB)*
Sulfate (SO_4)	*NA*	*250 mg/L*	*NA*	*250 mg/L (7)*	*(2)*	*500 mg/L (AO/AG)*	*250 mg/L (AeB)*

(1) 500 mg/L is recommended for continuous use with an upper limit of 1,000 mg/L. Short-term or intermittent use is allowed up to a TDS of 1,500 mg/L.
(2) Some chemical and physical parameters have been identified as not requiring a numerical guideline, because currently available data indicate that it poses no health risk or aesthetic problem at the levels generally found in drinking water.
(3) 900 µS/cm is recommended for continuous use with an upper limit of 1,600 µS/cm. Short-term or intermittent use is allowed up to an EC of 2,200 µS/cm.
(4) State Action Level that requires notification of the water users. Boron is not a regulated contaminant but is considered a contaminant of concern.
(5) Some chemical and physical parameters have been identified as not requiring a numerical guideline, because currently available data indicate that it poses no health risk or aesthetic problem at the levels generally found in drinking water.
(6) 250 mg/L is recommended for continuous use with an upper limit of 500 mg/L. Short-term or intermittent use is allowed up to a Cl of 600 mg/L.
(7) 250 mg/L is recommended for continuous use with an upper limit of 500 mg/L. Short-term or intermittent use is allowed up to a SO4 of 600 mg/L.
(8) MAC = Health based Maximum Acceptable Concentration; AO/OG = Aesthetic Considerations/Operational Guidance Value.
(9) HB = Health based; AeB = Aesthetic-based.

Table 4. Summary of Salinity-Related Objectives Adopted by California Regional Boards

Regional Board	Salinity-Related Constituents Explicitly Applicable to Entire Region				Narratives	Site-Specific Objectives	Other Considerations
	TDS	EC	Cl^-	SO_4			
Region 1	NA	NA	NA	NA	NA	Selected waterbodies have TDS and EC site specific objectives (SSO) using 90% and 50% percentile upper limits for a calendar year	Propose to incorporate all provisions of Title 22 of CA CCR (2012 proposal)
Region 2	500	900	250	250	Controllable water quality factors shall not increase the total dissolved solids or salinity of waters of the state so as to adversely affect beneficial uses, particularly fish migration and estuarine habitat	None identified	Title 22 regulations applicable to MUN use
Region 3	NA	NA	NA	NA	Controllable water quality factors shall not increase the total dissolved solids or salinity of waters of the state so as to adversely affect beneficial uses, particularly fish migration and estuarine habitat	SSOs for TDS, chloride, sulfate, boron and sodium established in selected surface waters and groundwaters	NA
Region 4	500 – applied if no SSO		250 – applied if no SSO	400-500 – applied if no SSO	NA	SSOs for TDS, chloride, sulfate, boron and Sodium Adsorption Ratio (SAR) established in selected surface waters. SSOs for TDS, sulfate, chloride and boron established for selected groundwaters	Portions of Title 22 regulations applicable to MUN use
Region 5 – Sacramento and San Joaquin River Drainages	500		250	250	NA	Sacramento/San Joaquin - Selected waterbodies have TDS, EC, and chloride objectives	Title 22 regulations applicable to MUN use

Table 4. Summary of Salinity-Related Objectives Adopted by California Regional Boards

Regional Board	Salinity-Related Constituents Explicitly Applicable to Entire Region				Narratives	Site-Specific Objectives	Other Considerations
	TDS	EC	Cl^-	SO_4			
Region 5 – Tulare Lake Basin	NA	NA	NA	NA	• For inland surface water, waters shall be maintained as close to natural concentrations of dissolved matter as is reasonable considering careful use of the water resources. • For ground waters, all waters shall be maintained as close to natural concentrations of dissolved matter as is reasonable considering carful use of the water resources. No proven means exist at present that will allow ongoing human activity in the Basin and maintain ground water salinity at current levels throughout the Basin. Accordingly, the water objectives for ground water salinity control the rate of increase.	Selected waterbodies have site-specific EC objectives	Title 22 regulations applicable to MUN use
Region 6	NA	NA	NA	NA	NA	Selected waterbodies have TDS, EC, chloride, sulfate, boron, SAR or adjusted SAR, % sodium objectives	Title 22 regulations applicable to MUN use
Region 7	NA	NA	NA	NA	Discharges are not allowed to increase the receiving water concentrations unless there is no adverse impact to affected beneficial uses.	TDS SSOs for specific reaches; any discharge (except agricultural) shall not cause TDS in surface waters to exceed annual average of 2000 mg/L or 4000 mg/L (waterbody dependent) and no discharge shall exceed 4,500 mg/L; SSOs applicable to the Salton Sea.	Apply only some of the Title 22 regulations

Table 4. Summary of Salinity-Related Objectives Adopted by California Regional Boards

Regional Board	Salinity-Related Constituents Explicitly Applicable to Entire Region				Narratives	Site-Specific Objectives	Other Considerations
	TDS	EC	Cl^-	SO_4			
Region 8	NA	NA	500 (Ground Water)	500 (Ground Water)	Groundwater - Hardness of receiving waters shall not be increased as a result of waste discharges to levels that adversely affect beneficial uses.	SSOs for TDS, hardness, chloride, sulfate, and sodium for selected inland waters, both surface water and groundwater	Groundwater – As a result of controllable factors, sodium shall not exceed 180 mg/L; boron shall not exceed 0.75 mg/L
Region 9	NA	NA	NA	NA	NA	SSOs for TDS, chloride, sulfate, % sodium, iron, manganese, boron for selected inland waters, both surface water and groundwater	Title 22 regulations applicable to MUN use

- Michigan regulations state that the addition of any dissolved solids shall not exceed concentrations which are or may become injurious to any designated use. Point sources containing dissolved solids shall be considered by the commission on a case-by-case basis and increases of dissolved solids in the waters of the state shall be limited through the application of best practicable control technology, except that in no instance shall total dissolved solids in the waters of the state exceed a concentration of 500 milligrams per liter as a monthly average nor more than 750 milligrams per liter at any time, as a result of controllable point sources.
- Mississippi and North Carolina regulations state that there shall be no substances added that will cause the TDS to exceed 500 mg/L in freshwater streams;
- New Jersey has a standard which prohibits an increase in background levels of TDS which may adversely affect the survival, growth or propagation of the aquatic biota or 500 mg/L, whichever is more stringent;
- New York has two standards based on the classification of the waterway. For A-Special (pristine waterways) the amount shall not exceed 200 mg/L and for other classes of potable waters it shall be kept as low as practicable to maintain the best usage of waters but in no case shall it exceed 500 mg/L;
- Oklahoma has a TDS narrative criterion stating that the waters will be maintained so as to be essentially free of substances of a persistent nature, from other than natural sources; and
- Utah set their TDS criteria at 1,200 mg/L although they have many site-specific salinity criteria because of the naturally high salinity levels in several parts of Utah. Site-specific salinity criteria range from 1,800 mg/L to 9,700 mg/L.

International Requirements

Westcot (2012) provides a summary of key international sources of MUN-related water quality standards (see Table 3 for jurisdictional comparison of MUN-related standards).

- *World Health Organization (WHO)* – Currently has no established guideline for TDS, based on a recent review that found no reliable data on health effects associated with water ingestion and TDS concentrations. Previously WHO provided the following guidance regarding elevated concentrations: TDS concentration below 1,000 mg/L is usually acceptable to consumers although acceptability may vary according to circumstances. In addition, WHO has not established guidelines for other salinity-related constituents for which EPA or California has established SMCLs or SDWS, respectively, including chloride and sulfate (see Table 3). The only relevant constituent of concern for which WHO has established a guideline is Boron, which is health-based.
- *Canada National Guidelines* – Canada has established guidelines of three types: (1) health-based standards listed as Maximum Acceptable Concentrations (MAC); and (2) Aesthetic

Considerations, which are listed as aesthetic objectives (AO), or operational considerations listed as Operational Guidance Values (OG). Table 3 provides a comparison between California and US federal requirements and Canadian guidelines. With the exception of boron, Canada has not established health-based standards for any salinity related constituents; other guidelines are based on aesthetic considerations.

- *Australia and New Zealand* – Australia/New Zealand jointly established national guidelines under the National Water Quality Management Strategy for ambient and drinking water. Salinity-related guidelines have been established for aesthetic reasons, not for any human-health-based concerns. Table 3 compares California and US federal requirements and Australia/New Zealand guidelines. Not shown in the table are Australia/New Zealand hardness guidelines. These guidelines provide a scale of < 60 mg/L $CaCO_3$ (soft but possibly corrosive) to > 500 mg/L $CaCO_3$ (severe scaling) with an optimum of 200 mg/L $CaCO_3$.

Salinity Effects on MUN-Related Uses

This section focuses on the effects of salinity-related constituents on (1) human health – through water consumption; and (2) other domestic, commercial and industrial uses of water.

Human Health – Water Consumption

Westcot (2012) the supplemental information developed for this memorandum show that human health concerns associated with salinity-related compounds are minimal. Concerns regarding these compounds are almost entirely related to aesthetic considerations. One key exception is boron. No federal MCL has been established for this constituent. However, although not regulated, California considers boron a contaminant of concern and has adopted a SDWS action level 1.0 mg/L. Exceedance of this level requires notification of the water users. The most important salinity-related constituents, e.g., those with SMCLS, including chloride, sulfate and TDS, are not known to be the cause of human health concerns. However, guidelines for these constituents, as well as other salinity-related compounds, are intended to address aesthetic considerations, including:

- *Odor and Taste* – Odor and taste of finished water varies with salinity levels and concentration of salinity related-ions. Examples include chloride, sulfate and TDS.
- *Color* – While increased color is often indicative of the amount of dissolved organic material, inorganic contaminants including TDS can be a potential cause of increased of color.

Table 5 summarizes health-related concerns associated with the most common salinity-related constituents as well as the other principal cations and anions included in this review. Some of these ions may cause some minor health effects at very high concentrations, but even at these high concentrations the effects are not toxic. For example, high levels of calcium and magnesium in water are believed to have a laxative effect. The information in Table 5 includes a compilation of information developed by Westcot (2012) (also see Attachment A) supplemented by other sources.

Table 5. Principal Salinity Related Cations and Anions

Constituent	Concentration in Natural Water (Todd 1980 unless otherwise noted)	Federal or State Standard[1]	Potential Health-Related Impacts	Other Potential Water Use Impacts (CASS 2003; Todd 1980)[3]
Bicarbonate (HCO_3^-)	Commonly less than 500 mg/L; may exceed 100 mg/L in water highly charged with carbon dioxide.	NA	Concentrations up to 700 mg/L of bicarbonate in drinking water considered harmless (McKee & Wolff 1963); concentrations of less than 150 mg/L recommended for domestic water use (Hibbard 1934).	Upon heating, bicarbonate is changed into steam, carbon dioxide, and carbonate (see carbonate below)
Boron (B)	Typically low in freshwaters (e.g., median of 0.01 mg/L in British Columbia waters; seawater averages 4.5 mg/L (Moss & Nagpal 2003).	1.0 mg/L[2]	Constituent has a long history of study (see Attachment A). The most recent drinking water guideline recommendation is 2.4 mg/L (WHO 2009a, 2009b, 2011). Canadian Guidelines are 5.0 mg/L.	None identified for domestic water uses. Primary concern is agricultural related.
Calcium (Ca^{2+})	Generally less than 100 mg/L; brine may contain as much 75,000 mg/L.	NA	Concentrations up to 1,800 mg/L of calcium in drinking water have been reported to be harmless. Hibbard (1934) recommended level in domestic water be less than 30 mg/L.	Calcium and magnesium combine with bicarbonate, carbonate, sulfate and silica to form heat retarding, pipe clogging scale in boilers and in other heat-exchange equipment. Calcium and magnesium combine with ions of fatty acid in soaps to form soap scum
Carbonate (CO_3^{2-})	Commonly less than 10 mg/L in groundwater. Water high in sodium may contain as much as 50 mg/L of carbonate.	NA	Not considered to be detrimental to public health	Upon heating, bicarbonate is changed into steam, carbon dioxide, and carbonate. The carbonate combines with alkaline earth – principally calcium and magnesium – to form crust like scale of calcium. Carbonate can retard flow of heat through pipe walls and restricts flow of fluids in pipes. Water containing large amounts of carbonate alkalinity is undesirable in many industries.
Chloride (Cl^-)	Commonly less than 10 mg/L in humid regions but up to 1,000 mg/L in more arid regions. About 19,300 mg/L in seawater; and as much as 200,000 mg/L in brine.	250 mg/L (SMCL, CA SDWS)	Generally not harmful to human beings until high concentrations reached, although chlorides may be injurious to some people suffering from diseases of the heart or kidneys. Restrictions based primarily on taste rather than on health, with a salty taste observed at concentrations as low as 100 mg/L. For average person, the taste threshold is 400 mg/L (McKee and Wolf 1963). WHO has not proposed a health-based guideline for chloride but note that concentrations above about 250 mg/L affect taste (e.g., WHO 2011).	Food processing industries usually require less than 250 mg/L. Some industries – textile processing, paper manufacturing, and synthetic rubber manufacturing – desire less than 100 mg/L.

Table 5. Principal Salinity Related Cations and Anions

Constituent	Concentration in Natural Water (Todd 1980 unless otherwise noted)	Federal or State Standard[1]	Potential Health-Related Impacts	Other Potential Water Use Impacts (CASS 2003; Todd 1980)[3]
Magnesium (Mg^{2+})	Generally less than 50 mg/L; ocean water contains more than 1,000 mg/L, and brine may contain as much as 57,000 mg/L.	NA	Considered relatively non-toxic and not a public health hazard because before toxic concentrations are reached, the taste is unpleasant (McKee and Wolf 1963). At elevated concentrations, magnesium is a strong laxative (Marier et al, 1979)	Magnesium combines with bicarbonate, carbonate, sulfate and silica to form heat retarding, pipe clogging scale in boilers and in other heat-exchange equipment. Magnesium combines with ions of fatty acid in soaps to form soap scum
Potassium (K^{+})	Generally less than about 10 mg/L; as much as 100 mg/L in hot springs; as much as 25,000 mg/L in brine.	NA	Potassium is an essential element for humans; seldom, if ever, found in at levels that could be a concern for human health; considered relatively non-toxic to man and not a public health hazard (e.g., WHO 2011).	More than 50 mg/L sodium and potassium in the presence of suspended solids causes foaming which accelerates scale formation and corrosion in boilers. Sodium and potassium carbonate in re-circulating cooling water can cause deterioration of wood cooling towers. More than 65 mg/L of sodium can cause problems in ice Manufacturing.
Sodium (Na^{-})	Generally less than 200 mg/L; about 10,000 mg/L in seawater; about 25,000 mg/L in brine.	NA	No firm conclusions drawn concerning possible association between sodium in drinking water and occurrence of hypertension; no WHO health-based guideline value proposed (e.g., WHO 2011). WHO does recognize that sodium may affect drinking water taste above about 200 mg/L.	
Sulfate (SO_4^{-})	Commonly less than 300 mg/L except in water supplies influenced by acid mine drainage. As much as 200,000 mg/L in some brine.	250 mg/L (SMCL, CA SDWS)	Taste threshold of about 250 mg/L; major physiological effect is diarrhea and in extreme cases, dehydration (Gutherie 1989). Water containing 600 mg/L of magnesium sulfate acts as a laxative (WHO 1996); however, sulfate is not toxic at this concentration (WHO 2003).	Sulfate combines with calcium to form an adherent, heat-retarding scale. More than 250 mg/L is objectionable in water in some industries.

Notes:
[1] NA – No applicable standards; MCL and SMCL – federal primary and secondary maximum contaminant levels, respectively; CA PDWS and CA SDWS – California primary and secondary drinking water standards, respectively
[2] – This value represents an action level; it has not been translated into a drinking water standard. If exceeded, requirement to notify water users.
[3] – The focus of this information is on water uses other than use of potable water for irrigation, e.g., golf course. However, these potential impacts are discussed below.

Other Domestic Uses of Drinking Water

There are numerous other uses of potable water that are residential, commercial, or industrial. Salinity-related effects for domestic uses other than drinking water generally fall into two key areas (also see Table 1):

- *Corrosivity/Staining* – Increased corrosivity or staining may affect the aesthetic quality of water and have significant impacts on water distribution system pipes and household fixtures. In addition, increased corrosivity can result in an objectionable metallic taste and cause a red or blue-green color to the water. Salinity-related constituents that relate to corrosion and staining include chloride and TDS.
- *Scaling/Sedimentation* - Scale is a mineral deposit which builds up on the insides of hot water pipes, boilers, and heat exchangers, restricting or even blocking water flow. Sediments are loose deposits in the distribution system or home plumbing. Both processes can have a significant impact on the life expectancy of mechanical devices.

Table 5 summarizes potential effects of most of the various salinity-related ions on other uses of water. For non-drinking water uses, this information primarily comes from Todd (1980), which was adapted and used by the Central Arizona Salinity Study (CASS 2003). Increased salinity can impact water use as described in the brief summary that follows (adapted from CASS 2003):

- *Residential* - Salinity reduces the useful life of household appliances, e.g., water heaters, evaporative coolers, faucets, garbage disposals, clothes washers and dishwashers. Homeowners also incur salinity "avoidance costs", e.g., buying bottled drinking water and installing water softening systems.

- *Commercial* - The commercial sector (schools, hospitals, retail stores, etc.) encounters impacts similar to homeowners with water-intensive operations bearing higher costs. Large commercial buildings commonly utilize cooling towers to provide air conditioning. Cooling towers operate by evaporating water using the same principle as evaporative coolers for individual homes, but employ a more sophisticated process in which the cooled water is passed through a heat exchanger to cool the air. As water evaporates it leaves behind salts, which inevitably accumulate in the remaining water. After a few cycles, depending on the source water, salinity and other factors, the water has to be discharged or the salts will precipitate out or scale on the copper tubing of the heat exchanger or the tower itself, reducing the efficiency of the system. High TDS water can be used through fewer cycles (than would be expected from low TDS water) before that water is discharged and freshwater or makeup water must be brought into the tower. The use of this additional water has an associated cost.

- *Golf Courses* – Many golf courses use reclaimed water for irrigation purposes. If this water has a salinity content of more than 1,000 mg/L TDS, it is more difficult to grow turf. The result can be additional costs to a golf course. The impacts are similar to what is seen in agricultural circumstances. High TDS tends to limit the ability of certain species of turf grasses to grow. Salt buildup in the root zone can become endemic and must be flushed with additional water. High-

TDS water also stains those facilities that receive any overspray. High sodium also causes clay soils to disperse, resulting in a relatively impermeable layer and poor subsequent infiltration. With aggressive maintenance regimens, golf course managers can maintain the greens and fairways but at a substantial increase in cost for chemicals and labor.

- *Industrial* - Some industries, such as food and beverage manufacturers and semiconductor manufacturing, require de-mineralized water, other industries require water softening. In such cases, relative costs are directly tied to the TDS content of the water received from potable systems. Cooling towers used in the industrial sector are usually larger and more robust than the commercial sector cooling towers, but have the same problems described above. Chemical suppliers publish a recommended maximum of six cycles, but data from Arizona shows that in practice the actual number of cycles is considerably lower, between 2.5 and 4.5, because of the high TDS. Corrosion in water and wastewater facilities is a concern and is primarily the result of elevated sulfides and chlorides. However, corrosion can be controlled at the water and wastewater facilities by using corrosion resistant construction materials such as stainless steel.

Attempts to estimate the economic cost of impacts of elevated salinity levels in potable water supplies have been previously made. Salinity impacts to infrastructure (e.g., pipes) and mechanical devices (e.g., appliances, plumbing fixtures) was the subject of several studies from the early 1970's to about 2000[3]. Ragan (2000) provides the following summary regarding these studies:

- Earliest studies of residential salinity damages were based on west and Midwest US community surveys [Black and Veatch Inc. 1967; Metcalf and Eddy, Inc. 1972, as summarized by Tihansky [1974] and d'Arge and Eubanks [1978]):
  - Black and Veatch conducted surveys of 38 communities in the Midwest. Water quality data were restricted to TDS. Estimates were made of the average lifetimes of galvanized water pipes, wastewater pipes, water heaters, faucets, toilet flushing mechanisms, garbage disposals, washing machines, and dishwashers. Water utility companies, plumbing contractors, and hardware and appliance dealers provided information for the survey. The lifetime for various fixtures was estimated as a function of TDS in the water at TDS levels of 250 mg/L and 1750 mg/L. Operation and maintenance (O&M) costs including repairs to infrastructure, soap and detergent purchases bottled water purchases and over-watering of lawns were also estimated. Costs/household were calculated but per the reviewer's opinion the usefulness of the results is low because of study characteristics, in particular only widely different TDS concentrations were evaluated, and the results are not easily extrapolated beyond the communities studied.
  - Metcalf and Eddy used a very different approach from Black and Veatch. Consumer interviews in 10 communities, primarily in the southwest, provided data that were supplemented by industry data. The study statistically tested various measures of water

[3] Note: for preparation of this memorandum, this study was the most recent found that attempts to relate salt concentration and economic cost.

quality for significance. The most important observed data relationships were (1) bottled water purchase versus TDS, softening costs and soap demand versus hardness, and the frequency of water heater replacement versus chloride levels. No significant effects were identified for lawn watering, clothing expenses and plumbing repairs. The reviewers noted that the findings contradict findings in other studies. Problems identified with study included costs were derived only in terms of hardness levels, interviews were conducted "primarily with housewives, most of whom lack awareness of damaging minerals other than hardness, which most recognize as affecting soap costs." Thus, cost estimates are biased towards hardness and omit other important water quality factors.

- Tihansky (1974) attempted to integrate the findings of previous efforts, including those described above and developed regression equations for the relationship between TDS and the expected life expectancies of washing appliances, garbage disposals, water heaters, water piping, wastewater piping, toilet facilities, sewage facilities, cooking utensils, and washable fabrics. O&M cost functions were also derived for all of the above except cooking utensils and washable fabrics. **Figure 1** provides two examples of the relationship between increasing TDS and water heater life expectancy and TDS and water heater O&M costs.

- d'Arge and Eubanks (1978) prepared "probably the most careful study of residential salinity damages" in a study conducted in collaboration with Bureau of Reclamation and a Colorado River Basin multi-university group. They surveyed appliance service and plumbing businesses in three locations in the Los Angeles Metropolitan area. Each location had different TDS levels in their water supply ranging from 210 mg/L (San Fernando Valley) to 728 mg/L (Costa Mesa-Newport Beach) and 457 to 759 mg/L (two locations in Long Beach). The life expectancy of appliances as related to salinity was measured. **Figure 2** shows a set of results from this paper. The paper summary states the study found a statistically significant difference in estimated mean lifetimes among locations. The Costa Mesa-Newport Beach area had a shorter estimated mean lifetime for dishwashers, washing machines, garbage disposals, brass faucets, water heaters, and galvanized pipes at the 10 percent level of significance. No significant difference was found for toilet flushing mechanisms, copper or plastic water pipes, or copper or cast iron wastewater pipes at that same level of significance.

- Lohman et al. (1988) updated and extended previous studies without collection of new primary data. Overall, estimated salinity damages (inflation-adjusted) were much higher than reported in previous studies. A primary cause of the elevated estimate was the inclusion of salinity effects on automobile radiators (an impact not previously evaluated in other studies). However, the reviewer notes that these estimates may have been inappropriate. It was assumed that all car owners only use local tap water in their automobiles. No data were gathered to verify this assumption; de-ionized water could have been used and potential costly damages avoided.

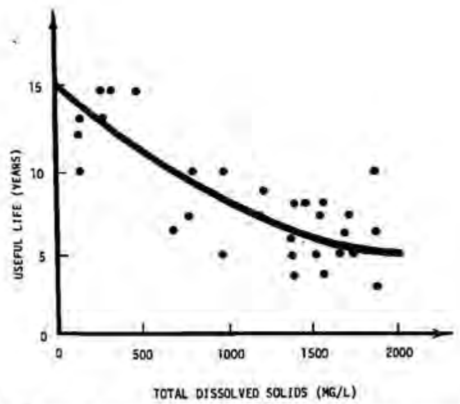

Fig. 1. Damage function for service life of water heater versus TDS levels.

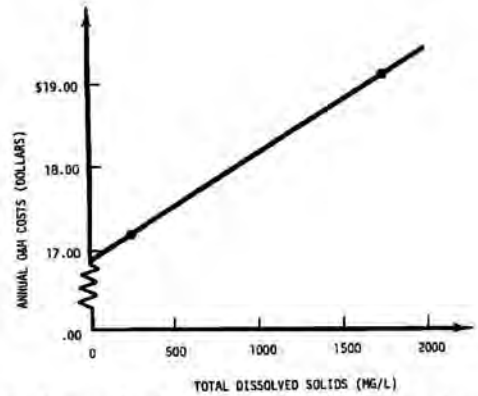

Fig. 2. Damage function for annual operation and maintenance costs of water heater versus TDS levels.

Figure 1. Example results from Tihansky (1974)

Table 4-2. Test for significantly different sample means.

	Estimated Mean Lifetime		
	San Fernando Valley (210 mg/l)	Costa Mesa-Newport Beach (728 mg/l)	Statistical Significance
Water Heater	8.74	5.22	Different at .005
Galvanized Wastewater Pipes	30.94	10.14	Different at .005
Galvanized Water Pipes	17.28	11.25	Different at .100
Toilet Flushing Mechanism	7.68	6.63	No difference
Copper Water Pipes	44.08	47.50	No difference
Plastic Water Pipes	48.33	60.00	No difference
Copper Wastewater Pipes	43.82	43.78	No difference
Plastic Wastewater Pipes	42.50	53.00	No difference
Dishwashers	9.60	6.50	Different at .005
Washers	8.50	7.38	Different at .100
Garbage Disposals	8.47	6.86	Different at .100
Brass Faucets	10.40	6.00	Different at .050

Figure 2. Example results from d'Arge and Eubanks (1978)

Ragan (2000) developed an improved method for evaluating economic impacts to avoid biases prevalent in previous studies. The location of the study was the Colorado portion of the Arkansas River Basin. TDS in tap water ranged (generally from upstream to downstream) as follows: Buena Vista, 91 mg/L; Leadville, 142 mg/L; Canon City, 158 mg/L; Florence, 279 mg/L; Salida, 258 mg/L; Pueblo, 319 mg/L; Pueblo West, 343 mg/L; St. Charles Mesa, 451 mg/L; Park Center, 957 mg/L; Rocky Ford, 988 mg/L; La Junta, 1253 mg/L; Lamar, 1440 mg/L; and Las Animas, 3,603 mg/L. Data were gathered for TDS, sulfate, chloride and hardness. The concentrations of these constituents were highly correlated; therefore, it was not possible to look at ion-specific impacts. All analyses relied on TDS as the measure of salinity.

Figure 3 illustrates the relationship between TDS concentration and the total excess annual cost ($/year) of appliance replacement per household (Ragan et al. 2000). Specific study findings included:

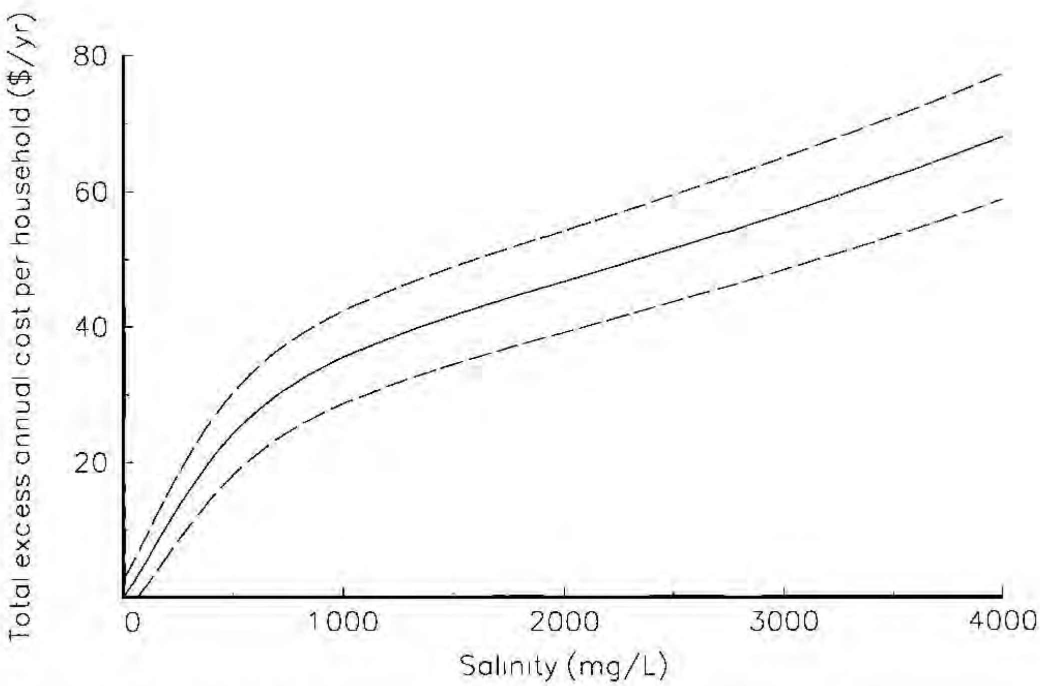

Figure 3. Total excess annual cost of appliance replacement per household.

Figure 3. Example results from Ragan (2000)

Evidence of statistically significant effects of salinity identified for five types of appliances: dishwashers, water heaters, food waste disposers, water softeners, and evaporative coolers; no statistically significant effects found for other appliances.

- Based on a reduction in TDS from 600 to 500 mg/L, results from the earlier literature, which are based on data from the 1960s and 1970s, suggest that the savings on appliance replacement costs (water heaters, clothes washers, and food-waste disposers) is more than three times greater than what was observed in this new study.

- Two factors may account for the observed differences between this study and past studies:
    - Inclusion of data on in-service appliances and use of methods appropriate to censored data (survey/statistical methods of previous studies ignored appliances that were still in use at the time of the survey), which may have led to previous overestimates of salinity damage;
    - Technological improvements in appliances have probably reduced the potential benefit from salinity reduction. For example, use of plastic and composite materials rather than metal for some appliance parts has likely reduced susceptibility to salinity damage.
- Continuing technological innovation and the gradual phasing out or retiring of old appliances is likely to result in a continued decline in observed adverse effects of salinity on household appliances.
- Study was not able to account for potentially disparate effects of various ions: "…it is possible that a similar study in a different basin, with a different mixture of ionic concentrations would yield significantly different results. In view of the large differences between our findings and those in the earlier literature, a similar study in another river basin, such as the Colorado, would be desirable to shed more light on the sources of the differences".

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Attachment A – Westcot (2012) – to be attached