Kennedy/Jenks Consultants

10850 Gold Center Drive, Suite 350
Rancho Cordova, California 95670
916-858-2700
FAX: 916-858-2754

and

Texas Agrilife Research
1229 North US Highway 281
Stephenville, Texas 76401

Salt and Nutrients: Literature Review for Stock Drinking Water

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San Joaquin Valley Drainage Authority
PO Box 2157
Los Banos, Ca 93635

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List of Abbreviations

AGR	Agricultural Beneficial Use
B	boron
BW	body weight
Ca	calcium
Cl	chloride
CO_3	carbonate
FAO	Food and Agriculture Organization of the United Nations
EC	Electrical Conductivity
HCO_3	bicarbonate
K	potassium
MCL	maximum contaminant limit
Mg	magnesium
mg/L	milligrams per liter
MTL	maximum tolerance limit
MUN	Municipal and Domestic Supply Beneficial Use
Na	sodium
NaCl	sodium chloride
NAS	National Academy of Science
NO_3-N	nitrate
NO_3	nitrate
NO_2	nitrite
NRC	National Research Council
NRWQC	National Recommended Water Quality Criteria
NWQMS	National Water Quality Management Strategy
P	phosphorous
PEM	polioencehalomalacia
ppm	parts per million (approximately equal to mg/L)
RWQCB	regional water quality control board
SAR	Sodium Adsorption Ratio
SO_4	sulfate
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
US EPA	United States Environmental Protection Agency
WHO	World Health Organization

Executive Summary

Salt and nutrient management is an important aspect in the Central Valley due to an increasing population and heavy agricultural components. With limited outlets for salt disposal, much of salt associated with imported water remains in the Central Valley. Nutrients associated with the large agricultural activity in the Central Valley tend to be more than the land or crops can assimilate. This results in increasing salt and nutrient quantities that then can potentially degrade the water quality of the region. To facilitate salt and nutrient planning in the region, Region 5 is charged with developing a salt and nutrient management plan by 2014 to comply with California's Recycled Water Policy. To accomplish this goal, Region 5 is evaluating water quality objectives for the various beneficial uses and developing ranges of water quality levels that ultimately will be translated into water quality objectives for a Basin Plan amendment.

The range of water quality objectives developed by this project will apply to the Central Valley for the beneficial use of stock drinking water supply as defined under Agricultural Beneficial Uses (AGR) in the Regional Water Quality Control Boards Basin Plans. The data and literature described in this report encompass the following constituents: total dissolved solids (TDS), specific conductance (EC), sodium (Na), chloride (Cl), sulfate (SO4), calcium (Ca), magnesium (Mg), hardness, Boron (B), nitrogen species and phosphorus species where the literature is available. This literature review's objective was to: 1) water quality criteria that could be used to establish water quality objectives and 2) existing water quality objectives, standards, goals, and policies that have been established to protect this beneficial use. The work was accomplished through literature and internet searches of university extension publications in California and other states, regulatory publications from the United States and other countries and an academic literature review.

A complete literature review was accomplished by following tasks as commissioned by the Central Valley Salinity Coalition and management of the San Joaquin Valley Drainage Authority. The tasks included 1) review of the numeric and narrative objectives or criteria of Basin Plans from the nine Regional Water Quality Control Boards (RWQCB); 2) an evaluation and summary of the various University Extension publications related to stock drinking water; 3) a review of the Federal documents used in developing water quality criteria for stock drinking water; 4) review international agencies water quality criteria, policies, and supporting documents; 5) provide an academic literature review of the most current science related to toxicity of salt and nutrient constituents in water on livestock and 6) summarize findings with recommendations that could be used as objectives.

High salt and nutrient levels in the water pose a health risk to livestock and could cause death at specific levels of exposure. Determining a water quality criteria for livestock and poultry depends on the amount of water consumed each day, the diet, and the weight of the animal to assess the levels of toxicity. Currently most agencies adopt objectives and criteria that include a safety factor to compensate for consumption and weight. However, the overall attitude at the state, federal, and international levels toward stock drinking water tend to follow that livestock are less sensitive to salt and nutrient toxicity as compared with other beneficial uses. None the less stock drinking water quality guidelines developed by various entities are used as the base to control stock drinking water quality. Of the nine Regional Water Quality Control Boards, only Region 2 has specific numeric criteria for stock drinking water quality whereas the remaining boards set objective through a narrative approach. Internationally, governing agencies provide water quality levels through guidelines and not specific numeric criteria.

Many of these objectives are based on publications from the National Academy of Science (NAS), the National Research Council (NRC), and Food and Agriculture Organization of the United Nations (FAO). However this report also presents new developments in the field of stock drinking water that expands on the information found in past publications. In terms of the individual salt and nutrient constituents in this report, safe levels for stock watering are higher than is currently required to protect other beneficial uses specifically human drinking water, aquatic life, and crop irrigation. However, nitrate and nitrite are equivalent to human drinking water standards since nitrate and nitrite have been shown to have adverse health effects on cattle above 100 mg/L and 10 mg/L, respectively.

Section 1: Regional Water Quality Control Board Basin Plans (RWQCB)

California manages water through nine Regional Water Quality Control Boards. Each board assigns water quality objectives and beneficial uses to the various waterbodies within the respective basins. The objectives of each Basin Plan (Plan) state that water quality of surface water and groundwater should not be degraded to prevent a beneficial use which includes stock watering. However, most Basin Plans do not specify stock watering for salt, nutrients or Boron with the exception of Region 2 and 3. All other regions that do have objective or guidelines for Agricultural Beneficial Uses (AGR) represent a general category that includes both irrigation and stock watering. Under the Basin Plans, the Agricultural Beneficial Use designation is defined as "Uses of water for farming, horticulture, or ranching, including, but not limited to, irrigation, stock watering, or support of vegetation for range grazing."

In the section below, the Basin Plans of the nine Regional Water Quality Control Boards were reviewed for salt, nutrient and Boron water quality objectives, criteria, or guidelines that specifically relate to stock drinking water. Since most of the Plans do not have specific numeric values for stock drinking water therefore the water quality objectives, criteria or guidelines for these constituents were reported in Table 1 below and specific AGR numeric values are reported when specified in the individual Plans.

Region 1 North Coast: Region 1 designates all inland and surface waters and groundwaters with the Agricultural Beneficial Use (AGR) designation and establishes objectives for electrical conductivity (EC), total dissolved solids (TDS) and Boron within each of the hydrologic regions. Table 1 shows the range for EC and TDS for the various hydrologic areas. The adopted range of salt objectives for Region 1 established an upper limit of 90% of the maximum levels of EC and TDS over a calendar year whereas the lower limit represents the 50% percentile of the monthly means for a calendar year.

Region 2 Bay Area: Region 2 is dominated by 1,100 square miles of estuaries and serves as the outflow for the Sacramento and San Joaquin Rivers via the Delta. Estuaries dominate the region and are not designated with an AGR beneficial use. A limited number of water bodies were designated as an AGR beneficial use and although the Basin Plan recognizes the distinction between livestock watering and irrigation, it does not establish separate criteria for each type of activity. However, the Basin plan does state that consideration be given to various factor including freely drunk water, the moisture content of the feed, and the irrigation water quality as it relates to the feed quality when establishing criteria.

Region 3 Central Coast: The Central Coast is characterized by lakes, streams, approximately 380 miles of coast line and heavily designated as Areas of Special Biological Significance. Due to the coastal location, groundwater supplies were recognized in the Basin Plan as susceptible to high TDS levels from salt water intrusion. Salt concentrations are critical in this region as agriculture and food processing are major industries. The Basin Plan does provide specific water quality guidelines for irrigation and agriculture for both surface and groundwater supplies but primarily focused to prevent any further degradation of the water sources. To control the potential sources of salt, the Plan provides irrigation guidelines for site specific assessments under which salt concentrations are controlled through the anti-degradation policy for irrigation waters. Although the Basin Plan distinguishes between irrigation water and livestock drinking water, only Boron has an established water quality objective that specifically relates to livestock drinking water with a level of 5.o mg/L. All other limits for salt and nutrients represent guidelines for use by the Water Board to determine site-specific objectives.

Region 4 Los Angeles: Although this region contains minimal agriculture, AGR designations are assigned to groundwaters. Salt and nutrient water quality objectives are extensive in this Plan but not specifically related to the AGR designation. No mention of stock drinking water occurs in this Plan most likely due to the dominate urban environment. However, the Basin Plan protects the AGR beneficial use with a broad policy stating that the water quality objectives should be applied such that the levels are protective of all beneficial uses.

Region 5 Central Valley: The Central Valley stretches from Kern County to the Oregon border. Within that region, several large urban areas occur between large agricultural regions. Crops and livestock as well as key waterways that support various biological species coexist. The Central Valley is divided into two plans the Sacramento-San Joaquin Basin Plan and the Tulare Lake Basin Plan. In the Sacramento- San Joaquin Basin Plan, Region 5 distinguishes the AGR beneficial use between irrigation and stock watering to the various water bodies, however, the water quality objectives apply to all beneficial uses assigned to the specific water body. The Delta region under the Sacramento-San Joaquin Basin Plan specifies agricultural water quality objectives by establishing EC levels for regions within the Delta. Under the Tulare Lake Plan, the established objectives for salts prevent the degradation of groundwaters.

Region 6 Lahontan: The Lahontan Basin Plan covers a wide range of microclimates from the Oregon border to the Mojave Desert including Lake Tahoe and Death Valley. The area is inland from the Central Valley and sees many extremes in terms of water resources. Water quality in the region is primarily impacted be non-point sources from mineral rich soils and rocks to livestock grazing activities. The Basin Plan simultaneously assigns AGR to all water bodies within the region and assigns site specific objectives for various constituents as shown in Table 1. AGR designations are not addressed specifically but included in the general water quality criteria for the region.

Region 7 Colorado River: Region 7 represents the inland areas including San Bernardino, San Diego and Riverside Counties. Agriculture is the largest beneficial use in the region particularly in the Coachella, Imperial, and Palo Verde Valleys. Although agriculture is a dominate characteristic of the region, salt and nutrient water quality objectives apply to all beneficial uses assigned to the water body and no specific mention of stock water is within the Plan.

Region 8 Santa Ana: Region 8 is a coastal basin with the Santa Ana River as the major water feature. The region is highly urbanized with little agriculture and is composed of coastal estuaries, inland surface waters and groundwater. With the exception of Big Bear Valley all groundwater has been designated with AGR beneficial uses while surface water have few AGR designation with the majority of this assignment occurring in the Upper Santa Ana River Basin surrounding Prado Dam. Water quality criteria in the table represent the numerical values for the various beneficial uses over the different reaches of the surface waters. The sodium absorption ratio (SAR) is the only numerical value linked to an AGR beneficial use as shown in Table 1. Although agriculture is recognized in the region no specific objectives are established specifically related to stock drinking water.

Region 9 San Diego: Region 9 encompasses all of San Diego County and portions of Orange and Riverside counties. The region is primarily urbanized with some high value crops such a nurseries however, livestock is generally not present. Most groundwater and surface waters have been designated with AGR but the water quality criteria for the Basin Plan are not specific to livestock or agriculture. The AGR beneficial use is generally protected through a statement establishing the water quality should be protective of this beneficial use.

Table 1: Salt, Nutrient, and Boron Objectives or Criteria from the Nine Regional Water Quality Control Board Basin Plans

Regional Board	Parameters	TDS (mg/L)	EC	B (mg/L)	Cl (mg/L)	NO_3 and nitrogen compounds (mg/L)	Phosphate (mg/L)	Na (mg/L)	SO_4 (mg/L)
Region 1	90% for TDS	115-275	150-2,000[a]	0.0-1.0[b]	-	-	-	-	-
	50% for TDS	75-170							
Region 2	Stock watering	10,000	0.2-0.3	5.0	-	100.0 (nitrate-nitrite)	-	-	-
	AGR	-	-	**2.0[d]**	**355.0[d]**	**30 (nitrate-nitrite)[d,j]**	**-**	**9.0 (SAR)[d,i]**	-
	Groundwater (Central Fringe basins)	Ambient or 500; Ambient or 1000	-	-	-	45	-	-	-
	Surface water	500[k]	-	-	250[k]	-	-	-	-
Region 3	AGR	-	-	**5.0[c,d]**	-	**100 (nitrate-nitrite)[d]**	-	-	-
	Groundwater	100-1500	-	0.1-2.8	50-430	1-10 (as N)	-	20-730	10-1025
	Surface water	150-1200	-	0.2-1	10-250	-	-	20-250	50-700
Region 4	Inland Surface	**450-2,000[d]**	-	**0.5-4.0[d]**	**100-355[d]**	45	-	**5-10 (SAR)[h]**	**350-600[d]**
	Groundwater	250-3,000	-	0.5-3.0	20-500	45	-	-	50-12000
Region 5 Sacramento and San Joaquin River	Bay- Delta AGR	-	0.45-2.78[l]	-	-	-	-	-	-
	Inland surface	100-125[m]	15-340[m]	0.8-1.0[n]	-	-	-	-	-
Region 5- Tulare Lake	Surface water	-	54-540	-	-	-	-	-	-
	Groundwater	-	Ambient + specified annual increase per site	-	-	-	-	-	-
Region 6		55-800	-	0.01-0.5[e]	= 836,820 x (lake volume in AF)$^{-0.98133}$	0.1-1.5 (NO_3)	0.01-3.75 (PO_4)	20-50%	0.4-100
Region 7	Various surface water	2,000-4,000[f]	-	-	-	10 (as N)	-	-	-
	Below Hoover Dam	723[g]							
	Below Parker Dam	747[g]							
	Imperial Dam	879[g]							

Region 8	Surface water	110-2,000	-	0.75	4-250	45 (as NO_3) or 10 (as N)	-	20-110 mg/L	10-310
	Groundwater	210-1,260	-	0.75	500	-	-	**9 (SAR)**[h]	500
Region 9	Surface water	300-2,100	-	0.75-1.0	50-500	-	0.1 or 0.025 (standing water)	60%	65-500
	Groundwater	500-3,500	-	0.75-2.0	60-800	5-45	-	60%	60-600

Indicates AGR specific designation for stock drinking water
Bold indicates AGR but not specific to stock drinking water
a. Specific conductance is measured at 77°F.
b. Represents levels for both groundwater and surface water.
c. Specifically relates to livestock drinking water.
d. Water Quality objective are specific to the AGR designation.
e. The average value of Boron permitted based on 3 samples at 3 different locations at any given time at Honey Lake. This number is not specifically related to AGR.
f. Annual average
g. Annual flow-weighted average
h. $SAR = \frac{Na}{[\frac{1}{2}(Ca + Mg)]^{1/2}}$
i. Based on "Guidelines for Interpretation of Water Quality for Agriculture" prepared by the University of California Cooperative Extension.
j. For sensitive crops, values are for NO_3-N +NH_4-N
k. Daily maximum
l. The range represents the limits throughout the year and the plan defines the limits for specific calendar dates.
m. Represents the 90th percentile
n. Monthly mean

Section 2: University Extension Water Quality Guidelines

2.1 University Extension

The top ten agricultural states were selected based on production statistics from the USDA however, not all of the top ten agricultural states published guidelines related to stock drinking water. As a result, the search expanded beyond the top ten agricultural states to and universities with strong agricultural state university extension programs. The extension programs included in this portion of the review include Colorado State University, University of Kentucky, University of California, Davis, University of Missouri, Ohio State University, Alabama Cooperative Extension, Texas Agricultural Extension, Iowa State University, Oklahoma Cooperative Extension, South Dakota State University, and North Dakota State University, University of Wyoming, and New Mexico State University.

Of the publications reviewed, information and numerical salt and nutrient guidelines were found related to dairy cattle, sheep, and poultry. The publications focused on TDS and nitrate levels but information was found on the various salt and nutrient constituents as well as Boron. The majority of the cooperative extension recommendations were based on the following publications National Academy of Science (NAS) (1972) National Research Council (NRC), (1974) and NRC (2001). Although these publications served as the basis for many of the recommendations, stock drinking water recommendations represent wide ranges of data for salt and nutrient constituents and only occasional consensus occurred when using data beyond the NAS and NRC publications. However, the most recent publications showed that higher levels of salt can be tolerated by livestock when compared with the numerical values currently used as guidelines in Basin Plans, NAS publication, and NRC publication.

2.1.1 TDS

Table 2 shows the increasing health effects and level of safety needed for stock drinking water at various TDS levels. It is widely recommended in University Extension publications that the absolute upper limit for cattle is considered 10,000 mg/L whereas poultry are much more sensitive to TDS with an upper limit of 3,000 - 5,000 mg/L with the safest level at <1,000 mg/L. Iowa University Extension Service (Lammers, et al., 2007) determined that 3,000 mg/L is a safe TDS level for swine production. Additional studies reported by University Extension publications showed that consumption of water with levels of 4,400 mg/L TDS by cattle showed no difference in milk production and levels of 6,000 mg/L TDS do not adversely affect feedlot cattle (Payne and Zhang, Accessed 2012).

2.2 Sodium

TDS includes sodium as a constituent however, when the TDS contains higher sodium percentages, sodium toxicosis occurs in some species particularly poultry. Toxicosis and death from high sodium percentage typically occur with inadequate water consumption resulting in dehydration. However, in most cases, higher sodium percentage levels in water tend to increase water consumption by livestock which allows most species to compensate for the loss of water resulting from diahrretic effects that high sodium may cause. Particularly in cattle, sodium levels greater than 800 mg/L result in a decrease in milk production (German et al., 2008).

Many University Extension publications concur that sodium alone is not the factor leading to the greatest health risks but sodium with complementary anions such as sulfates in water creates a condition that leads to increased health risk. In poultry, symptoms such as diarrhea are prevalent with higher sodium levels especially when sulfates are present (German et al., 2008). Table 3 summarizes the health effects of sodium on livestock and poultry based on the guidelines published in various University Extension literature.

Table 2: TDS and EC levels for Stock Drinking Water

TDS level (mg/L)	EC level (dS/m)	Livestock	Cattle	Poultry
<1,000	<1.5	No effects	No effects	No effects
1,000 to 2,999	1.5-5	No serious effect- may cause diarrhea	No serious effect- may cause diarrhea	No serious effect- watery droppings
3,000 to 4,999	5-8	Satisfactory water- may cause diarrhea	Satisfactory water- may cause diarrhea	Increased mortality and decreased growth- turkeys most sensitive
5,000 to 6,999	8-11	Reasonably safe for sheep, swine, and horses – Not safe for pregnant or lactating animals	Reasonably safe - Not safe for pregnant or lactating animals	Always causes health issues- not acceptable
7,000 to 10,000	11-16	Probably not fit for swine. Risk to pregnant and lactating horses and sheep. Risk to young and older species.	Risk to pregnant and lactating cows. Risk to young and old.	Unfit for poultry
>10,000	>16	Should not be used	Should not be used	Should not be used

Source: NRC, 2001

Table 3: Health Effects of Sodium in Stock Drinking Water Shown in Selected University Extension Service Bulletins

Sodium Level (mg/L)	Livestock	Cattle	Poultry
<50	-	-	Low risk
50-100	-	-	Diuretic effects. Affects performance with high sulfates and chlorides in the water. Detrimental to broiler gains
<800	Health risk when high sulfates are present in the water	Diarrhea and drop in milk production	-
Approximately 6,000	-	Reduction in body weight and some death	-
10,000-15,000 (NaCl)	Sheep neonatal mortality, decrease in feed intake, decreased body weight Swine show stiff nervous and decreased water intake	-	-
19,500	-	Disruption in Central Nervous System function	-

Sources: Blake and Hess, 2001; German, et al. 2008; Raisbeck, et al., 2008

2.3 Chloride

No data was found related to chloride and stock drinking water amongst the University Extension Services surveyed. Human studies are the primary source of information and the studies show that chloride is primarily an aesthetic issue and is associated with a salty taste in the water. However, a single study was cited which showed that at 5,000 mg/L of $CaCl_2$ cattle refused to drink water even though this water was its sole source. At 3,000 mg/L of $CaCl_2$ cattle showed an increase in consumption but no health effects were observed (Raisbeck, et.al., 2008).

2.4 Sulfates

Sulfates are cited amongst the various University Extension publications as producing laxative effects and interfering with mineral uptake amongst the various livestock species (Blake and Hess, 2001). Detrimental effects on poultry performance can occur at 50 mg/L while other livestock are less sensitive to sulfate in water. In swine, Iowa State University Extension Service cites 1,000 mg/L as the safe sulfate level (Lammers et al., 2007) while in cattle, an overall increase in sulfate from 400 to 4,700 mg/L shows an overall decline in daily gain and dry matter intake. In ruminants on grain diets, sulfates greater than 3,000 mg/L increased the risk of polioencehalomalacia (PEM -necrosis of specific regions of the brain). Studies also showed that 3,045 mg/L of sulfate reduced gains in calves and milk production while at 2,600 mg/L of sulfate no health affects occurred in cattle (German et al., 2008). Kentucky Extension recommends lower sulfate levels for calves with the maximum recommended sulfate not to exceed 500 mg/L sulfate or 167 mg/L sulfate-sulfur (as sulfur). For adult cattle the maximum recommended sulfate levels should not exceed 1,000 mg/L sulfate and 333 mg/L sulfate-sulfur (Higgins et al., 2008).

Table 4: Health Effects of Sulfate in Stock Drinking Water as Shown in Selected University Extension Service Bulletins

Sulfate Level (mg/L)	Livestock	Cattle	Poultry
<50	Safe	Safe	Safe for poultry[a]
<250	Safe may have laxative effect	Safe may have laxative effect	May reduce performance
<1,500	No harmful effect	No harmful effect	May reduce performance
1,500-2,500	No harmful effect; may reduce copper availability in ruminants; temporary diarrhea	No harmful effect; may reduce copper availability in ruminants; temporary diarrhea; calculation needed for total sulfur intake	May reduce performance
2,500-3,500	Very laxative: substantial reduction in copper availability	Very laxative: substantial reduction in copper availability; sporadic PEM	Not recommended especially for turkeys

Sulfate Level (mg/L)	Livestock	Cattle	Poultry
3,500- 4,500	Not recommended in lactating or pregnant ruminants or horses in confinement	Not recommended in lactating or pregnant cattle; Risk of PEM	Unacceptable for poultry
>4,500	Unacceptable under all conditions	Unacceptable under all conditions	Unacceptable under all conditions

Sources: German et al., 2008; Higgins et al., 2008

a. 50 mg/L represents the critical number where potential health risks begin.

2.5 Boron

Although there has not been significant research related to the effects of boron in stock drinking water, the University Extension publications reviewed all reported 5.0 mg/L boron as the maximum safe level for this constituent in drinking water. Boron in water is known to slow growth in livestock while levels between 150-300 mg/L cause edema and inflammation in cattle (Runyan et al., 2009).

2.6 Nitrate

High levels of nitrates attach to the heme group of red blood cells leading to asphyxiation in livestock which is a similar condition that occurs in humans called methemoglobinemia ("blue-baby syndrome"). Although methemoglobinemia is seen in livestock and is the most severe consequence of high nitrates, nitrate in water are tolerated by animals at higher levels as compared with humans. Yet, chronic exposure to nitrates results in milder symptoms including poor growth, infertility, reduced vitamin A absorption, and lower milk production. Swine and poultry which are monogastric tolerate higher levels of nitrate as compared with horses which have long cecums and ruminants such as cattle and sheep. In the anaerobic environment of the rumen and horse cecum, microbes convert nitrate to nitrite thus causing a higher nitrite exposure than would occur from direct consumption of water with nitrites. Nitrites for all species have higher toxicity than nitrates and are tolerated at much lower levels.

In determining the levels of nitrates in water, all University Extension publications concur that the nitrate in feedstock and water consumption rate must be taken into consideration. When a low nitrate level in water but high water consumption rate occur, nitrate toxicity for ruminants may result just as if there were high nitrates with a low consumption rate. Under the condition where low nitrates in water occur yet high nitrate feedstock, nitrate toxicity may also be observed in livestock. Therefore, the absolute upper limit considered safe for cattle is 300 mg/L of nitrate (Faries et al.,1998) while other University Extension publications suggest ranges of 221-660 mg/L and 100-300 mg/L would increase the risk of death in cattle. These ranges result from an uncertainty due to consumption rates of nitrates from feedstock and water. Table 5 shows the health effects of nitrates in water as shown in various extension service bulletins.

Table 5: Health Effects of Nitrate in Stock Drinking Water as Shown in Selected University Extension Service Bulletins

Nitrate (NO_3)[a] Level (mg/L)	Nitrate-Nitrogen[b] (NO_3-N) (mg/L)	Livestock	Cattle	Poultry
<44	0-10	Safe	Safe	Safe
45-132	11-20	Safe with low nitrate feeds	Safe with low nitrate feeds	Safe
133-220	21-40	Harmful with long periods of exposure	Harmful with long periods of exposure	-
<440	<100	Safe	Safe	Safe
221-660	41-100	-	Risk of death	-
440-1,300	100-300	Safe with low nitrate feeds	Safe with low nitrate feeds	Safe
500	-	-	Safe with low nitrate feeds	-
>661	>101	-	Unsafe for consumption	-
>1,300	>300	Avoid due to nitrate contribution to total salt content for swine. Nitrate poisoning for ruminants and horses.	Nitrate poisoning	Avoid due to nitrate contribution to total salt content

Sources: Faries et al., 1998; Higgins et al., 2008; German et al., 2008; Raisbeck, et al., 2008

a. NO_3 at 45 mg/L is equivalent to 10 mg/L Nitrate as N.
b. 1 mg/L nitrate-nitrogen (NO_3-N) equivalent to 4.4 mg/L nitrate (NO_3)

2.7 Hardness

Hardness measures the concentration of divalent cations in water expressed as the sum of magnesium and calcium concentrations in equivalents of calcium carbonate. The levels of magnesium and calcium do not to have direct health affects in livestock but high hardness levels impact the absorption of other key nutrients (German et al., 2008; Higgins et al., 2008). Reduced absorption of copper, zinc and selenium occurs with high hardness levels in water. Karst (limestone rich) regions contain high hardness levels and magnesium and calcium levels should be considered in association with the nutrition. For example, a safe level for calcium in swine is 1,000 mg/L (Lammers et al., 2007). Most University Extension bulletins recommend greater consideration toward the divalent anions in the water which can form compounds with the magnesium and calcium cations thus resulting in laxative compounds such as magnesium sulfate. These compounds tend to have the greater health effect on the livestock and poultry. Poultry suffer wet dropping with higher levels of magnesium sulfate in the water and the sulfate association with the cation is the cause of the wet dropping not the magnesium by itself. However, no data related to the compound formed and health effects on livestock were found. Hardness guidelines are provided below in Table 6 to assess when high levels occur.

Table 6: Water Hardness Guidelines

Hardness (mg/L)	Description
0-60	Soft
61-120	Moderately hard
121-180	Hard
181-350	Very hard
>350	Brackish

Section 3: Federal and State Agency Water Quality Criteria

3.1 Federal

Under the Clean Water Act, the US Environmental Protection Agency (US EPA) has published National Recommended Water Quality Criteria (NRWQC). The first publication occurred in 1968 followed by updates in 1972, 1976, and 1986 which were referred to as the Green, Blue, Red, and Gold books, respectively (US EPA 1986, 1973, 1976 and 1986). These publications contain the water quality criteria and supporting evidence for those criteria. Subsequent updates in 2002, 2003, and 2009 add additional criteria specific for freshwater, saltwater or human health protection and generally refer to the "Gold" book (US EPA, 1986) for other criteria not updated. A summary of the water quality criteria of interest is shown in Table 7 along with the most critical beneficial use as identified in the Gold book associated with a particular salt or nutrient. None of the salt and nutrient criteria identified livestock or wildlife drinking water as the reason for the prescribed critical limit. The limited attention from the USEPA regarding stock drinking water results from a general acceptance that other beneficial uses are more sensitive to salt and nutrient constituents in water as compared to livestock. However, boron and TDS are discussed as related to stock drinking water but no specific numeric criteria were assigned. The NRWQC discussion on boron included a cited a study performed on dairy cattle that showed no health effects occurred with exposures of 16-20 g/day of boric acid over a 40-day period. TDS limits were supported by studies where exposures of up to 15,000 mg/L of TDS showed no health effects on chickens, swine, cattle and sheep. However, additional citations showed that the limit depended on the type of salt ions present; thus with a composition of sodium and calcium carbonate the upper limit for livestock was recommended to be reduced to 5,000 mg/L. These references supported the premise that stock drinking water is not the most sensitive beneficial use and did not require specific numeric limits.

Table 7: National Recommended Water Quality Criteria for Salts and Nutrients

Parameter	Criteria (mg/L)	Target beneficial use	Source
Boron	0.75	Agriculture- crops	Gold Book
Chloride	250	Domestic water supply	53 FR 19028
Hardness[a]	120 (textile) 5,000 (electric company)	Industrial uses	Gold Book
Nitrate		Domestic water supply	Gold Book
Phosphate-Phosphorus	50 µg/L 25 µg/L	Stream Reservoir	Gold Book
Sulfate	250	Domestic water supply	Gold Book
TDS	500	Domestic water supply	Gold Book

a. $CaCO_3$

3.2 States

3.2.1 Colorado

The State of Colorado controls water quality standards through the Department of Public Health and Environment. Water quality criteria associated with the agricultural beneficial use are evaluated based on the most sensitive agricultural use. For example, livestock tolerate higher levels of boron yet the water quality criteria was based on boron sensitive crops thus the maximum boron level for groundwater under Regulation 41 currently stands at 0.75 mg/L. The series of regulations established for Colorado do not specifically associate livestock drinking water with specific criteria rather the criteria tend to be generalized for each basin to cover all beneficial uses (Table 8). The assumption made for each basin was that the water quality limits represent a level that is protective of all beneficial uses for all reaches of the rivers and streams and not just stock drinking water.

Table 9 represents the TDS guidelines and established criteria for TDS in groundwater as promulgated in Regulation 41. The guidelines represent a scale that is based on the background TDS in each of the groundwater basins. As mentioned previously Colorado does not direct their standards toward stock drinking water but toward the most sensitive use within the basins. In addition to Regulation 41, Regulation 39 provides narrative guidance for surface water TDS limits. The State of Colorado participates in the Colorado River Basin Salinity Control Forum. Although much of the water quality is heavily managed downstream of the Colorado tributaries, Colorado represents the upper most reaches of the Colorado River Basin. Under Regulation 39, Colorado states that no activities in these upper reaches will permanently degrade downstream salinity limits as prescribed by Federal limits:

- Below Hoover Dam 723 mg/L
- Below Parker Dam 747 mg/L
- At Imperial Dam 849 mg/L

Table 8: Colorado Water Quality Criteria for Salt and Nutrients

Parameter	Water type	Limit (mg/L)
Boron	Groundwater and Surface water	0.75
Chloride	Groundwater and Surface water	250
Nitrate-nitrite	Groundwater and Surface water	100
Nitrite	Groundwater	10
	Surface water	5
Sulfate	Groundwater and Surface water	250

Table 9: Colorado Water Quality Guidelines for TDS

Water Type	Description	Maximum TDS level (mg/L)
Groundwater	0-500 mg/L background TDS	400 mg/L or 1.25 times background whichever is least restrictive
	501-10,000 mg/L background TDS	1.25 times the background
	10,001 or greater mg/L background TDS	No limit

3.2.2 Nebraska

The Nebraska Department of Environmental Quality established water quality standards under Title 117 for surface waters and Title 118 for groundwaters. The standards are based on the most sensitive beneficial use associated with the waterbody. In general the criteria are applied to all water bodies in the State with some site specific objectives when necessary. The groundwater criteria for the State below represent general salt and nutrient criteria but are not specific to stock drinking water:

- Nitrate+nitrite as N = 10 mg/L
- Nitrite as N= 1 mg/L
- TDS = 500 mg/L
- Chloride = 250 mg/L
- Sulfate = 250 mg/L

For agricultural beneficial uses, the Department divides surface water criteria into two classifications with Class A representing irrigation and livestock watering and Class B representing waters with background constituent levels that limit the use by Class A activities. Class A water's standards are not to exceed 2,000 µmhos/cm for conductivity and not to exceed nitrate-nitrite at 100 mg/L between April 1 and September 30. Criteria were not assigned to Class B waters under Title 117 for the protection of agricultural beneficial uses.

3.2.3 Texas

The State of Texas regulates water standards under Rule 307. Agricultural beneficial uses are recognized within the state however, it is only domestic, recreational, and aquatic life beneficial uses that receive specific water quality criteria. In general under Rule 307, nutrients levels should occur such that no excessive growth of vegetation occurs. For salinity, the levels should not degrade the water quality such that it precludes a beneficial use.

3.2.4 Missouri

The Department of Natural Resources in the State of Missouri promulgates the water quality criteria for the State. Although stock watering is recognized as a beneficial use, the majority of the criteria focus on aquatic life, drinking water, human health, and groundwater. The Clean Water Commission within the Department established that "no acute toxicity" should occur to livestock due to water quality conditions. The better statement is that the state has not set any numeric criteria for protecting livestock watering and wildlife for the constituents of interest. It should be noted that the State of Missouri has no TDS water quality criteria but other numeric criteria for salt and nutrient constituents are found in Chapter 7 of the code as follows:

- Boron = 2 mg/L (irrigation and groundwater)
- Chloride= 250 mg/L (drinking water)
- Sulfate = 250 mg/L (drinking water)
- Nitrate-N = 10 mg/L (drinking water and groundwater)

3.2.5 Arizona

The Department of Environmental Quality controls the water quality standards for the State of Arizona. Narrative criterion states that the water quality must not be toxic to animals but the State has not set any numeric criteria specific to stock drinking water for the constituents of interest in this review. Nutrient levels are established based on domestic use and aquatic life and those criteria ranges are as follows:

- Total Phosphorous = 50-160 µg/L for lakes and reservoirs
- Total Nitrogen = 1.0-1.9 mg/L for lakes and reservoirs
- TKN = 0.7 – 1.6 mg/L for lakes and reservoirs.
- Nitrate = 10,000 µg/L drinking water standard

3.2.6 South Dakota

Under the Administrative Rules of South Dakota, the Department of Environment and Natural Resources established surface water quality standards. Administrative Rule 74:51:01:52 set the criteria for stock watering but also includes the beneficial uses of fish and wildlife propagation, and recreation. For TDS, ≤2,500 mg/L for a 30-day average or ≤4,375 mg/L daily maximum is allowed in surface water while the 30 day average for conductivity at 25°C is ≤4,000 µmhosµ/cm and ≤7,000 µmhos for a daily maximum. Only NO_3 as N was listed for nutrients for which a permitted level of ≤50 mg/L for a 30-day average or ≤88 mg/L daily maximum is listed. South Dakota classifies its groundwaters by TDS. All groundwaters with a TDS of <10,000 mg/L are subject to the following salt and nutrient criteria unless the ambient concentration falls below the criteria.

- Chloride = 250 mg/L
- Nitrate = 10 mg/L
- Nitrite = 1 mg/L
- Sulfate = 250 mg/L
- TDS = 1,000 mg/L

3.2.7 Nevada

Administrative code NAC 445A.122 sets the water quality standards for the State of Nevada and designates numeric criteria specifically for the beneficial use of stock watering. Maximum stock watering levels for boron were set at 5.0 mg/L while chloride water quality levels are set at ≤250 mg/L and ≤250 mg/L sulfate. Nitrate diverges from the standards set by many states using water quality levels of NO_3 as N at ≤90 mg/L and nitrite as at N ≤5.0 mg/L. As stated in the code, nitrate within state waters must not come from any source other than a natural source of nitrogen. Depending on the water body, TDS water quality levels are assigned either a criteria of 1) ≤500 mg/L or the 95th percentile (whichever is less) or 2) ≤1,000 mg/L.

Section 4: International Water Quality Criteria

4.1 International

4.1.1 Food and Agriculture Organization of the United Nations

The Food and Agriculture Organization of the United Nations (FAO) provides guidelines that are based on work done by the National Academy of Science in 1972 and 1974. The published FAO guidelines provide many conditions for animal drinking water salinity and nutrient levels (Ayers and Westcot, 1986). The FAO recommends that the age, feed, water source type (groundwater vs. surface water), seasonal changes (hot temperatures, evaporation etc.), and species be considered when determining the appropriate water quality levels. Each of these factors either contributes or influences the salt and nutrient concentrations in water throughout the year thus may affect the condition or health of the particular species. In addition to mere exposure to salts, animal behavior also drives the consumption of saline waters. The FAO states that gradual increases in exposure to saline waters allows the livestock to tolerate the exposure, however, the saline waters may also cause a decrease or increase in water consumption. Therefore, animal behavior must be observed when water quality changes occur.

Table 10 is based on the work from the National Academy of Science which serves as the criteria for many of the international and university extension guidelines that have adopted criteria for the beneficial use of stock drinking water. Table 11 represents additional water quality parameters in which magnesium was given particular attention by FAO. Magnesium levels recommended were based on a 1969 publication from Australia (AWRC, 1969) and magnesium was given particular attention due to negative health effects in livestock. However, more recent publications specifically from the University Extension services have documented that the effect of magnesium results from magnesium sulfate and other compounds when high sulfates are present in the water.

Table 10: Water Quality Guide For Livestock and Poultry Uses[a]

Water Salinity (EC) (dS/m)	Rating	Remarks
<1.5	Excellent	Usable for all classes of livestock and poultry.
1.5 – 5.0	Very Satisfactory	Usable for all classes of livestock and poultry. May cause temporary diarrhea in livestock not accustomed to such water; watery droppings in poultry.
5.0 – 8.0	Satisfactory for Livestock	May cause temporary diarrhea or be refused at first by animals not accustomed to such water.
	Unfit for Poultry	Often causes watery feces, increased mortality and decreased growth, especially in turkeys.
8.0 – 11.0	Limited Use for Livestock	Usable with reasonable safety for dairy and beef cattle, sheep, swine and horses. Avoid use for pregnant or lactating animals.
	Unfit for Poultry	Not acceptable for poultry.
11.0 – 16.0	Very Limited Use	Unfit for poultry and probably unfit for swine. Considerable risk in using for pregnant or lactating cows, horses or sheep, or for the young of these species. In general, use should be avoided although older ruminants, horses, poultry and swine may subsist on waters such as these under certain conditions.
>16.0	Not Recommended	Risks with such highly saline water are so great that it cannot be recommended for use under any conditions.

a. Table from Water Quality for Agriculture – Food and Agriculture Organization of the United Nations (Ayers and Westcot, 1985)

Table 11: Water Quality Guidelines for Additional Salt and Nutrient Parameters[a]

Parameter	Species	Maximum level (mg/L)
Boron	All	5.0
Magnesium	Poultry and swine	<250
	Horses, lactating cows, ewes with lambs	250
	Beef cattle	400
	Adult sheep on dry feed	500
Nitrate+nitrite	All	100.0
Nitrite	All	10.0

a. From AWRC, 1969 as cited in Water Quality for Agriculture – Food and Agriculture Organization of the United Nations (Ayers and Westcot, 1986)

4.1.2 Canada

In 1987, Canada established a task force to determine the drinking water quality for livestock which remains the water quality levels currently used by the various provinces. The task force established two sets of criteria; one set represented the water quality that is protective of animal health and the second set represents guidelines for the use of sub-optimal water quality for livestock. Sub-optimal guidelines for TDS water quality were obtained from the FAO publication as shown in Table 10. For TDS, the Canadian Water Quality Task Force determined that any water with a TDS of less than 1,000 mg/L is safe for all classes of livestock. The Canadian Plan Service evaluated TDS levels for poultry and reported higher levels of tolerance for three classifications of poultry. Safe levels for young turkey poults were reported at <1,500 mg/L while safe levels for young and mature poultry were 3,000 and 4,000 mg/L TDS, respectively.

Magnesium and sodium alone were classified as having no health risk to the animals but when other constituents in the water specifically sulfate, a laxative effect could occur. Although a maximum of 1,000 mg/L of sulfate was considered safe, the task force recognized that sulfate may result in a detrimental effect in livestock based on the weight and age of the animal. Sulfate levels of 1,000 – 1,500 mg/L results in chronic diarrhea in weanling pigs and >2,000 mg/L causes a drop in milk production in cattle. In terms of aesthetics, sulfate levels at 150 mg/L potentially may cause a drop in water consumption for livestock due to taste. Table 12 represents the adopted guidelines base on the cited research (Canadian Plan Service, 2001).

Table 12: Canadian Water Quality Guidelines for Livestock As Defined in Canadian Plan Service (2001)

Parameter	Livestock Maximum Recommended Limit (mg/L)	Poultry Recommended Limits (mg/L)	Horses Recommended Limits (mg/L)	Additional information
Boron	5	-	-	-
Calcium	1,000	600	500	-
Chloride	-	250	3,000	-
Hardness	-	180	200	Poultry levels
Magnesium	300-400	125	125	Based on other constituents in water
Nitrate and nitrite	100	25	400	For horses 400 mg/L nitrate
Nitrite alone	10	4	10	For swine maximum level 750 mg/L
Sodium	800	50	2,500	Based on other constituents in water specifically sulfate of chloride
Sulfate	1,000	250	2,500	-
TDS	3,000	1,500 - 4,000	6,500	-

a. Sodium compounds specifically sodium sulfate or sodium chloride may result in a lower tolerance to sodium in some species.

4.1.3 Australia

Australia and New Zealand establish their water quality guidelines at the federal level through the Department of Sustainability, Environment, Water, Population, and Communities. The guidelines provide the state and local levels of government with a roadmap for planning within the individual regions. As Australia contains a great diversity of landscapes and climate patterns the Department recognizes that the best management of water quality issues will be with the stakeholders at the local level. The National Water Quality Management Strategy (NWQMS) is a federal document that lays out the regulatory structure of two nations. NWQMS identifies three dominate beneficial uses which include ecosystems, primary industries and human health with livestock drinking water as a sub set of the primary industries. The guidelines were based on observed data which included several factors such as animal weight, water intake, and a safety factor. The water quality guidelines developed by Australia and New Zealand are found below in Table 13 while TDS guidelines are provided in Table 14 and represent recommended levels with no health risks (ANZECC/ARMCANZ, 2000).

Table 13: Australia and New Zealand Water Quality Guidelines for Livestock Drinking Water as Established Under the National Water Quality Management Strategy (NWQMS) (ANZECC/ARMCANZ, 2000)

Parameter	Livestock Maximum Recommended Limit (mg/L)	Additional information
Boron	5	Can be tolerated at higher levels for a short period of time
Calcium	1,000	
Chloride	-	
Hardness	-	
Magnesium	None	No level has been determined to date
Nitrate	400	Based on nitrate levels in feed stocks
Nitrite alone	30	
Sodium	-	
Sulfate	1,000	

Table 14: Australia and New Zealand TDS Guidelines for Various Livestock as Established Under the National Water Quality Management Strategy (NWQMS) (ANZECC/ARMCANZ, 2000)

Livestock type	No adverse health effect (mg/L)	No adverse health effect; adaptation required (mg/L)
Beef Cattle	<4,000	4,000 - 5,000
Dairy	<2,400	2,400 – 4,000
Sheep	<4,000	4,000 – 10,000
Horses	<4,000	4,000 – 6,000
Pigs	<4,000	4,000 - 6,000
Poultry	<2,000	2,000 - 3,000

Source: ANZECC/ARMCANZ, 2000

4.1.4 South Africa

The Department of Water Affairs and Forestry established the federal water quality guidelines for livestock drinking water for South Africa. South Africa selects the levels based on several factors including water up take, animal weight and synergistic effects when measurable. The level prescribed in the guidelines should have no adverse health effect on the beneficial use. The target water quality range represents where no adverse health effect occurs for any class of livestock. Within the guidelines, the chloride target level was set based on poultry being the most sensitive with adverse health effects at chloride levels greater than 1,500 mg/L. Other livestock such as cattle, sheep, and other ruminants, the target water quality can reach up to 3,000 mg/L before obtaining an adverse health effect.

Nitrate levels are based on two factors: ruminant vs. monogastric and pregnant and not pregnant. The target level set in the guidelines does not cause an adverse health effect in any category however, higher levels of nitrate can be tolerated by all livestock with the exception of pregnant monogastric species. Between 100 and 200 mg/L nitrate, adverse health effects may be observed in pregnant monogastric livestock and mild health effects in non-pregnant monogastrics.

TDS guidelines do not provide a specific recommended level however, a table is provided to determine whether a class of livestock is susceptible to a specific concentration. In most cases large livestock can tolerate higher levels of TDS in water thus reflected in the guidelines. The guidelines recognize that the amount of TDS exposure to a particular species of livestock also depends on the TDS present in the feed. With low TDS feed stock and higher level of TDS water can be tolerated and vice versa. Table 15 represents the salt and nutrient levels for stock drinking water in South Africa.

Table 15: South Africa Water Quality Guidelines for Livestock Drinking Water

Parameter	Target Water Quality (mg/L)	Additional information
Boron	< 5	
Calcium	<1,000	Ruminants may handle higher levels
Chloride	<1,500	Poultry most sensitive
Hardness	NA	
Magnesium	<500	
Nitrate (NO_3)	<100	Other livestock tolerate higher levels
Nitrite	NA	
Sodium	<2,000	>2,000 mg/L mild health effects in cattle and sheep; severe health effects in other livestock
Sulfate	<1,000	Young livestock less tolerant
TDS	<1,000	No health effect all livestock
	1,000 – 2,000	Effects on dairy pig and poultry
	2,000 – 3,000	Effects on beef, horses, dairy, pigs and poultry
	3,000 – 4,000	Effects on sheep, beef, horses, dairy, pigs and poultry
	>4,000	Health effects increase as the concentration increases
	>13,000	Extreme caution should be taken

Source: Republic of South Africa, Department of Water Affairs and Forestry

Section 5: Academic Literature Review

This section represents a review of water quality criteria available in peer reviewed articles. The articles included in the reference list represent the literature cited in this section and a list of all documents considered. The primary task involved an extensive literature search of peer reviewed literature. Peer review literature being defined as animal nutrition textbooks and National Research Council reports (publications of the National Academy of Sciences) related to animal dietary requirements. The intent being to identify existing scientific information available to develop criteria for livestock and poultry drinking water quality for identified constituents of concern. The focus is on dissolved mineral constituents and include: Total Dissolved Solids (TDS), Specific Conductance (EC), Sodium (Na), Chloride (Cl), Sulfate (SO_4), Calcium (Ca), Magnesium (Mg), the trace element Boron (B), Nitrogen species (total, total Kjeldahl, organic, nitrate, nitrite, and ammonia) and Phosphorus species (both total and dissolved). The literature reviews used two previous works competed by the Central Valley Regional Water Quality Board as the starting point for the literature review. The two completed reviews include: Salinity: A Literature Summary for Developing Water Quality Objectives (Davis, 2000) and Boron: A Literature Summary for Developing Water Quality Objectives (Davis, 1999). The primary animal species being addressed includes cattle, dairy cattle, sheep and goats, swine, poultry (broilers, layers, turkeys) and horses. For the purposes of this review, toxicity is defined as the lowest level in animal drinking water that produced a measurable effect on health and/or production.

Texas A&M AgriLife Research and Tarleton State University utilized a current graduate student to conduct the search under the mentoring of a former head of the Department of Animal Science in the College of Agricultural and Environmental Science and a senior research scientist with AgriLife Research. The combination of both organizations provides local access to the library of Tarleton State University and online access to the resources in the library at Texas A&M University. Both library systems provide extensive search capabilities with recognized peer review journals not commonly available through a simple web search. The literature review also benefited from information previously collected as part of the Phase I Beneficial Use and Objective Study and other work performed in the Central Valley related to permitting. A table of findings is included in this report to illustrate the extent of data located and where the gaps exist in the peer reviewed literature. Consideration was also given to the difference in tolerances between dairy and beef cattle, poultry species as well as between young and adult animals.

This section is broken into four major sections: salinity, salt ions, boron, and nutrients. The salinity section will define many of the terms commonly associated with water quality and the measurements commonly used to address water quality criteria as it relates to livestock and poultry operations. The salts ion section will be subdivided into major anions (chlorides and sulfates), major cations (sodium, calcium, and magnesium) and a discussion on combinations of anions and cations. Boron will be addressed by independently representing a mineral group. The final section entitled Nutrients will be subdivided into nitrogen and phosphorus although most sources are thought of as being natural. The summary section will conclude the literature review and be presented as a table. The table will illustrate the current Industry – accepted Standards, the information found in the literature review, and address the gaps existing which might benefit from further research.

5.1 Salinity

Total dissolved solids (TDS) refers to the total amount of all inorganic and organic substances such as minerals, salts, metals, cations or anions that are dispersed within a volume of water. By definition, the solids must be small enough to be filtered through a 2 micron (micrometers) sieve. The concentrations are equal to the sum of positively charged ions (cations) and negatively charged ions (anions) in the water. The amount of TDS in a water sample is measured by filtering the sample through a 2.0 μm pore size filter, evaporating the remaining filtrate and then drying what is left to a constant weight at 180^{O}C. TDS is becoming less important to states developing Water Quality Criteria for Livestock (Raisbeck et al., 2008; Iowa DNR, 2009).

Electrical Conductivity (EC) measurements provide an indication of the total salts in water with conversion factors defining the relationship with TDS levels. EC is a measure of the ability of water to pass an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, bicarbonate, carbonate, nitrate, sulfate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, potassium, iron, and aluminum cations (ions that carry a positive charge). Conductivity is also affected by temperature: the warmer the water, the higher the conductivity. For this reason, EC is reported as conductivity at 25 degrees Celsius (25 °C). Conductivity is also affected by the presence of organics in the water as they also conduct electricity however natural or unpolluted waters rarely contain significant quantities of organics and are normally ignored in research literature. Specific EC values for livestock tolerance are not often found in research literature. Rather they are usually obtained by dividing the ppm or mg/L TDS value by 0.64 (multipliers in the literature range from 0.60 to 0.67) to provide a relative measure of salinity in μmhos/cm.

Both the United States and Canada have developed guidelines for water quality criteria related to saline waters and livestock watering. The Canadian Task Force on Water Quality (Canada, 1987) published both a Summary and Guide to Use of Saline Water for Livestock Watering. The guideline value for TDS was set at 3,000 mg/l. The National Research Council (NRC, 1974) published a guide as well that stated "if the TDS is between 1,000 – 2,999 mg/l, the waters should be satisfactory for all classes of livestock and poultry. They may cause temporary and mild diarrhea in livestock not accustomed to them or water droppings in poultry, but should not affect their health or performance" (Ayers and Westcott, 1994). The consensus in the literature suggest that while TDS may still be relied upon in the absence of any other information, levels less than 500 mg/l (USEPA, 1986) should ensure safety from almost all inorganic constituents. Above 500 mg/l, the individual constituents contributing to TDS should be identified, quantified and evaluated.

In general, a TDS less than 1,000 mg/L is suitable for most all livestock (NRC, 1974) while levels higher than 10,000 are not recommended for any livestock uses under any conditions. Many different studies have reported the effect of TDS on livestock productivity. Among ruminant animals, dairy cattle are the most sensitive to TDS (Olkowski, 2009). Several authors have reported that dairy cattle consuming water with less than 2,500 (Beede, 2005; Olkowski, 2009) should not suffer any health or performance issues.

Highly saline water itself is not likely to be problematic for beef cattle; however, certain ions in saline water can be extremely detrimental to animal performance and can, in some cases, be fatal (Wright, 2007). It is generally stated that water with less than 3,000 mg/L TDS should be satisfactory for all classes of beef cattle (NRC, 1974). Olkowski (2007) reported higher limits including 4,000 mg/L for all classes, 5,000 mg/L for pregnant and lactating cattle and all classes of sheep, and 7,000 mg/L for young calves and older cattle. Poultry are much more sensitive to TDS than other livestock discussed previously. Ross Breeders (1999) suggests water with less than 500 mg/L is safe for broiler/layer chickens while others have suggested that water with less than 1,000 mg/L is safe for chickens and turkeys (NRC, 1974). Water with greater than 3,000 mg/L has been shown to increase mortality and decrease growth in both chickens and turkeys (NRC, 1974).

Olkowski (2009) suggested that the maximum tolerable concentration of TDS in water for all working horses is 6,000 mg/L and 10,000 mg/L for other horses. Swine and horses consuming water with less than 1,000 mg/L should experience no problems related to TDS.

In summary, while there is peer reviewed literature showing a connection between salinity and livestock, it is quite limited and varies considerably. Rather, there is a growing body of evidence to demonstrate that fewer entities are relying upon TDS to evaluate water quality for livestock and wildlife. If no other information is available, however, then TDS concentrations less than 500 mg/L should be considered safe from almost all inorganic constituents. Above 500 mg/L, the individual constituents contributing to TDS should be identified, quantified, and evaluated (Raisbeck et al., 2008). Much of the literature indicates individual ions rather than TDS criteria/limits are more appropriate to characterize toxicity related to TDS. One study in Iowa (using 1,000 mg/L) along with their extensive literature review supports this conclusion (Iowa DNR, 2009). Their approach is to replace the TDS criteria with numerical sulfate and chloride criteria. One of the difficulties in developing TDS criteria is that there are not national criteria or a toxicity database available for many substances that make up TDS. In view of current knowledge, water quality parameters such as salinity, TDS, or TSS provide very little, if any, information that would benefit pathological, physiological or toxicological relevance.

5.2 Salt Ions

5.2.1 Introduction

The constituents discussed in this section can be broken down into three distinct categories depending on their valance and affinity to form salts by combining with other substances. The anions possess a negative charge and include chlorides, nitrates, nitrites and sulfates. Cations possess a positive charge and include sodium, calcium and magnesium. Some constituents are very frequently encountered as combinations and thus will be discussed in combinations in those cases.

5.2.1.1 Anions

Chloride (Cl^-) has limited data regarding the anion alone in water as it is commonly encountered in combination with cations such as sodium or calcium. “The limited data available regarding Cl^- in water seems to indicate that it is primarily a palatability factor (Raisbeck et al., 2008).” Mathieu et al. (1966) reported that cattle drinking water with 3,000 mg/L of calcium chloride ($CaCl_2$) showed increased water intake coupled with urinary acidification, but resulted in no effect on cattle performance or health. They further reported that cattle refused to consume water containing 5,000 mg/L $CaCl_2$ even when deprived of water for 18-24 hours. Data with higher concentrations are not available.

Nitrates (NO_3^-) may be found in plant tissue or water. The maximum daily intake of nitrates should include consideration of all sources of nitrate intake. Nitrates themselves are not as toxic as the related molecule, **nitrite (NO_2^-)**. For ruminant animals, nitrates are converted to ammonia by ruminal bacteria with an intermediate conversion to nitrite. The nitrite molecule itself causes toxicosis by converting hemoglobin to methemoglobin, thereby reducing oxygen carrying capacity of the blood, resulting in oxygen deprivation at the cellular level.

When evaluating water for nitrate/nitrite concentration, the level of nitrate in feed should be considered to determine if the total daily intake of nitrate/nitrite is within acceptable limits (NRC, 2001). Table 16 represents the generally accepted guidelines for nitrates in livestock drinking water.

Table 16: Generally Accepted Guidelines for Nitrite and Nitrate Nitrogen Concentrations in Livestock Drinking Water

Nitrate (NO_3) (mg/L)	Nitrate Nitrogen (NO_3-N) (mg/L)	Guidelines
0–44	0–10	Safe for consumption by ruminants
45–132	10–20	Generally safe in balanced diets with low nitrate feeds
133–220	20–40	Could be harmful if consumed over long periods
221–660	40–100	Cattle at risk; and possible death
661	100	Unsafe- possible death; should not be used as a source of water

Source: National Research Council (NRC, 1974); (NRC, 2001).

Experimental data related to nitrate poisoning is somewhat sparse. The lowest toxic dose of NO_3 in cattle in an experimental study reviewed here is less than 200 mg NO_3 -/kg BW, although there were several experiments which failed to produce any effect at considerably higher concentrations (as much as 800 mg/kg BW) or doses (Raisbeck et al., 2008). Additionally, some reports indicate that short term exposure to nitrates (500 mg/L) are acceptable while the same report indicates long term exposure limits should be less than 100 mg/L (Raisbeck et al., 2008).

While there is a great deal of anecdotal evidence that NO_2 is more toxic than NO_3, especially in non-ruminants, this review did not find a great deal of quantitative dose-response data about oral exposure in livestock or wildlife. However, NRC recommended keeping NO_2 extra low to compensate for NO_2 formation in slurried feedstuffs for swine. This practice is no longer common, nor is the caveat appropriate to range conditions. (Raisbeck et al., 2008).

A study in Denmark measured the effect of nitrate on early weaned piglets and growing pigs, and concluded that early weaned piglets and growing pigs can tolerate at least 2,000 mg/L nitrate in drinking water (Sorensen et al., 1994). There does not appear to be a link between reproductive performance and nitrate/nitrite concentration in swine as is known to exist in chickens. (Bruning-Fann, 1993)

Sulfate (SO_4^-) found in drinking water in concentrations above the recommended levels generally lead to laxative effects and are thus not suitable for livestock and poultry production. The most common form of sulfur found dissolved in water is the sulfate ion (SO_4). High-sulfate water is found throughout the US, particularly in the Western and Great Plains regions. High dietary sulfur in ruminants can cause various ailments leading to poor productivity, as well as acute death. The relative toxicity of sulfates in animal drinking water depends on the total water intake of the animal, which is tied to highly variable factors such as level of feed intake, feed type, physiological state of the animal (lactation, etc.) and environmental temperature. Because of this, sulfate levels in drinking water are often referenced in the literature only as a percentage relative to overall sulfate intake, rather than as individual threshold levels in the water alone (mg/L). In one example, 1,000 mg/L SO_4 in animal drinking water contributed from 0.1 – 0.27% of total sulfates intake under differing conditions (Olkowski, 1997).

The effects of elevated sulfate levels in drinking water are also variable. The toxicity of sulfur in sheep and cattle often is tied to Polioencephalomalacia (PEM), a neurological condition that can be fatal. One report of drinking water with SO_4 levels as low as 2,000 mg/L produced PEM in 1 of 9 steers (Loneragan et al., 1997). Studies have shown decreased dry matter and/or water intake for cattle with drinking water sulfates ranging from 1,000 – 3,000 mg/L (Loneragan et al., 2001, Harper et al., 1997). Although cattle will still drink water with toxic levels of SO_4, a preference test showed that levels of SO_4 as low as 1,450 mg/L were discriminated against by cattle, and water with 2,150 mg/L of SO_4 were rejected if other sources were available (Weeth & Capps, 1972). While Digesti and Weeth (1976) reported that up to 2,500 mg/L of SO_4 in cattle drinking water caused no change in productivity, others have reported much lower concentrations (539 mg/L) resulted in decreased productivity (Loneragan et al., 2001).

In addition to the direct toxic effects that sulfur has on the animal, it is also known to interact with other elements. Concentrations of SO_4 in cattle drinking water as low as 500 mg/L have been shown to reduce copper absorption in the gastrointestinal tract (Gooneratne et al., 1989, Smart et al., 1996).

Concentrations of SO_4 that are safe in ruminants should provide adequate protection for horses, as they are monogastric and are at less risk of toxic effects of sulfates that involve ruminal generation of sulfide (Raisbeck et al., 2008).

Summary: Based on normal dietary and environmental conditions, keeping SO_4 levels in drinking water below 1,800 mg/L should minimize the possibility of acute death in cattle. Concentrations less than 1,000 mg/L should not result in any easily measured loss of performance (Raisbeck et al., 2008).

5.2.1.2 Cations

Sodium (Na^+) is a primary cation in extracellular fluid and commonly supplemented to the diet of animals in the form of sodium chloride. Water very high in sodium can lead to sodium ion toxicosis (elevated sodium in plasma, or brain tissue) (Gould, 1998). Elevated sodium intake can lead to a diuretic effect and many salts of sodium such as sodium sulfate (Na_2SO_4) or sodium chloride (NaCl) can have a significant laxative effect in livestock. More information on NaCl is available in the next section of this document, but it is generally stated that most of the toxic effects of NaCl are due to the sodium content rather than the chloride. Toxicity of NaCl is related to the availability of water (water intake increases with elevated sodium intake) (Jaster et al., 1978) but if a dose of Na is high enough it can be toxic regardless of water intake (Sandals, 1978).

Cattle consuming water containing 5,850 mg/L of sodium demonstrated a reduction in food and water intake and overall body weight. When levels of sodium of 6,726 mg/L of sodium or greater were consumed in water, death resulted in at least some animals (Weeth and Lesperance, 1965, Ohman 1939). As expected, some variability exists between experiments when sodium toxicity is experimentally induced. There is also an adaptive ability for sodium which allows animals to adjust to higher doses over time, but if given abruptly will cause more serious reactions. Cattle drinking water containing 975 mg/L of sodium for 28 days showed increased water intake, decreased milk production and diarrhea (Jaster et al., 1978) while others reported that cattle consuming water with 5,000 mg /L NaCl or 2,000 mg /L of sodium appeared clinically normal throughout two 30-day experimental periods (Weeth et al., 1968). Overall, it appears that the no-effect level is 1,000 mg/L of sodium for livestock, with serious effects – including death – likely at 5,000 mg/L of sodium.

Sodium Chloride (NaCl) is the common salt that is normally supplemented to livestock, often in free-choice or compressed lick blocks. "The effects of Na and Cl are difficult to separate since neither exists in its pure state in nature, and the elements usually occur together in water…nevertheless it is the Na ion that seems to be responsible for most of the recognized effects of 'salt' poisoning (Raisbeck et al., 2008)." Studies with sheep drinking water containing 15,000 mg/L NaCl showed decreased feed consumption and reduced body weight, and water with concentrations of 10,000 – 13,000 mg /L NaCl caused complications including increased incidence of stillborn and death rate in lambs within 48 hours of birth in twin-bearing ewes (Wilson, 1966, Peirce, 1957, Potter and Mcintosh, 1974). Based on published values, swine seem to be equal or slightly more sensitive than cattle to acute toxicity from NaCl. One study reported that abruptly switching gilts to a diet containing 13,600 mg/L NaCl resulted in feed refusal and diarrhea (Pretzer, 2000).

The toxicity of sodium when combined with chloride as NaCl, the Na is the more toxic component and therefore the "threshold" factor. Neither Na or NaCl is reliable when looking at mg/L or ppm unless they are taken in conjunction with water availability and feed composition. There is also an adaptive ability for Na which allows animals to adjust to higher doses over time, but if given abruptly will cause more serious reactions. We are recommending that CV-SALTS adopt the recommendation of one summary report which reads as follows: "Assuming water consumption typical of a rapidly growing steer…the no-effect level would be about 1,000 mg Na/L or 2,500 mg NaCl/L. Serious effects, including death, become likely at 5,000 mg Na/L. We recommend keeping drinking water Na concentrations at less than 1,000 mg/L, although short-term exposure to concentrations up to 4,000 mg/L should be well-tolerated" (Raisbeck et al., 2008).

Magnesium (Mg^{++}) is required for normal metabolism and is an important component of extracellular fluid and bones. It is generally described in combination with other constituents, i.e. $MgSO_4$ or as a component of "hardness" where it is implicated along with calcium. Hardness does not seem to have any measureable effects on animal health or production at even high levels commonly found in drinking water, so Mg is rarely a part of a drinking water analysis for livestock. In fact, most published literature related to Mg relates to its dietary supplementation to improve production, rather than on threshold or toxicity levels (Frederick et al., 2006, Peeters et al., 2006, Atteh and Leeson 1983). The main adverse effect of elevated Mg in the overall diet (feed and water intake) is related to diarrhea, leading to differing conclusions as to the level of Mg that is considered to have no effect on overall productivity. Studies with sheep (Peirce, 1959 and 1968a) reported maximum Mg concentrations of 250 ppm for young stock, 400 ppm for lactating stock, and 500 ppm for dry mature animals. Later work found that there was no adverse effect on young cattle using water with up to 500 ppm Mg (Saul and Flinn, 1985). A suggested upper limit of 300-400 mg/L has been recommended for lactating dairy cattle (Peterson, 2000).

Calcium (Ca^{++}) is required for normal metabolism and is an important component of extracellular fluid as well as bone. Few publications exist on calcium toxicity because it is considered to be safe even at relatively high levels in drinking water. It seems to have little or no effect on animal health or productivity. The following is a quote from National Research Council Guidelines (NRC, 2005), "Required macro elements such as calcium, magnesium, phosphorus, and potassium are unlikely to be at levels that cause toxicosis, but are more likely to result in aesthetic secondary standard effects (p 471)." Thus calcium is not a constituent deemed toxic to livestock as a result this present review was unable to find any peer-reviewed reference to a toxic level in drinking water for livestock.

Boron (B) is essential for optimal bone health, brain function, and immune function in higher animals. Boron is not, however, viewed as important to animals as it is to plants. A clearly defined specific biochemical function is a major obstacle to wide acceptance of boron importance to animals (NRC, 2005).

Boron has been found to occur in streams throughout California and the western United States, especially in areas that drain old marine formations. Boron in seawater is approximately 5 mg/L and in general is the most abundant trace element in unpolluted freshwater. Eighty percent of surveyed streams in California showed concentrations of boron to be less than 1 mg/L. The highest level was 12.5 mg/L found in a stream west of Interstate 5 in Fresno County which drains an area of known marine formations. Livestock seem to be comparatively more tolerant to boron in drinking water than other uses in agriculture. One review proposed a maximum allowable concentration is 5 mg/L (Davis 1999).

Several peer-reviewed studies have reported that water not exceeding 5 mg/L should be safe for livestock, and other reports have taken a less conservative approach and listed the maximum tolerated level between 40 and 150 mg/L (Table 2). In 2003, a committee of the National Research Council was convened on minerals and toxic substances in diets and water for animals (NRC, 2005). They concluded that cattle consuming water containing 150-300 mg/L boron exhibited toxicity signs including decreased food consumption and weight. They concluded that it is unlikely that boron toxicity under normal environmental conditions is a concern for animals (NRC, 2005).

While limited information exist on guidelines for livestock watering, a recommended boron concentration of less the 5.0 mg/L has evolved over time (Moss, 2003). Table 17 shows a generally wide acceptance of this level including the US EPA, States of New Mexico and Kansas, along with Canada, Australia, and New Zealand.

Australia and New Zealand have developed water quality guidelines for agricultural water use under the National Water Quality Management Study (NWQMS). They recommend that if boron concentration in water exceeds 5.0 mg/L, the total boron content of the livestock diet should be investigated. They acknowledge that higher concentrations in water may be tolerated for shorter periods of time (ANZECC/ARMCANZ, 2000). They developed the guideline based on principles adopted for the World Health Organization (WHO) and found that guideline values for various types of livestock ranged for 5.8 (pigs) to 11.3 (chicken) mg/L boron (Moss, 2003) (Table 18). The approach of ANZECC/ARMCANZ is an extremely important contribution to the literature as many authors suggest their data is limited in value as body weight, water intake, etc. was not taken into consideration.

Table 17: Boron Guidelines for Livestock Water Supply from Various References

Guideline Statement	Guideline Value	Date	Reference
The boron concentration in water used by livestock should not exceed 5.0 mg/L	5.0 mg/L	1973	NAS
The boron concentration in water used by livestock should not exceed 5.0 mg/L	5.0 mg/L	1987	Canadian Council of Ministers of the Environment
The boron concentration in water used by livestock should not exceed 5.0 mg/L	5.0 mg/L	1983	Williamson
Maximum allowable	5 mg B/L	1981	Weeth et al (1981), NAS (1980), Seal and Weeth (1980), Green and Weeth (1977) in Eisler (1990)
Maximum tolerated	40 mg B/L	1980	Seal and Weeth (1980) in Eisler (1990)
"Safe"	40-150 mg B/L	1977	Green and Weeth (1977) in Eisler (1990)
Adverse effects	>150 mg B/L	1986	Nielsen (1986) in Eisler (1990)
The following numeric standards shall not be exceeded: Dissolved boron	5.0 mg/L	1995	New Mexico Water Quality Control Comm.
Recommended maximum levels (Livestock)	<5.0-30 mg/L	1994	Puls
Quality criteria for agriculture Livestock	5.0 mg/L	1988	US EPA
If the concentration of boron in water exceeds 5 mg/L, the total boron content of the livestock diets should be investigated. Higher concentrations in water may be tolerated for short periods of time.	5.0 mg/L	2000	Australia and New Zealand Environment and Conservation Council (2000)

Table 18: Summary of Calculations Used to Develop a Guideline for Boron in Livestock Drinking Water (ANZECC/ARMCANZ, 2000)

Animal	Body Weight (kg)	Peak water Intake (L/d)	Peak food Intake (kg/d)	Calculated Value (mg/L)
Cattle	150	85	20	7
Pigs	110	15	2.9	5.8
Sheep	100	11.5	2.4	6.2
Chickens/Poultry	2.8	0.4	0.15	11.3
Horses	600	70	20	8.6

The 2005 NRC book on mineral tolerances is an important reference regarding boron. Although gaps exist, maximum tolerance levels were established to determine the level of excessive exposure. This publication cited that excessive exposure to boron is rare and established a dietary MTL at 150 mg/L. Australian and New Zealand studies assumed that 20% of mineral intake was in the water thus suggesting 30 mg/L of boron in the diet from the drinking water would be considered an appropriate level without harming the animal. (ANZECC/ARMCANZ, 2000). (Weiss, 2008).

5.2.2 Nutrients

<u>Introduction</u>

The nutrients discussed in this section (Total, Kjeldahl, ammonia and organic nitrogen and total and dissolved orthophosphate) are of great importance in relation to water quality for recreational, aquatic life, and other domestic uses. The thresholds that have been established for these nutrients for domestic uses are generally much lower than any critical level for livestock drinking water. Exceptions to this, such as instances where animals became poisoned after drinking fertilizer contaminated water, etc., will be discussed below. In general terms the forms of nitrogen, when described, were related to the state of oxidation of the nitrogen molecule and were nitrate, nitrite, ammonia, organic nitrogen, most to least oxidized, respectively.

Total nitrogen – Total nitrogen is the sum of all types of nitrogen (regardless of oxidation state) in a water sample.

Kjeldahl nitrogen (TKN) – This method, pioneered by Danish chemist Johan Kjeldahl in 1833, converts all ammonia- and organic-nitrogen in a sample to ammonia. The resulting ammonia is quantified. The nitrogen contained in the ammonia analyzed resulted from ammonia N and organic nitrogen in the original sample. (EPA Method 351.1)

Organic nitrogen – Organic nitrogen is defined as nitrogen that is incorporated into protein, amino acids or other carbon containing molecules. Organic nitrogen is measured during Kjeldahl N analysis by conversion to ammonia. It can be estimated indirectly by subtracting the ammonia concentration in the sample from the total Kjeldahl N. (EPA Method 351.1)

Ammonia – Ammonia (NH_4) is measured directly in water samples. (EPA Method 350.1)

Total PO_4 and Dissolved PO_4 – Both total and dissolved orthophosphate are measured directly in water sample. Total PO_4 is measured on unfiltered water, and thus might contain phosphorus that is not "dissolved" in the sample and could be contained in organic material. Dissolved PO_4 is measured by first passing water through a 0.45 micron filter. (EPA Method 365.1)

Most of the nutrients discussed in above (Total nitrogen, Kjeldahl nitrogen, organic nitrogen, total phosphate and dissolved phosphate) are not found in drinking water or natural water supplies at levels that are thought to be toxic to livestock. Thus there is no mention in the peer-reviewed literature related to their toxicity in drinking water.

Ammonia

We were unable to locate any original peer reviewed-research dealing with drinking water ammonia concentrations. One report of accidental ammonia exposure took place at a Midwest county fair in Illinois (Campagnolo, 2002). The water was brought into the fairgrounds by a tanker truck that had previously transported liquid fertilizer (liquid ammonium nitrate and urea). Six animals died (1 Holstein cow, 3 Holstein heifers, 1 goat, and a lamb). Analysis of the rumen contents of the affected animals revealed ammonia concentrations ranging from 1,000 to 1,440 ppm. Although elevated nitrate (>6,000 ppm) levels were discovered in the water buckets and troughs, the clinical signs associated with nitrate poisoning were not evident in the animals affected.

5.3 Conclusion from peer reviewed journals

A review of the literature on drinking water standards and salinity will take the reviewer down many different paths. While they are all related to the goal of establishing water quality criteria, the terms and definitions can vary greatly. In addition to criteria, which have a more regulatory tone, terms such as standards, guidelines, thresholds, and MTL (Maximum Tolerable Levels) are widely used as well. The literature suggests that US EPA numbers for human health guided most of the early decisions. The World Health Organization (WHO) also played a role in some of the early numbers again related closely to human health needs. Most studies in livestock agriculture, while limited in number, found the criteria for human drinking water standards to provide a margin of safety of livestock and poultry.

Although US EPA has never come out with their own criteria for livestock, most states have developed some level of narrative criteria to address stock drinking water. The livestock industry's concern would be to push for numeric values to ensure the dietary needs of livestock animals without potential health risks. As a result, research would be guided largely by salinity, and Total Dissolved Solids (TDS) and would emerge as the industry measurement of choice. Along the same lines, the US EPA standard for human health would set the bar at 500 mg/L TDS and various entities would adopt this numeric value therefore protecting livestock and many of the more sensitive beneficial uses within the region.

Production loss resulting from poor health and even death would take the research down two paths: Veterinary related research would provide a clear focus on toxicity to livestock, while industry focus kept production losses in the spotlight. In the literature there is a clear demarcation between industry- and veterinary-driven water quality standards for livestock, with a range of numerical values representing a clear divide in study design and measurable results. However, neither group would jump immediately to the level of detail being requested today.

The major universities were able to advance the research agenda under the heading of livestock health and begin to move the literature beyond just measuring salinity. The toxicology literature began to explore toxicity to the level of specific salts that comprise salinity. Their research was guided largely by cases where salinity was not found to be at an alarming rate yet livestock health was being compromised and often resulting in the death of an animal. The specific salts along with their combinations provided great insight into the concern for salinity. At the same time, universities were working with industry to improve the production of livestock and reduce those elements impacting their performance. And while little specific guidance emerged regarding individual salts or minerals, it became clear that testing of the water should be examined much closer when TDS was elevated in the case that a specific salt was responsible for the high levels reported.

At the same time the toxicology literature is evolving resulting in water quality standards with a strong scientific base that can be set representing various beneficial uses including those for livestock and poultry. Canada, Australia, New Zealand, South Africa, and the United States have proactively addressed livestock drinking water quality with either a narrative or specific numeric value. Most countries were guided by literature reviews and began to establish new levels of concern that would distinguish them from the earlier numbers being guided by US EPA and human health concerns. The toxicity levels provided an upper end for what one might consider new guidelines. The literature was increasingly being pulled into the forefront and led largely by the National Academy of Science publication entitled "*Guide to the Use of Saline Waters for Livestock and Poultry*" (NRC, 1974). The Canadian Task Force on Water Quality also published "*Summary and Guide to Use of Saline Water for Livestock Watering." (Canada, 1987)* and *"A Guide to Use of Saline Water for Livestock Watering*" (Canada, 1987). Other countries would begin to publish similar documents and most being guided by similar literature. Textbooks would quickly begin to incorporate the new standards being developed which were in most cases higher than the earlier ones being guided by the US EPA and WHO.

As the literature continued to evolve, much of it began to address the criteria in place and the difficulties in utilizing it for setting any kind of water quality criteria. Most of the individual salts by themselves did not threaten the livestock. Yet in specific combinations that was not necessarily the case.

Regulatory frameworks drive States to begin developing numeric standards and again incorporate literature reviews into their process. The State of Wyoming included 663 references in their report entitled "*Water Quality for Wyoming Livestock & Wildlife*" (Raisbeck et al., 2008). Iowa included numerous references in their report written for the purpose of changing water quality standards related to livestock drinking water. Reports originating in Canada (Saskatchewan) entitled "*Livestock Water Quality: A Field Guide for Cattle, Horses, Poultry and Swine*" (Olkowski, 2009) resulted in 365 references. The conclusions of these independent reviews were arriving at similar outcomes. Those outcomes addressed the relative lack of importance given to direct measures of salinity via TDS or EC numbers. While they collectively agreed on the importance of examining the individual salts, they concluded that a number of them would not be considered a threat to livestock. But the most important finding was the need to begin examining the drinking water sources to determine the level of threat that might exist within the current criteria. Saskatchewan and Iowa researchers concluded there were many areas where unpolluted waters (i.e. groundwater, surface water, and irrigation) already provided a safe level of protection in many instances.

5.4 Summary of Academic Findings

The evolution of the drinking water criteria for livestock was guided in large part by the numbers that are reported in Table 19 that follows. In some instances, the numbers are used to illustrate the vulnerability of certain chemical species or in another case how animal weight, water consumption, etc. contribute to a more representative number, but also point to the most vulnerable of the livestock species. The following is a bulleted summary of our findings relative to the minimal level of a constituent that produced any measurable effect on health and or production.

- There was little if any evidence to suggest that decreasing boron levels below 5.0 mg/L would be more protective of livestock health. Recent literature suggests this level of boron or less should sufficiently protect the weakest of the species and local conditions are normally well below that level.

- Canadian recommended guidelines for total dissolved solids (TDS) is at 3,000 mg/L while in the US the range based on the literature is between 1,000 to 2,500 mg/L, it gives the committee a reasonable range in which to operate. One could screen for TDS with a meter and if levels are below 500 mg/L (800 µmhos/cm (EC)), you would need not be concerned but if above 500 mg/L it would be wise to look into the individual salts. There may be little reason to debate the other numbers as TDS in and of itself is of little value.

- Sulfate levels for livestock drinking water are extremely variable, and directly related to percentage of total dietary intake of the animal. Based on normal dietary and environmental conditions, keeping SO_4 levels in drinking water below 1,800 mg/L of SO_4 should minimize the possibility of acute death in cattle. Concentrations less than 1,000 mg/L should not result in any easily measured loss of performance.

- Although sodium chloride is usually found as a compound in drinking water, it is sodium that is primarily responsible for toxic effects. The limited data available regarding chloride in water seems to indicate that it is primarily a palatability factor. Although there is some adaptive ability of animals to adjust to long-term Na exposure, overall, it appears that the no-effect level is 1,000 mg/L of sodium for livestock, with serious effects – including death – not likely to occur unless the concentration exceeds 5,000 mg Na/L.

- The main adverse effect of elevated magnesium in the overall diet (feed and water intake) is related to diarrhea, leading to differing conclusions as to the level of Mg that is considered to have no effect on overall productivity. Studies with sheep reported maximum Mg concentrations of 250 mg/L for young stock, 400 mg/L for lactating stock, and 500 mg/L for dry mature animals, but overall threshold values for livestock are variable.

- Much has been written about nitrate and nitrite levels in drinking water for livestock. It is important to remember that total daily nitrate/nitrite intake is an important factor to consider since nitrates/nitrites are contained in plant tissues as well as drinking water. A general guideline that continues to surface in the literature as an upper threshold for livestock and poultry is 100 mg/L for nitrate nitrogen and 10 mg/L for nitrite-nitrogen. Certainly some authors have reported problems at lower levels and some reports indicate much higher levels of these compounds in drinking water without observation of detrimental effects. However, the threshold values listed above are the dominant guidelines used and referenced in the majority of publications dealing with nitrates and nitrites.

- We were unable to locate any peer-reviewed research related to livestock drinking water concentrations for several of the constituents covered in this review. Those constituents for which we were unable to locate peer-reviewed publications related to drinking water were Total Nitrogen, Kjeldahl Nitrogen, Organic Nitrogen, Ammonia, Total Phosphate, Orthophosphate and Calcium.

Table 19: Summary of Salt and Nutrient Toxicity Data for Livestock and Poultry

(Units are mg/L or ppm)

Livestock/ Constituent			Small Ruminants	Poultry				
	Dairy Cows	Beef Cattle	Sheep and Goats	Chickens (Broilers)	Chickens (Layers)	Turkeys	Horses	Swine
Total Dissolved Solids (TDS)	2500[10] 975[1]	4000[10]	5000[10]	2000[10]			4000[10]	4000[10]
Electrical Conductivity (EC)	No research could be found directly equating EC measurement to livestock/poultry health and performance. A conversion factor ranging from 0.60 - 0.67 is used to convert from EC to TDS.							
Sodium (Na)	1,000-5,000[5]							
Chloride (Cl)		3000[4]	3000[4]	1500[4]			1500[4]	
Sulfate (SO_4)		539[2]		1000[4,5]				
Calcium (Ca)	No research could be found directly equating Calcium in drinking water to livestock/poultry health and performance.							
Magnesium (Mg)			250 (young), 400 (lactating), 500 (adult)[3]					
Boron (B)	7[11]	7[11]	6.2[11]	11.3[11]			8.6[11]	5.8[11]
Total Nitrogen (N)	No research could be found directly equating Total-, Kjeldahl- or Organic-N in drinking water to livestock/poultry health and performance.							
Total Kjeldahl (TKN)								
Organic Nitrogen (N)								
Nitrate (NO_3)	100[6,7] 440[8]	100[6]	100[4] 200[8]	45[11]				2000[9]
Nitrite (NO_2)	10[6,7] 33[8]	100[6]						
Ammonia (NH_4)	No research could be found directly equating Ammonia in drinking water to livestock/poultry health and performance.							
Total Phosphorus (P)	No research could be found directly equating total or dissolved phosphorus to livestock/poultry health and performance.							
Dissolved Phosphorus (P)								

1. Jaster et al., 1978
2. Loneragan et al., 2001
3. Pierce, 1959, 1968a
4. South Africa, 1996
5. Canada, 1987
6. Raisbeck et al., 2008
7. NAS, 1974
8. NRC, 2005;
9. Sorensen et al., 1994
10. Olkowski, 2009
11. Moss and Nagpal, 2003 and ANZECC/ARMCANZ, 2000.

Section 6: Water Quality Recommendations

The overall assumption regarding for stock drinking water is that livestock will be less sensitive to salt and nutrients than other beneficial uses; therefore, limited numeric water quality criteria exists but, narrative objectives are found in various agency documents. In California, only in Region 2 adopted specific numerical values associated with salt and nutrient levels for stock watering water quality while international water quality objectives tend not to set values but rather provide guidelines as to the most appropriate ranges for salt and nutrients in water.

With new studies being published related to salt and nutrient toxicity, a more focused understanding has evolved regarding water quality criteria and livestock. Table 20 represents recommended salt and nutrient levels that will result in no health effects in animals in second column and the highest tolerable level before health effects are seen in the most sensitive species in the third column. The highest tolerable level represents a level of exposure that is tolerated if it is the sole constituent in water. However, if other factors such as high levels of a constituent in feed stock, then the highest tolerable level may not be appropriate and mild health effects may be observed.

Generally information on most of the salt and nutrient constituents was available with TDS having the majority of the information. TDS is expected to continue as the primary indicator of salinity in water. The literature review revealed that livestock of all types tolerate higher TDS levels than humans with the most protective level ranging between at 1,000 -2,500 mg/L. The most sensitive specie was poultry with the highest tolerable level of TDS exposure at 5,000 mg/L with no health effects.

Sodium health effects are mostly observed in poultry with 50-100 mg/L of sodium as a safe level. In most livestock cases sodium is more of a palatability issue, however, when combined with anions such as chloride or sulfate, the compound may reduce the levels of sodium tolerance in livestock particularly poultry resulting in a health risk.

Sulfate in livestock can be tolerated at much greater levels than in humans. At 1,000 mg/L of sulfate no health effects are seen in any type of livestock while 1,800 mg/L of sulfate is considered safe but accounting for other sources of sulfate in the diet would be necessary at this level. The most sensitive species toward sulfate is cattle. Sensitivity is attributed to the anaerobic environment in the rumen of cattle which reduce sulfates to sulfites (a more toxic version of sulfur ions).

Similarly, nitrate and nitrite tolerance in livestock are relatively low. Low levels of nitrate and nitrite in the water may result in a version of methemoglobinemia where oxygen on red blood cells is replaced by nitrate or nitrite thus leading to suffocation. Ruminants and horses are the most susceptible to the toxicity due to the anaerobic environment of the rumen which reduces nitrate to nitrite. Additionally, nitrate from feedstock can increase the dose of nitrate even when nitrate levels are low in water. Generally, all publications indicate that even when other sources of nitrate are present, 100 mg/L of nitrate and 10 mg/L of nitrite are safe levels in water sources.

Limited information exists for chloride toxicity in water related to stock drinking water. The majority of water quality criteria adopted by States relates to human drinking water standards with a level of 250 mg/L chloride. A single citation was found about the effects of chloride on livestock. This citation showed that chloride levels of 3,000 mg/L caused cattle to reject a water sources and would not drink the water even if there were no other sources of water. Although this is just one data point, the level indicates that chloride levels for stock drinking water safety are higher as compared with human drinking water. Additionally the health effects are not related to toxicity but rather a refusal to drink the water.

Hardness levels in water which consists of calcium and magnesium did not result in any citations of toxicity; rather the health effects were a result from the formation of compounds with complementary anions present in water. For example, magnesium alone does not cause an effect in livestock but when high sulfate levels are present in the water magnesium sulfate may have a laxative effect in livestock. Of the livestock, the poultry industry will have the greatest concern due to scaling as a result from high hardness levels. Scaling may cause blockages in the water distribution system thus some poults may not receive water. Therefore, low hardness levels to prevent scaling should be the focus for this water quality objective possibly at level of 180 mg/L.

All agencies and university extension publications recommend a level of 5.0 mg/L boron in water. No divergence in this adopted number was found in agencies or University Extension literature. Only through the academic literature review were levels above 5.0 mg/L found with swine being the most sensitive livestock. Documented health effects in swine occur at 5.8 mg/L boron and other livestock are less sensitive with ruminants ranging from 6.8 to 7.0 mg/L. Since the swine industry is limited in the State of California, water quality levels of boron up to 7.0 mg/L could be adopted. However, crops sensitivity to boron will result in a lower adopted boron level since crop tolerance of the most sensitive crop species occurs at 0.75 mg/L of boron.

In general, livestock tolerate higher water quality levels of the salt and nutrient constituents in this review as compared with other beneficial uses specifically human drinking water, aquatic life, and crop irrigation. However, nitrate and nitrite are more toxic to ruminant livestock thus requiring water quality objectives equivalent to human drinking water objectives. As presented in Table 20 are recommended ranges of water quality levels that may be used for the development of a Basin Plan amendment.

Table 20: Guidelines for Stock Drinking Water

Parameter	Recommended level (mg/L)	Tolerable value(s) (mg/L)	Sensitive species
Boron	5.0	7.0	All
Chloride	250	3,000	None identified
Nitrate	100	440-1,300	Ruminants and Horses
Nitrite	10	100-300	Ruminants and Horses
Sodium	50-100	<800	Poultry
Sulfate	250	<1,800	Cattle
TDS	<1,000	<5,000	Poultry especially turkeys

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