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Salt and Nutrients: Literature Review for Stock Drinking Water Final Report

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CV-SALTS

Managed by

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List of Abbreviations

AGR	Agricultural Beneficial Use
B	boron
BW	body weight
Ca	calcium
Cl	chloride
CO ₃	carbonate
CV-SALTS	Central Valley Salinity Alternatives for Long-Term Sustainability
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
meq/L	milliequivalent per liter
MTL	maximum tolerance limit
MUN	Municipal and Domestic Supply Beneficial Use
N	nitrogen
Na	sodium
NaCl	sodium chloride
NAS	National Academy of Science
NO ₃ -N	nitrate as nitrogen
NO ₃	nitrate as nitrate
NO ₂	nitrite
NRC	National Research Council
NRWQC	National Recommended Water Quality Criteria
NWQMS	National Water Quality Management Strategy
P	phosphorus
PEM	polioencephalomalacia
ppm	parts per million (approximately equal to mg/L)
Region 5	Central Valley Regional Water Quality Control Board
Regional Boards	California Regional Water Quality Control Boards
SAR	sodium adsorption ratio
SO ₄	sulfate
State Board	State Water Resources Control Board
TDS	total dissolved solids
TKN	total kjeldahl nitrogen
US EPA	United States Environmental Protection Agency
WHO	World Health Organization
≤	less than or equal to

Executive Summary

Salinity and nutrient management is an important issue of concern in the Central Valley of California due to an increasing population and significant agricultural activity. With limited outlets for salinity disposal, much of salinity associated with imported water remains in the Central Valley. Nutrient application associated with agricultural activity in the Central Valley can be at levels higher than what the land or crops can assimilate. As a result, increased salinity and nutrient loads to surface waters and ground waters can potentially degrade the water quality of the region and impact beneficial uses of water in the Central Valley. To facilitate salinity and nutrient planning in the region, the Central Valley Regional Water Quality Control Board ("Region 5") is charged with developing a salinity and nutrient management plan by 2014 to comply with California's Recycled Water Policy. This plan is being developed collectively by a broad coalition representing agriculture, cities, industry and regulatory agencies through the Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS) initiative.

To support development of Central Valley salt and nutrient management plan, CV-SALTS and the Central Valley Salinity Coalition in conjunction with the California Department of Food and Agriculture, State Water Resources Control Board and Dairy CARES commissioned a study to evaluate the technical and regulatory literature to identify: 1) water quality criteria that could be used to establish water quality objectives to protect water used as a stock watering source, and 2) existing water quality objectives, standards, goals, and policies that have been established to protect this beneficial use.

The range of water quality criteria evaluated by this project encompassed the following constituents: dissolved minerals including total dissolved solids (TDS), electrical conductivity (EC), sodium (Na), calcium (Ca), magnesium (Mg), hardness, chloride (Cl), and sulfate (SO₄), the trace element boron (B), and nutrients (nitrogen species and phosphorus species). This evaluation was accomplished through completion of the following tasks:

- Review of the numeric and narrative objectives or criteria of Basin Plans from the nine California Regional Water Quality Control Boards (Regional Boards);
- A review of federal documents and their numerical thresholds was used in developing recommended water quality criteria for stock drinking water. Selected state reports were also reviewed to provide information regarding how other states have established water quality criteria for nutrients/salinity;
- A review of international agencies water quality criteria, policies, and supporting documents;
- An evaluation and summary of selected University Extension publications related to stock drinking water;
- Completion of a review of relevant literature of the most current science related to toxicity of salinity and nutrient constituents in water on livestock; and
- Development of a summary of findings and recommendations for establishment of water quality objectives to protect a stock watering beneficial use.

High salinity, boron, and nutrient concentrations in the water may pose a health risk to livestock and could cause significant health effects or even death at specific levels of exposure. Identifying water quality criteria that are protective for livestock, including poultry, depend on the amount of water consumed each day, the diet, and the weight of the animal. Where agencies have adopted objectives to protect stock watering, they include a safety factor to compensate for consumption and weight. However, many agencies have not adopted numeric objectives. For example, of the nine Regional Boards, only Regions 2 and 3 have specific numeric objectives to protect stock drinking water quality; whereas the remaining Regional Boards set objectives through a narrative approach or have established waterbody-specific objectives for salinity and nutrient-related constituents not specific to any beneficial use. Few other states have set numerical objectives specifically to protect stock watering, but instead rely upon US Environmental Protection Agency (US EPA) adopted National Recommended Water Quality Criteria (NRWQC) for salinity, boron, and nutrients that are based on protection of human health and aquatic life, which are more stringent than criteria needed to protect stock watering. Internationally, the reviewed agencies protect stock watering through the use of guidelines rather than establishment of specific numeric criteria.

Many of the recommended criteria to protect a stock watering use are based on a review of 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 expand on the information found in past publications. A key finding of this review is that for individual salinity constituents and boron, safe concentrations for stock watering are higher than required to protect other beneficial uses, specifically human drinking water, aquatic life, and crop irrigation. For the nutrients nitrate and nitrite, the recommended criteria are conflicting, possibly due to confusion between expressing nitrate and nitrite as their ions or as nitrogen (N). Nonetheless, concentrations of nitrate and nitrite of 100 mg/L as N and 10 mg/L as N, respectively, which are an order of magnitude higher than human drinking water standards, appear to be protective of drinking water for cattle and other livestock.

Section 1: Introduction

This section provides the background, objectives, and authorization for this Salt and Nutrients Literature Review for Stock Drinking Water.

1.1 Background

Salinity and nutrient management is an important issue of concern in the Central Valley of California due to an increasing population and significant agricultural activity. With limited outlets for salinity disposal, much of salinity associated with imported water remains in the Central Valley. Nutrient application associated with agricultural activity in the Central Valley can be at levels higher than what the land or crops can assimilate. As a result, increased salinity and nutrient quantities can potentially degrade the water quality of the region and impact beneficial uses of water in the Central Valley. To facilitate salinity and nutrient planning in the region, the Central Valley Regional Water Quality Control Board ("Region 5") is charged with developing a salinity and nutrient management plan by 2014 to comply with California's Recycled Water Policy. This plan is being developed collectively by a broad coalition representing agriculture, cities, industry and regulatory agencies through the Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS) initiative.

1.2 Objectives

CV-SALTS and the Central Valley Salinity Coalition in conjunction with the California Department of Food and Agriculture, State Water Resources Control Board (State Board) and Dairy CARES commissioned this study to evaluate the technical and regulatory literature to identify:

- Water quality criteria that could be used to establish water quality objectives to protect water used as a stock watering source; and
- Existing water quality objectives, standards, goals, and policies that have been established to protect this beneficial use.

This evaluation was accomplished through completion of the following tasks:

- Review of the numeric and narrative objectives or criteria of Basin Plans from the nine California Regional Water Quality Control Boards (Regional Boards);
- A review of federal documents and their numerical thresholds was used in developing recommended water quality criteria for stock drinking water. Selected state reports were also reviewed to provide information regarding how other states have established water quality criteria for nutrients/salinity;
- Review of international agencies water quality criteria, policies, and supporting documents;
- Evaluation and summary of selected University Extension publications related to stock drinking water;
- Literature review of the most current science related to toxicity of dissolved minerals, boron, and nutrient constituents in water on livestock; and

- Summary of findings and recommendations for establishment of water quality objectives to protect the stock watering beneficial use.

1.3 Water Quality Constituents of Concern to Stock Water

This evaluation is limited to three classes of constituents of concern for stock drinking water:

- **Dissolved Minerals**

Specific dissolved minerals considered include total dissolved solids (TDS) and electrical conductivity (EC) that are measurements of salinity, the cations sodium, calcium, and magnesium, and the anions chloride and sulfate. Values for all of these constituents except EC are reported in units of milligrams per liter (mg/L). EC values provided in this report are in units of decisiemens/meter (dS/m), which is equivalent to values expressed as microsiemens per centimeter ($\mu\text{S}/\text{cm}$) or millimhos per centimeter (mmho/cm), and equal to 1,000 micromhos per centimeter ($\mu\text{mhos}/\text{cm}$) typically used in literature regarding human drinking water quality. TDS and EC can be correlated and typical ratios of TDS to EC range from 590 to 690 when TDS is expressed as mg/L and EC is expressed as dS/m. However, this relationship can vary by area depending on factors such as the individual ionic constituents, temperature, and ionic strength. Where TDS is converted to EC in this document, the assumed ratio is noted.

- **Trace Elements**

Boron is the only trace element included in this study. Molybdenum has already been evaluated by Region 5 (Palmer et al. 1989) and was excluded from this study.

- **Nutrients**

Specific nutrients considered are nitrogen species (total nitrogen, Kjeldahl, organic, nitrate, nitrite, and ammonia) and phosphorus species (total phosphorus and dissolved orthophosphate). Total nitrogen is the sum of organic nitrogen, ammonia, nitrate, and nitrite, all expressed as mg/L of nitrogen (N). Total Kjeldahl nitrogen (TKN) measures both organic nitrogen and ammonia, thus organic nitrogen concentration is calculated by subtracting the ammonia nitrogen from the Kjeldahl nitrogen. Nitrate and nitrite are sometimes reported as the ions NO_3^- and NO_2^- and sometimes as N. In this evaluation, information on nitrate and nitrite are provided as N unless the reference is ambiguous as to what units were used.

1.4 Authorization and Acknowledgments

CV-SALTS and the Central Valley Salinity Coalition in conjunction with the California Department of Food and Agriculture, State Board and Dairy CARES commissioned Kennedy/Jenks Consultants to perform this study. The project is authorized under Agreement Number 11-0208 dated 1 January 2012. The literature review was performed with assistance from Texas A&M University AgriLife Research and Tarleton State University. 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.

Section 2: Regional Water Quality Control Board Basin Plans

This Section provides a summary of our review of Regional Board basin plans for water quality objectives specific to stock watering. For perspective, site specific objectives that cover multiple beneficial uses, including stock water and agriculture, are also discussed.

2.1 Basin Plan Water Quality Objectives for Stock Watering

In California, the State Board and nine Regional Boards are responsible for the protection of water quality. Each Regional Board assigns water quality objectives and beneficial uses to the various waterbodies within its respective jurisdiction. The objectives of each Water Quality Control Plan (Basin Plan) state that water quality of surface water and groundwater should not be degraded such that beneficial uses, including stock watering, are precluded. Under all Basin Plans, the Agricultural Beneficial Use (AGR) represents a general category that includes both irrigation and stock watering. The AGR 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.”

The Basin Plans of the nine Regional Boards were reviewed for information on dissolved minerals, boron, and nutrient water quality objectives, criteria, or guidelines that specifically address stock drinking water. Table 1 provides a summary of that review. Only Regions 2 (Bay Area) and 3 (Central Coast) specify water quality objectives for dissolved minerals, boron, and/or nutrients to protect stock watering. Specifically, Region 2 has established stock watering objectives for TDS (10,000 mg/L), boron (5.0 mg/L), and nitrate + nitrite (100 mg/L N), while Region 3 has adopted stock watering objectives for boron (5.0 mg/L), nitrate + nitrite (100 mg/L) and nitrite (10 mg/L) (both are assumed to be as N; however, Basin Plan does not specify).

2.2 Other Basin Plan Water Quality Objectives for Dissolved Minerals, Boron, and Nutrients

Most Basin Plans include at least some water quality objectives for dissolved minerals, boron, or nutrients of interest to this study. These objectives are often either set to protect other more sensitive beneficial uses than stock watering, or they are waterbody-specific objectives not applicable to any specific beneficial use. Table 2 provides a summary of these objectives by Region.

2.2.1 Region 1: North Coast

Region 1 designates all inland and surface waters and ground waters with the AGR beneficial use and has established objectives for EC, TDS and boron within each of its hydrologic regions. These objectives are the 90th percentile for a calendar year and the 50th percentile of the monthly mean values for a calendar year. Table 2 summarizes the ranges of 90th and 50th percentile objectives observed across Region 1.

2.2.2 Region 2: San Francisco Bay Area

A limited number of waterbodies in Region 2 are designated with an AGR beneficial use. However, Region 2 is one of two regions that have established a few water quality objectives specific to the protection of stock watering (see Table 1). In addition, the Basin Plan includes the following narrative statement: “To establish water quality criteria for livestock water supply, the Water Board must consider the relationship of water to the total diet, including water freely drunk, moisture content of feed, and interactions between irrigation water quality and feed quality”.

2.2.3 Region 3: Central Coast

Region 3 has adopted objectives specific to stock watering protection for boron, nitrate + nitrite and nitrite (see Table 1). Additional objectives or guidelines have been established to protect waters used for irrigation. Basin Plan Tables 3-7 and 3-8 also establish waterbody-specific objectives for surface water and groundwater “sub-basins/sub-areas”. These objectives, which are based on annual mean or median values of datasets, include the following constituents for surface and ground waters: TDS, chloride, sulfate, boron and sodium. For ground waters waterbody-specific objectives have also been established for total nitrogen (as N).

2.2.4 Region 4: Los Angeles

Salt and nutrient-related water quality objectives have been established for selected surface waters and ground waters in the Region 4 Basin Plan. However, these are waterbody specific and not established specifically to protect the AGR beneficial use. Table 2 summarizes the ranges of objectives established for TDS, chloride, sulfate, boron, nitrate + nitrite (as N) and sodium absorption ratio (SAR). For surface waters that do not have specific objectives established, the Basin Plan includes guidelines for TDS, chloride, sulfate and boron for establishing effluent limits to protect the AGR beneficial use.

2.2.5 San Francisco/Sacramento-San Joaquin Delta Estuary

The State Board is responsible for the adoption of water quality objectives in this area of the state often referred to as the “Bay Delta”. Salinity or nutrient-related objectives have not been adopted to specifically protect the AGR use. However, the Bay Delta Basin Plan does include waterbody-specific EC objectives that vary by season and hydrologic condition (see Table 2 for a summary of the range of EC objectives included in the Basin Plan). These objectives are measured as the maximum 14-day running average of mean daily EC.

2.2.6 Region 5: Central Valley

Water quality in Region 5 is governed by one of two Basin Plans: Sacramento River - San Joaquin River Basin Plan or the Tulare Lake Basin Plan. In the Sacramento-San Joaquin Basin Plan, salinity or nutrient-related waterbody-specific objectives (TDS, EC and boron) have been established for selected surface waters. No numeric groundwater objectives have been adopted.

The Tulare Lake Plan includes a general salinity narrative that states for surface waters: “Waters shall be maintained as close to natural concentrations of dissolved matter as is

reasonable considering careful use of the water resources”. In addition, EC objectives have been established for selected surface waters and streamflow measuring stations. For groundwater a salinity narrative objective, similar to the wording above for surface water has been adopted. In addition, EC objectives have been established for hydrographic units that establish the maximum allowable average annual increase in EC.

2.2.7 Region 6: Lahontan

The Basin Plan does not include use-specific objectives to protect the AGR beneficial use. Instead, waterbody-specific objectives have been adopted for many surface water hydrologic units (or watersheds) and ground waters in the Mojave Hydrologic Unit. These objectives generally include the following constituents (actual constituents with objectives may vary by unit): TDS, sodium (as percent or SAR), chloride, sulfate, boron, various nitrogen-related constituents and, in a few areas, phosphorus (e.g., Tahoe Lake and Truckee River). Table 2 provides the ranges of objectives across hydrologic units. The Basin Plan also states that the taste and odor of ground waters in four specific hydrologic units may not be altered. While the Basin Plan does not relate this statement to salinity, certainly changes in concentrations of salt-related constituents may affect taste and odor.

2.2.8 Region 7: Colorado River

Region 7 represents the inland areas in the southeastern part of the state including portions of San Bernardino, San Diego and Riverside Counties. Although agriculture is a significant beneficial use in the region, particularly in the Coachella, Imperial, and Palo Verde Valleys, this region has only adopted limited salinity and nutrient water quality objectives (Table 2). Similar to other regions, these objectives are waterbody-specific and not established to protect a specific beneficial use.

2.2.9 Region 8: Santa Ana

Table 2 summarizes the surface waterbody-specific objectives established in this region’s Basin Plan for TDS, chloride, sulfate, sodium, and total inorganic nitrogen. Although not included in Table 2, Region 8 has also established hardness objectives for many surface waters. For groundwater, the Santa Ana Region has adopted TDS and nitrate-nitrogen objectives for Groundwater Management Zones. Basin Plan Table 4-1 includes both the historical ambient quality TDS and nitrate-nitrogen objectives (labeled as “antidegradation” objectives) and objectives based on consideration of a “maximum benefit” analysis in specific management zones. In addition, groundwater quality objectives have been adopted for sodium, chloride, and sulfate in two specific groundwater basins (Big Bear Valley and Gardner Valley).

2.2.10 Region 9: San Diego

Region 9 encompasses all of San Diego County and portions of Orange and Riverside counties. 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. Instead, as in many regions, waterbody-specific objectives have been established for salinity and nutrient related constituents, including TDS, sodium, chloride, sulfate, boron and nitrate. Table 2 summarizes the range of objectives applicable to the region.

Section 3: Federal and State Agency Water Quality Criteria

This section provides a review of federal documents used in developing water quality criteria to protect stock drinking water.

3.1 Federal

Under Section 304(a) of the Clean Water Act, the US Environmental Protection Agency (US EPA) publishes National Recommended Water Quality Criteria (NRWQC) that is used as guidance to adopt surface water quality standards. However, US EPA has not adopted specific criteria for stock watering. Instead, NRWQC are based on protection of human health and aquatic life beneficial uses that are more stringent than protection of stock water use. However, US EPA policy allows states to establish criteria to protect other beneficial uses such as stock watering.

USEPA and its predecessor agency (Federal Water Pollution Control Administration) published a series of water quality criteria documents that contain water quality criteria recommendations and provide supporting evidence for use of those criteria. The first publication occurred in 1968 followed by updates in 1973, 1976, and 1986 which were referred to as the Green, Blue, Red, and Gold Books, respectively (FWPCA 1968, NAS and NAE 1973, US EPA 1976, 1986). 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. For stock watering criteria, US EPA typically refers to the Green Book (FWPCA 1968) and the Blue Book (NAS and NAE 1973), which contain similar criteria recommendations. The Blue Book provides the following recommendations for dissolved minerals, boron, and nutrients for stock watering:

- **TDS:** “From the standpoint of salinity and its osmotic effects, waters containing 3,000 milligrams of soluble salts per liter or less should be satisfactory for livestock under almost all circumstances. While some minor physiological upset resulting from waters with salinities near this limit may be observed, economic losses on serious physiological disturbances should rarely, if ever, result from their use.”
- **Boron:** “Experimental evidence concerning the toxicity of this element is meager. Therefore, to offer a large margin of safety, an upper limit of 5.0 mg/L of boron in livestock water is recommended.”
- **Nitrate and Nitrite:** “In order to provide a reasonable margin of safety to allow for unusual situations such as extremely high water intake or nitrite formation in slurries, the NO₃N plus NO₂N content of drinking waters for livestock and poultry should be limited to 100 ppm or less, and the NO₂N content alone is limited to 10 ppm or less.”

In addition, the Blue Book provides a guide to the use of saline waters for livestock and poultry, as shown in Table 3.

The Gold Book (US EPA 1986) provides criteria for some dissolved minerals, boron, and nutrients for protection of beneficial uses other than stock watering. Table 4 provides a

summary of the water quality criteria of interest 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. However, these criteria are often important to States for adoption of site specific objectives or standards.

3.2 States

Water quality standards for several other western states were reviewed to identify water quality standards set specifically for stock drinking water. This review included the following states: Arizona, Colorado, Missouri, Nebraska, Nevada, South Dakota, and Texas.

3.2.1 Arizona

The Department of Environmental Quality is responsible for the adoption of water quality standards for the State of Arizona (Arizona Administrative Code Title 18, Chapter 11, Article 1). One of the narrative water quality standards states that the water quality must not be toxic to animals; however, Arizona has not set any numeric criteria specific to livestock drinking water for the constituents of interest in this review.

The state has established numeric water quality standards (annual mean, 90th percentile and not to exceed concentrations) for total nitrogen and phosphorus for a number of major river watersheds. These criteria are not use-specific. In addition, numeric targets for selected nutrient related constituents have been established in a number of lakes and reservoirs to protect human health, domestic water supply and aquatic life uses, e.g., total nitrogen ranges from 1.0 to 1.9 mg/L and total phosphorus ranges from 50 to 160 µg/L.

Arizona has also adopted TDS water quality standards for the portion of the Colorado River below Hoover Dam. These standards, which have been adopted by all Colorado River Basin states as required by EPA and the Colorado River Basin Salinity Control Forum, are described below in Section 3.2.2.

3.2.2 Colorado

The Colorado Department of Public Health and Environment develops water quality standards recommendations that are subject to consideration by the Colorado Water Quality Control Commission. Water quality criteria associated with the agricultural beneficial use are evaluated based on the most sensitive agricultural use. For example, livestock tolerate higher concentrations of boron yet the water quality criterion was based on boron-sensitive crops thus the maximum boron level for groundwater under Regulation 41 (5 Code of Colorado Regulations [CCR] 1002-41) 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 5). 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 6 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 set its standards to protect stock drinking water but to protect the most sensitive use within the basins. In addition to Regulation 41, Regulation 39 (5 CCR 1002-39) provides narrative guidance for surface water TDS limits. The State of Colorado participates in the Colorado River Basin Salinity Control Forum which has established the following flow-weighted annual average numeric TDS criteria for the lower Colorado River (note these are the same criteria established by the Colorado River Basin Region (Region 7):

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

Colorado recently adopted interim numerical values for total nitrogen and phosphorus under Regulation 31 (effective as of January 31, 2013) (5 CCR 1002-31) to protect aquatic life. The established criteria vary by waterbody type and protection of cold or warmwater species. For example, the total nitrogen criteria range from 426 – 910 µg/L for lakes and reservoirs, respectively, and 1,025 to 2,010 µg/L for protection of cold and warmwater species. These criteria are not self-implementing, that is, they will be used as the basis for adopting waterbody-specific nitrogen water quality standards, where deemed appropriate, after May 31, 2017.

3.2.3 Missouri

The Missouri Department of Natural Resources (Department) 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 protection. The state has established that “no acute toxicity” should occur to livestock due to water quality conditions; however, the state has not set any numeric criteria for protecting livestock watering and wildlife for the constituents of interest. Salinity and nutrient limits have been adopted for protection of other beneficial uses (Division 20, Chapter 7 [Water Quality] of the Code of State Regulations):

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

3.2.4 Nebraska

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

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

- Nitrite as N = 1 mg/L

For agricultural beneficial uses, the Nebraska divides surface water criteria into two classifications with Class A representing irrigation and livestock watering and Class B representing waters with background constituent concentrations that limit the use by Class A activities. Class A water quality standards are: not to exceed 2,000 $\mu\text{mhos/cm}$ (2.0 dS/m) for EC and not to exceed 100 mg/L for nitrate + nitrite (N) between April 1 and September 30. Criteria were not assigned to Class B waters under Title 117 for the protection of agricultural beneficial uses.

3.2.5 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 livestock watering. The maximum livestock watering concentration for boron is set at 5.0 mg/L and the water must be suitable for watering of livestock without treatment. In addition, waterbody specific criteria have been established for various salt and nutrient-related constituents. TDS water quality levels are assigned either a criteria of: 1) less than or equal to (\leq) 500 mg/L or the 95th percentile (whichever is less) or 2) \leq 1,000 mg/L. Water quality concentrations for chloride and sulfate are set at \leq 250 mg/L and \leq 250 mg/L, respectively. Nitrate and nitrite concentrations are set at \leq 90 mg/L N and \leq 5.0 mg/L N, which differ from standards for these constituents set by many states. As stated in the Nevada code, nitrate within state waters must not come from any source other than a natural source of nitrogen.

3.2.6 South Dakota

Under the Administrative Rules of South Dakota, the Department of Environment and Natural Resources establishes surface water quality standards. Administrative Rule 74:51:01:52 sets the criteria for stock watering but also includes the beneficial uses of fish and wildlife propagation, and recreation. For TDS, \leq 2,500 mg/L for a 30-day average or \leq 4,375 mg/L daily maximum is allowed in surface water while the 30-day average for EC is \leq 4.0 dS/m and \leq 7.0 dS/m for a daily maximum. Only NO_3 as N was listed for nutrients, for which a permitted level of \leq 50 mg/L for a 30-day average or \leq 88 mg/L daily maximum is listed.

South Dakota classifies its ground waters by TDS. All ground waters with a TDS of $<$ 10,000 mg/L are subject to the following salinity and nutrient criteria unless the ambient concentration falls below the criteria:

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

3.2.7 Texas

The State of Texas regulates water quality standards under Texas Administrative Code Chapter 307. Agricultural beneficial uses are recognized within the state. However, it is only domestic water, recreational, and aquatic life beneficial uses that receive specific water quality criteria.

Site-specific objectives for TDS, chloride, and sulfate have also been established for most surface waters, but these criteria (maximum annual averages) are not established to protect any specific beneficial use. In general nutrient levels should be such that no excessive growth of vegetation occurs. No numeric criteria have been established for nitrogen species, but chlorophyll a criteria have been adopted for many reservoirs.

Section 4: International Water Quality Criteria

This section summarizes the review of documents from international organizations used in developing water quality guidelines for stock drinking water.

4.1 International

4.1.1 Food and Agriculture Organization of the United Nations

The Food and Agriculture Organization of the United Nations (FAO) published *Water Quality Guidelines* (Ayers and Westcot 1985; originally published in 1976), which includes guidelines for salinity, boron, and nutrients in stock drinking water. These guidelines are widely used by many of the international and university extension guidelines that have adopted criteria for beneficial use of stock drinking water.

Table 7 provides salinity guidelines, using EC, for stock drinking water, based on work from the NAS and NAE (1973) and NRC (1974), as reported in Ayers and Westcot (1985). The FAO guidance 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 limits. Each of these factors either contributes or influences salinity concentrations in water throughout the year, which 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 guidelines assume that the effect is from total salt content (osmotic effect) and state that "... from a salinity standpoint, livestock drinking water with an EC level less than 5 dS/m should be satisfactory under any circumstances." 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 should be observed when water quality changes occur.

Table 8 provides guidelines for additional water quality parameters including magnesium, boron, and nitrate. The magnesium concentrations recommended are based on an Australia Water Resources Council (AWRC) 1969 publication from Australia (AWRC 1969), in which magnesium was given particular attention due to negative health effects in livestock. However, more recent publications from the University Extension services have documented that the effect attributed to magnesium results from magnesium sulfate or from waters with high sulfate concentrations (See Section 5.1.5).

4.1.2 Canada

In 1987, the Canadian Council of Ministers of the Environment (CCME) established drinking water quality guidelines for livestock. Those guidelines are non-binding recommended water quality limits that are currently used by the various provinces. Table 9 provides a summary of the present guidelines for maximum recommended limits for protection of stock drinking water (Canada 2012). Table 9 also provides guidance from the Canada Plan Service (2001), similar to a State University Extension, as discussed in Section 5) for poultry and from Olkowski (2009) for horses. The recommendations for poultry appear to be based primarily on Cater and Sneed 1987 (revised 1996), which provides guidance for selecting well water sources to minimize effects on poultry performance and has not been used by regulatory agencies in setting stock watering guidelines (see Section 5).

The CCME guidelines establish a recommended TDS maximum limit of 3,000 mg/L for all classes of livestock. The Canada Plan Service (2001) recommends TDS limits of <1,500 mg/L for young turkey poults, 3,000 mg/L for young poultry, and 4,000 mg/L for mature poultry.

Magnesium and sodium alone were classified as having no health risk to the animals but when sulfate is present in the water, a laxative effect could occur. Although a maximum of 1,000 mg/L of sulfate was considered safe, the guidelines recognize that sulfate may result in a detrimental effect in livestock based on the weight and age of the animal. Sulfate concentrations 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 concentrations at 125 mg/L potentially may cause a drop in water consumption for livestock due to taste.

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 (Australian and New Zealand Environmental and Conservation Council, Agriculture and Resource Management Council of Australia and New Zealand [ANZECC/ARMCANZ 2000] 2000). 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 the two nations. The NWQMS identifies three dominant beneficial uses which include ecosystems, primary industries and human health, with livestock drinking water included as a subset of the primary industries. The guidelines are based on observed data that include several factors such as animal weight, water intake, and a safety factor. The recommended guidelines represent recommended limits with no health risks (ANZECC/ARMCANZ 2000). Table 10 summarizes guidelines for TDS, while guidelines for specific dissolved mineral, boron, and nutrient constituents are provided in Table 11.

4.1.4 South Africa

The Department of Water Affairs and Forestry establishes federal water quality guidelines for livestock drinking water in South Africa. The Department selects guidelines based on several factors including water uptake, animal weight and synergistic effects when measurable. The concentrations 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 concentrations greater than 1,500 mg/L. For other livestock such as cattle, sheep, and other ruminants, the target water quality can reach up to 3,000 mg/L before observing an adverse health effect.

Nitrate levels are based on two factors: (a) ruminant vs. monogastric; and (b) pregnant vs. 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.

Table 12 represents the salinity, boron, and nutrient guidelines for stock drinking water in South Africa. TDS guidelines do not provide a specific recommended level. However, guidance is provided on TDS concentrations 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 as 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 a higher level of TDS water can be tolerated and vice versa. .

Section 5: University Extension Water Quality Guidelines

This section reviews water quality criteria for stock drinking water identified in selected University Extension programs at universities known for strong agricultural programs. These Universities 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, North Dakota State University, University of Wyoming, and New Mexico State University.

Of the publications reviewed, information primarily focused on TDS and nitrate concentrations but information was found on other dissolved minerals, boron, and nutrient constituents of interest. The majority of the cooperative extension recommendations are based on the following publications: NAS and NAE (1973), NRC (1974), and NRC (2001). Although these publications serve as the basis for many of the recommendations, stock drinking water recommendations represent wide ranges of data for salinity, boron, and nutrient constituents and only occasional consensus was identified when using data beyond the NAS and NAE and NRC publications. However, the most recent publications show that higher concentrations of salinity constituents can be tolerated by livestock when compared with some of the numerical values currently used as guidelines in Regional Board Basin Plans and NAS and NAE and NRC publications.

5.1 Salinity (Dissolved Minerals)

University Extensions provide water quality guidelines for dissolved minerals including TDS and EC, sodium, hardness (calcium and magnesium), chloride, and sulfate. The recommendations for poultry appear to be based primarily on Cater and Sneed 1987 (revised 1996), which provides guidance for selecting well water sources to minimize effects on poultry performance and has not been used by regulatory agencies in setting stock watering guidelines.

5.1.1 TDS and EC

Table 13 shows the increasing health effects and level of safety needed for stock drinking water at various TDS and EC concentrations (NRC 2001). University Extension publications widely recommend an upper limit for cattle of 10,000 mg/L (and EC of 1.5 dS/m), whereas for poultry, which are considered much more sensitive to TDS, the recommended upper limit is in the range of 3,000 - 5,000 mg/L (1.5-5 dS/m). The Iowa University Extension Service determined that 3,000 mg/L is a safe TDS level for swine production (Lammers, et al. 2007). Additional studies reported by University Extension publications show that consumption of water with concentrations of 4,400 mg/L TDS by cattle showed no difference in milk production and concentrations of 6,000 mg/L TDS do not adversely affect feedlot cattle (Payne and Zhang 2012).

5.1.2 Sodium

Table 14 summarizes the health effects of sodium on livestock and poultry based on the guidelines in various University Extension publications. In most cases, the effect of higher sodium concentrations in water tend to increase water consumption by livestock which allows most species to compensate for the loss of water resulting from diuretic effects that high sodium may cause. In cattle, sodium concentrations greater than 800 mg/L result in a decrease

in milk production (German et al. 2008). Above 4,000 mg/L sodium (10,000 mg/L sodium chloride), more severe effects occur including sodium ion toxicosis and increased mortality.

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 concentrations especially when sulfate is present (German et al. 2008).

5.1.3 Hardness (Calcium and Magnesium)

Hardness measures the concentration of divalent cations in water, often expressed as the sum of magnesium and calcium concentrations in equivalents of calcium carbonate. The concentrations of magnesium and calcium do not have direct health effects in livestock but high hardness concentrations may 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 concentrations in water. Lammers et al. (2007) recommend a safe level of 1,000 mg/L calcium for swine. Waters containing high magnesium or calcium sulfate are known to produce laxative effects in livestock and poultry, but most University Extension bulletins attribute this to sulfate rather than the magnesium or calcium (see later discussion under sulfate). Poultry suffer wet droppings with higher levels of magnesium sulfate in the water.

5.1.4 Chloride

No data were found related to chloride and stock drinking water among the University Extension Services surveyed. Raisbeck et al. (2008) indicate that chloride is primarily an aesthetic issue and is associated with a salty taste in the water. However, they cite a single study in which cattle refused to drink water containing 5,000 mg/L of calcium chloride, even though this water was the only available source. At 3,000 mg/L of calcium chloride, the cattle showed an increase in consumption, but no health effects were observed.

5.1.5 Sulfate

Sulfate is cited in 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 (see Table 15). In swine, Iowa State University Extension Service cites 1,000 mg/L as the safe sulfate concentration (Lammers et al. 2007) while in cattle, an overall increase in sulfate from 400 to 4,700 mg/L was observed to cause a decline in daily weight gain-to-dry matter intake. In ruminants on grain diets, sulfate greater than 3,000 mg/L increased the risk of polioencephalomalacia (PEM -necrosis of specific regions of the brain). Studies also showed that 3,045 mg/L of sulfate reduced weight gains in calves and milk production while at 2,600 mg/L of sulfate no health effects occurred in cattle (German et al. 2008). The Kentucky Extension recommends that the maximum sulfate concentration not exceed 500 mg/L sulfate and 1,000 mg/L sulfate for calves and adult cattle, respectively (Higgins et al. 2008).

5.2 Boron

Although there has not been significant research related to the effects of boron in livestock drinking water, the University Extension publications reviewed all reported 5.0 mg/L boron as the maximum safe concentration for this constituent in stock drinking water. Boron in water is

known to slow growth in livestock while concentrations between 150-300 mg/L cause edema and inflammation in cattle (Runyan et al. 2009).

5.3 Nutrients

University Extensions provide water quality guidelines for nitrate and nitrite, but no information was found for other nitrogen species or phosphorus.

5.3.1 Nitrate and Nitrite

Table 16 summarizes the health effects of nitrate in water as shown in various extension service bulletins. High nitrate concentrations are a concern in stock feed water because of “nitrite poisoning”, which actually depends on the reduction of nitrate to nitrite in the upper gastrointestinal track where it can be absorbed into the bloodstream and potentially leading to asphyxiation (methemoglobinemia) in livestock. Although methemoglobinemia is seen in livestock and is the most severe consequence of high nitrate concentrations, nitrate in water is tolerated by animals at higher concentrations as compared with humans. However, chronic exposure to nitrate can result in milder symptoms including poor growth, infertility, reduced vitamin A absorption, and lower milk production. Swine and poultry, which are monogastric, can tolerate higher concentrations of nitrate than 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 nitrite. Nitrite for all species has higher toxicity than nitrate and is tolerated at much lower concentrations.

In determining the recommended concentrations of nitrate in water, University Extension publications concur that the nitrate in feedstock must be taken into consideration in conjunction with water consumption rate. As a result, one publication considers an upper safe limit for cattle for nitrate of 300 mg/L as N (Faries et. al.1998), while some University Extension publications suggest that ranges of 51-150 mg/L as N or 100-300 mg/L as N would increase the risk of death in cattle unless nitrate in the feed is low. This latter guidance appears to be based on an NRC publications (NRC 1974, 2001), which may be outdated (see discussion in Section 6.4.1). Other University Extension publications adopt the NAS and NAE (1973) upper limit guidelines of 100 mg/L (as N) for nitrate plus nitrite and of 10 mg/L (as N) for nitrite alone. These ranges in the guidelines result from the uncertainty associated with consumption rates of nitrates from feedstock and water.

Section 6: Review of Relevant Literature

This section presents a review of relevant literature related to the effects of selected salinity (dissolved minerals), boron, and nutrient constituents in stock water on livestock and poultry.

6.1 Scope of Literature Review

The literature reviewed includes peer-reviewed journal articles, animal nutrition textbooks, NRC reports (publications of the National Academy of Sciences) related to animal dietary requirements, and other relevant publications. The intent of this review is to identify existing scientific information to facilitate development of criteria for livestock and poultry drinking water quality for constituents included in this report. Two previous works completed by Region 5 were used as the starting point for the literature review: 1) *Salinity: A Literature Summary for Developing Water Quality Objectives* (Davis 2000); and 2) *Boron: A Literature Summary for Developing Water Quality Objectives* (Davis 1999). A large number of publications were reviewed, but only the references cited in the following subsections are included in the reference section of this report. One cited publication (Carter and Sneed 1996), which focuses on drinking water for poultry, was reviewed but the findings were not included in the findings or recommendations of this report. This decision is based on the anomalous nature of the document's recommendations¹.

The primary animal groups evaluated include beef cattle, dairy cattle, sheep and goats, horses, swine, and poultry (broilers, layers, turkeys). 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.

The constituents of interest in the remainder of this section are presented in three major groups: dissolved minerals, boron, and nutrients. The dissolved minerals (salinity) section includes TDS and EC, sodium, calcium, magnesium, chloride, and sulfate. The trace element boron is addressed in its own section. The nutrient section addresses nitrogen and phosphorus species.

6.2 Dissolved Minerals

This section addresses dissolved mineral constituents including salinity (TDS and EC), sodium, calcium, magnesium, chloride, and sulfate.

¹ The recommendations contained in Carter and Sneed (1996) for poultry drinking water in North Carolina are anomalous when compared to all other literature, that is, they are much lower than what other publications recommend. For example, Carter and Sneed (1996) states that studies show that sodium concentrations above 50 mg/L are detrimental to broiler performance, in particular if the sulfate concentration is also 50 mg/L or higher and the chloride concentration is 14 mg/L or higher. The reference in the document to "studies" that provide the basis for the recommendations are not cited in Carter and Sneed; therefore, the basis for the low numbers is unclear. One possible reason for the low concentrations has to do with the purpose of the document, i.e., it was directed to users of well water and the values provided are often provided in contrast to typical well water concentrations of the same constituent. Regardless of the reason for the difference, it is notable that the recommendations have not been used by any US or international government publication that establishes guidelines for stock watering. Therefore, while the document is acknowledged, it will not be used as a basis for recommendations in this document.

6.2.1 Salinity (TDS and Electric Conductivity)

The peer-reviewed literature showing a connection between salinity and livestock tolerance is quite limited and reported results vary considerably. The variability is likely due to the lack of information of individual ions represented by TDS, as certain ions in saline water can be extremely detrimental to animal performance and can, in some cases, be fatal (Wright 2007). The literature reviewed generally presents salinity data in terms of TDS rather than EC. In general, stock water with TDS concentrations less than 1,000 mg/L (~ EC 1.5 dS/m) is suitable for most livestock while concentrations higher than 10,000 mg/L are not recommended for any livestock uses under any conditions (NRC 1974).

Several studies report 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 TDS concentration less than 2,500 mg/L should not suffer any health or performance issues (Beede 2005; Olkowski 2009). Highly saline water itself is not likely to be problematic for beef cattle. 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 (2009) reported higher acceptable 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 affected by TDS than other livestock, as discussed above. 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 TDS 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.

Raisbeck et al. (2008) state that for water with a TDS concentration above 500 mg/L, the individual constituents contributing to TDS should be identified, quantified, and evaluated. This recommendation was based on the finding that water quality constituents such as TDS and EC, by themselves, may not provide consistent protection for different water sources.

6.2.2 Sodium

Sodium (Na^+) is a primary cation in extracellular fluid and is commonly supplemented in 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. Most of the toxic effects of sodium chloride are due to the sodium content rather than the chloride. Stock animals have an adaptive ability with sodium concentrations that allows them to adjust to higher doses over time, but a higher dose given abruptly will cause more serious reactions. Toxicity of sodium chloride is related to the availability of water (water intake increases with elevated sodium intake) (Jaster et al. 1978), but if a dose of sodium 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 concentrations of sodium of 6,726 mg/L or higher were consumed in water, death resulted in at least some animals (Weeth and Lesperance 1965, Ohman 1939). As expected, some variability exists among experiments when sodium toxicity is experimentally induced. Also, animals can adapt to doses that increase over time such that eventually they can tolerate doses that would cause adverse effects if experienced during a short term exposure. 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 sodium chloride (2,000 mg/L 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 (Raisbeck et al. 2008).

Studies with sheep drinking water containing 15,000 mg/L sodium chloride (5,900 mg/L sodium) showed decreased feed consumption and reduced body weight, and water with concentrations of 10,000 – 13,000 mg /L sodium chloride (3,900 – 5,100 mg/L sodium) caused complications including increased incidence of stillborn and increased 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 sodium chloride. One study reported that abruptly switching gilts to a diet containing 13,600 mg/L sodium chloride (5,350 mg/L sodium) resulted in feed refusal and diarrhea (Pretzer 2000).

6.2.3 Calcium

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

6.2.4 Magnesium

Magnesium (Mg^{++}) is required for normal metabolism and is an important component of extracellular fluid and bones. It is generally described in combination with sulfate (MgSO_4) or as a component of “hardness” along with calcium. Hardness does not seem to have any measureable effects on animal health or production at even high concentrations commonly found in drinking water, so magnesium is rarely a part of a drinking water analysis for livestock. In fact, most published literature relates to magnesium as a dietary supplement to improve production, rather than on threshold or toxicity levels (Frederick et al. 2006a,b, Peeters et al. 2006, Atteh and Leeson 1983). 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 magnesium concentrations that are considered to have no effect on overall productivity. Studies with sheep (Peirce 1959 and 1968) reported maximum magnesium concentrations of 250 mg/L for young stock, 400 mg/L for lactating stock, and 500 mg/L for dry mature animals. Later work

found that there was no adverse effect on young cattle using water with up to 500 mg/L magnesium (Saul and Flinn 1985). Peterson (2000) suggests an upper limit of 300-400 mg/L for lactating dairy cattle.

6.2.5 Chloride

Chloride (Cl⁻) is commonly considered in combination with sodium or calcium in water sources. Hence, only limited data are available on the specific effects of chloride. Raisbeck et al. (2008) stated that, “[t]he limited data available regarding Cl⁻ in water seems to indicate that it is primarily a palatability factor.” Mathieu and Pelletier (1966) reported that drinking water with 3,000 mg/L of calcium chloride (1,920 mg/L chloride) showed increased water intake coupled with urinary acidification for cattle, but resulted in no effect on cattle performance or health. They further reported that cattle refused to consume water containing 3,200 mg/L of chloride even when deprived of water for 18-24 hours. Data with higher concentrations are not available.

6.2.6 Sulfate

Sulfate (SO₄²⁻) in high concentrations in stock drinking water can lead to laxative effects and such waters are usually not suitable for livestock and poultry. High dietary sulfur in ruminants can cause various ailments leading to poor productivity, as well as death. The relative toxicity of sulfate 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 (e.g., lactation, etc.) and environmental temperature. Because of this, sulfate concentrations in drinking water are often referenced in the literature only as a percentage relative to overall sulfate intake, rather than as individual threshold concentrations in the water alone. In one example, 1,000 mg/L sulfate in stock drinking water contributed from 0.1 – 0.27% of total sulfate intake under differing conditions (Olkowski 1997).

The effects of elevated sulfate levels in stock drinking water are also variable. The toxicity of sulfate in sheep and cattle often is tied to Polioencephalomalacia (PEM), a neurological condition that can be fatal. One report on drinking water with sulfate concentrations at 2,000 mg/L reportedly 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 sulfate ranging from 1,000 – 3,000 mg/L (Loneragan et al. 2001, Harper et al. 1997). Although cattle will still drink water with toxic concentrations of sulfate, a preference test showed that concentrations of sulfate of 1,450 mg/L were discriminated against by cattle, and water with 2,150 mg/L of sulfate was rejected if other sources were available (Weeth and Capps 1972). While Digesti and Weeth (1976) reported that up to 2,500 mg/L of sulfate in cattle drinking water caused no change in productivity, others have reported much lower concentration (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 sulfate in cattle drinking water of 500 mg/L have been shown to reduce copper absorption in the gastrointestinal tract (Gooneratne et al. 1989, Smart et al. 1996).

Concentrations of SO₄ that are safe in ruminants should provide adequate protection for horses, as they are monogastric and are at less risk of toxic effects of sulfate that involve ruminal generation of sulfide (Raisbeck et al. 2008). Based on normal dietary and environmental

conditions, sulfate concentrations in livestock drinking water below 1,800 mg/L should minimize the possibility of acute toxicity (death) in cattle. Concentrations less than 1,000 mg/L should not result in any measurable loss of performance (Raisbeck et al. 2008).

6.3 Boron

Boron 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. Identification of a clearly defined specific biochemical function is a major obstacle to wide acceptance of boron importance to animals (NRC 2005).

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. For example, in 2003, an NRC committee was convened on minerals and toxic substances in diets and water for animals (NRC 2005). That committee concluded that cattle consuming water containing 150-300 mg/L boron exhibited toxicity signs including decreased food consumption and weight. The committee also concluded that it is unlikely that boron toxicity under normal environmental conditions is a concern for animals (NRC 2005).

While limited information exists on guidelines for stock watering, a recommended boron concentration of less than 5.0 mg/L has evolved over time (Moss and Nagpal 2003). Recommended concentrations in guidelines for boron in stock water are discussed in Section 3 (federal and states) and Section 4 (International) of this report, Table 17 provides a summary of recommended boron concentrations that support the 5.0 mg/L recommended concentration.

Australia and New Zealand have developed water quality guidelines for agricultural water use under the NWQMS (also see Section 4). The guidelines recommend that if boron concentration in water exceeds 5.0 mg/L, the total boron content of the livestock diet should be investigated. The guidelines also acknowledge that higher concentrations in water may be tolerated for shorter periods of time (ANZECC/ARMCANZ 2000). The guidelines are based on principles adopted for the World Health Organization (WHO) and result in guideline values for various types of livestock ranging from 5.8 (pigs) to 11.3 (chicken) mg/L of boron (Moss and Nagpal 2003) (Table 18). The approach of ANZECC/ARMCANZ is an important contribution to the literature as it takes into account factors such as body weight and water intake that are missing in many other works.

The 2005 NRC publication 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 states that excessive exposure to boron is rare and established a dietary Maximum Tolerance Level 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 tolerance level without harming the animals (ANZECC/ARMCANZ 2000; Weiss 2008).

6.4 Nutrients

The nutrients considered include both nitrogen (total N, TKN, organic N, nitrate, and nitrite) and phosphorus (total and dissolved orthophosphate) species. The literature review identified only

nitrate, nitrite, and ammonia as having potential impacts on stock drinking water and the discussion below is limited to those constituents.

6.4.1 Nitrate and Nitrite

The maximum daily intake of nitrate should consider all sources of nitrate intake (both plant tissue and drinking water). Nitrate is not as toxic as the related molecule, nitrite (NO_2^-). For ruminant animals, nitrate is 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 and nitrite concentrations, 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 19 (NRC 1974, 2001) presents NRC guidelines for nitrate in stock drinking water, which are often cited by University Extensions. These guidelines were derived from older, fragmented studies and may be out of date. As discussed in Section 4, Canada has set livestock watering guidelines for nitrate and nitrite at 100 mg/L N and 10 mg/L, respectively, and Australia has set similar guidelines. Additional studies, discussed below suggest that stock animals have higher tolerance to nitrate than indicated in Table 19.

Experimental data related to nitrate poisoning is somewhat sparse. The lowest dose of nitrate reported to produce adverse effect in cattle among the studies reviewed is less than 200 mg NO_3^- /kg body weight (BW). However, several experiments reported in literature failed to produce any adverse effect at considerably higher concentrations (as much as 800 mg/kg BW) or doses (Raisbeck et al. 2008). Raisbeck et al. (2008) indicates that exposure to 500 mg/L nitrate (110 mg/l N), equivalent to 100 mg/kg BW, is acceptable assuming negligible nitrate in feed.

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 (Sørensen 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).

Although nitrite is considered more toxic than nitrate, especially in non-ruminants, this review did not find information on quantitative dose-response data for oral exposure in livestock or wildlife. However, NRC (2005) recommends keeping nitrite concentrations low (about 10 percent of nitrate concentration) to compensate for nitrite formation in slurried feedstuffs for swine. This practice is no longer common, nor is the caveat appropriate to range conditions. Raisbeck et al. (2008) notes that further research is needed in this area and suggests that 100 mg/L nitrite (30 mg/L N) should not cause poisoning in livestock.

6.4.2 Ammonia

Original research addressing ammonia concentrations in stock drinking water do not appear in the literature reviewed, although one report of an accidental ammonia exposure took place at a Midwest county fair in Illinois was found (Campagnolo et. al. 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 mg/L. Although elevated nitrate (>6,000 mg/L) concentrations were discovered in the water buckets and troughs, the clinical signs associated with nitrate poisoning were not evident in the animals affected.

6.5 Summary

Table 20 provides a summary of concentrations of dissolved minerals, boron, and nutrients that were identified as tolerable (i.e., would not be expected to serious effects in stock animals) in stock drinking water. Where appropriate, differences among animal species of young and adults are included to help identify the most vulnerable of the livestock species.

Section 7: Findings and Water Quality Goal Recommendations

This section presents the key findings of this study and provides recommendations on a range of water quality criteria that are potentially applicable to stock water use in the Central Valley Region.

7.1 Findings

The overall assumption regarding stock drinking water is that for individual salinity constituents, safe concentrations for stock watering are higher than those required to protect other beneficial uses including human drinking water, aquatic life, and crop irrigation. Therefore, limited numeric water quality criteria exist for stock watering but, narrative objectives are found in various agency documents. In California, only Regions 2 and 3 have adopted specific salinity or nutrient objectives for protection of a stock watering beneficial use. International water quality objectives tend not to set criteria but rather provide guidelines regarding the most appropriate ranges for salt and nutrients in water.

Specific findings for the protection of stock watering identified in this study include:

Dissolved Minerals

- Canada's recommended guideline for TDS is 3,000 mg/L while in the US the range is between 1,000 to 10,000 mg/L. However, much of the literature indicates that criteria for individual ions (e.g. sulfate) rather than TDS may be more appropriate to characterize toxicity related to TDS. For example, Raisbeck et al. (2008) suggests that for TDS above 500 mg/L (EC above 0.75 dS/m), the individual constituents contributing to TDS should be identified, quantified, and evaluated.
- Although sodium chloride is often discussed as one constituent in the literature, it is sodium that is primarily responsible for toxic effects. The limited data available regarding chloride in water seem to indicate that water quality concerns associated with chloride are primarily associated with palatability. Although there is some adaptive ability of animals to adjust to long-term sodium exposure, overall, evidence from the literature suggests that there are no adverse effects at levels of 1,000 mg/L of sodium (palatability effect) for livestock, with serious effects – including death – not likely to occur unless the concentration exceeds 5,000 mg/L sodium.
- The main adverse effect of elevated magnesium in the overall diet (feed and water intake) is related to diarrhea, leading to differing conclusions concerning the concentration of magnesium that is considered to have no effect on overall productivity. Studies with sheep have reported no adverse effects at maximum magnesium 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.
- Recommendations regarding safe sulfate concentrations in stock water are extremely variable, and directly related to the percentage of total dietary sulfate intake of the animal.

Based on normal dietary and environmental conditions, keeping sulfate concentrations in stock drinking water below 1,800 mg/L should minimize the possibility of acute toxicity (death) in cattle. Sulfate concentrations less than 1,000 mg/L should not result in any easily measured loss of performance.

Boron

- Overall, evidence in the literature suggested that boron concentrations of 5.0 mg/L in stock drinking water would be protective of livestock health.

Nutrients

- There is extensive literature concerning nitrate and nitrite concentrations in drinking water for livestock. Total daily nitrate/nitrite intake is an important factor to consider because nitrates/nitrites are contained in plant tissues as well as drinking water. A general guideline found throughout the literature is an upper threshold for livestock and poultry of 100 mg/L for nitrate as N and 10 mg/L for nitrite as N. Some researchers report problems at lower concentrations; however, some publications indicate that much higher concentrations of these constituents in stock drinking water do not result in detrimental effects. There is also a lack of uniformity to reporting nitrate and nitrite as the ions NO_3^- and NO_2^- versus reporting both as N. However, the threshold values of 100 mg/L and 10 mg/L for nitrate and nitrite as N, respectively, are the dominant guidelines in use and referenced in the majority of publications dealing with these nutrient constituents in stock drinking water.

7.2 Recommended Water Quality Goals

Table 21 provides a range of concentrations for salinity, boron, and nutrient constituents that should be tolerable to livestock and may be considered for establishment of water quality objectives to protect a stock water beneficial use. The lower concentration values (Column 2 of Table 21) should result in no health effects in animals and the upper tolerable concentration (Column 3 of Table 21) should not result in serious health effects, but some mild effects or loss in productivity may be observed in the most sensitive species². Other factors such as high levels of a constituent in feed stock may require use of stock water with concentrations below the upper tolerable level.

In general, salinity and nutrient-related water quality concentrations necessary to protect a stock watering beneficial use are substantively higher than concentrations required to protect other Central Valley beneficial uses, including municipal and domestic supply, aquatic life, and agricultural crop irrigation. Even nitrate and nitrite, although potentially toxic to ruminant livestock, are generally found to be tolerable at concentrations an order of magnitude higher than the water quality objectives established to protect MUN (i.e., 10 mg/L nitrate as N). Table 21 presents recommended ranges of water quality concentrations for protection of a stock watering beneficial use that may be considered for the development of a Basin Plan amendment. Following is a summary of the range of potential water quality criteria deemed protective for various constituents evaluated as part of this Study.

² As discussed above, we have discounted information from University Extension guidelines and instead based the range of recommended water quality goals on government agency guidelines.

7.2.1 Dissolved Minerals

A range of potential water quality criteria are recommended for consideration for TDS and EC, sodium, chloride, and sulfate. No potential criteria are proposed for calcium and magnesium.

7.2.1.1 TDS and EC

TDS (or EC) is expected to continue as a primary indicator of salinity in water, with the primary concern being palatability of the stock water source. The literature review showed that livestock of all types tolerate higher TDS (EC) levels than humans with the most protective level ranging between 1,000 - 2,500 mg/L (1.5 - 3.8 dS/m). The most susceptible group is poultry. The highest concentration of TDS (EC) exposure with no health effects to sheep and goats is 5,000 mg/L (7.5 dS/m).

7.2.1.2 Sodium

Similar to TDS, concerns regarding sodium generally relate to palatability. Canada and Australia have not adopted guidelines for sodium, while South Africa has set a no health effects target limit of 2,000 mg/L.

7.2.1.3 Chloride

Limited information exists for chloride toxicity in association with stock drinking water. This information suggests that chloride concentrations protective of stock drinking water are higher than concentrations recommended for protection of municipal and domestic water supplies. The limited data available regarding chloride in stock water suggest that chloride effects are primarily related to palatability of the drinking water source. Canada and Australia have not adopted guidelines for chloride, while South Africa has set a no health effects target limit of 1,500 mg/L chloride.

7.2.1.4 Sulfate

Sulfate in livestock drinking water can be tolerated at concentrations much greater than what is tolerated for humans. At 1,000 mg/L of sulfate no health effects are seen in any type of livestock. A concentration of 1,800 mg/L of sulfate is considered safe but it is necessary to account for other sources of sulfate in the diet at this concentration. The most sensitive livestock with regards to sulfate is cattle. This sensitivity is attributed to the anaerobic environment in the rumen of cattle which reduce sulfates to sulfites (a more toxic version of sulfur ions).

7.2.2 Boron

All agencies and university extension publications recommend a maximum concentration of 5.0 mg/L boron in water to protect livestock. Some published literature suggest that concentrations above 5.0 mg/L are acceptable with swine being the most sensitive livestock. For example, 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.

7.2.3 Nutrients

A range of potential stock drinking water criteria are proposed for nitrate and nitrite. No criteria are proposed for total nitrogen, ammonia, Kjeldahl nitrogen, or organic nitrogen, or for phosphorus.

Livestock tolerate higher concentrations of nitrate and nitrite tolerance than humans. Nitrate and nitrite in stock water may result in methemoglobinemia where oxygen in red blood cells is replaced by nitrate or nitrite thus leading to suffocation. Ruminants and horses are the most susceptible to 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 concentrations are low in water. Generally, most publications indicate that even when other sources of nitrate are present, 100 mg/L of nitrate (N) and 10 mg/L of nitrite (N) are safe concentrations in stock drinking water sources.

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Tables

Table 1. Water Quality Objectives for Stock Watering in Basin Plans

Regional Board	Dissolved Minerals							Trace Element	Nutrients	
	TDS (mg/L)	EC (dS/m)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (mg/L)	SO ₄ (mg/L)	B (mg/L)	NO ₃ +NO ₂ (mg/L)	PO ₄ (mg/L)
1	NA ^(a)	NA	NA	NA	NA	NA	NA	NA	NA	NA
2	10,000	NA	NA	NA	NA	NA	NA	5.0	100	NA
3	NA	NA	NA	NA	NA	NA	NA	5.0	100 ^(b)	NA
4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Notes:

- (a) NA = not applicable (no objective specific to stock watering has been adopted)
- (b) The Region 3 Basin Plan also has an objective of 10 mg/L for nitrite for livestock watering for the AGR beneficial use, as also noted below in Table 2.

Table 2: Other Dissolved Mineral, Trace Elements, and Nutrient Objectives or Criteria from the Various Water Quality Control Board Basin Plans

Regional Board	Beneficial Use	Water Quality Parameter							
		TDS (mg/L)	EC (micromhos/cm)	Na (mg/L), SAR (meq/L), and %Na	Cl (mg/L)	SO ₄ (mg/L)	B (mg/L)	Nitrogen Compounds (mg/L)	Phosphorus (mg/L)
North Coast Region (Region 1)	Inland Waters ^(a)	115-275, (90% upper limit) ^(b)	150-2,000, (90% upper limit) ^{(b), (d)}	-	-	-	0.0-1.0 (90% upper limit) ^(b)	-	-
		75-170, (50% upper limit) ^(c)	100-1,300, (50% upper limit) ^{(c), (d)}				0.0-0.5 (50% upper limit) ^(c)		
San Francisco Bay Region (Region 2)	AGR ^(e)	10,000 (Limit specific to stock watering)	200-3,000	SAR (Adj.) ^(f) : • 3.0 (Threshold); • 9.0 (Limit)	• 142.0 (Threshold); • 355.0 (Limit)	-	• 0.5 (Threshold); • 2.0 (Limit); • 5.0 (Limit specific to stock watering)	• NO ₃ + NO ₂ (as N) 5.0 (Threshold); • 30 ^(g) (Limit); • 100 (Limit specific to stock watering)	-
	Groundwater (Central Basin) ^(h)	Ambient or 500, whichever is lower	-	-	-	-	-	45 (Nitrate as NO ₃)	-
	Groundwater (Fringe Sub-basins) ^(h)	Ambient or 1,000, whichever is lower						45 (Nitrate as NO ₃)	
	Surface Waters ^{(h), (i)}	• 250 (90-day mean) • 360 (90-day 90 th percentile) • 500 (daily maximum)	-	-	• 60 (90-day mean) • 100 (90-day 90 th percentile) • 250 (daily maximum)	-	-	-	-
Central Coast Region (Region 3)	AGR ⁽ⁱ⁻¹⁾	_(i-2)	_(i-2)	_(i-2)	_(i-2)	-	• 0.75 (irrigation supply) ^(k) ; • 5.0 (stock watering)	• 100 as NO ₃ + NO ₂ (stock watering); • 10 as NO ₂ (stock watering) • See Table Note j-2	-
	Groundwater ^(l)	100-1,500	-	10-730 (Na)	20-430	10-1,025 ^(m)	0.1-2.8	1-10 (as Nitrogen)	-
	Surface Waters ⁽ⁿ⁾	150-1,400	-	20-250 (Na)	10-250	10-700	0.2-1.0	-	-

Table 2: Other Dissolved Mineral, Trace Elements, and Nutrient Objectives or Criteria from the Various Water Quality Control Board Basin Plans

Regional Board	Beneficial Use	Water Quality Parameter							
		TDS (mg/L)	EC (micromhos/cm)	Na (mg/L), SAR (meq/L), and %Na	Cl (mg/L)	SO ₄ (mg/L)	B (mg/L)	Nitrogen Compounds (mg/L)	Phosphorus (mg/L)
Los Angeles Region (Region 4)	Inland Surface Waters ^(o)	225-2,000	-	2-10 (SAR) ^(p)	6-500	25 -650	0.5-2.0 ^(q)	5-10 (as NO ₃ -N +NO ₂ -N)	-
	Groundwater ^(r)	250-3,000	-	-	15-500	20-1,200	0.2-3.0	45 (as NO ₃) or 10 (as N) (MUN)	-
San Francisco Bay/ Sacramento-San Joaquin Delta Estuary	AGR		450-2,780 ^(s)						
Central Valley Region (Region 5) - Sacramento and San Joaquin River Basins	Inland Surface Waters	100-125 ^(t)	150-340 (90 th percentile) ^{(t), (u)}	-	-	-	0.8-2.6 ^{(w) (x)}	-	-
			230-240 (50 th percentile) ^{(u), (v)}						
Central Valley Region (Region 5) - Tulare Lake Basin	Surface Waters	-	54-429 (90 th percentile) ^(y)	-	-	-	-	-	-
			100-450 (maximum) ^(z)						
	Groundwater	-	Maximum average annual increase of 1-6 ^(aa)	-	-	-	-	-	-
Lahontan Region (Region 6)	Surface Waters ^(bb)	<ul style="list-style-type: none"> • 10-400 (annual avg); • 11-585 (90th percentile); • 11-800 (mean of monthly means) 	-	Only a few watersheds have either %Na or SAR based objectives	<ul style="list-style-type: none"> • 0.01-75 (annual avg); • 0.2-110 (90th percentile); • 0.1-110 (mean of monthly means) 	<ul style="list-style-type: none"> • 0.4-100 (annual avg); • 0.5-121 (90th percentile and mean of monthly means) 	<ul style="list-style-type: none"> • 0.01-1.8 (annual avg); • 0.02-2.6 (90th percentile); • 0.01-2.6 (mean of monthly mean) 	Constituents (e.g., nitrate, TKN, total N) vary by hydrologic unit	Total P objectives established for selected waterbodies
	Groundwater	245 -560 (maximum)	-	-	-	-	-	-	1-11 (NO ₃ as NO ₃)

Table 2: Other Dissolved Mineral, Trace Elements, and Nutrient Objectives or Criteria from the Various Water Quality Control Board Basin Plans

Regional Board	Beneficial Use	Water Quality Parameter							
		TDS (mg/L)	EC (micromhos/cm)	Na (mg/L), SAR (meq/L), and %Na	Cl (mg/L)	SO ₄ (mg/L)	B (mg/L)	Nitrogen Compounds (mg/L)	Phosphorus (mg/L)
Colorado River Basin Region (Region 7)	Various Surface Waters ^(cc)	2,000-4,000 (annual avg) ^(dd)	-	-	-	-	-	10 (NO ₃ -N)	-
	Colorado River (above Imperial Dam) ^{(cc), (ee)}	2,500-4,500 (maximum) ^(dd)							
Santa Ana Region (Region 8)	Surface Waters	110-2,000 ^(ff)	-	10-110 ^(ff)	500 for MUN	500 for MUN	0.75	45 (as NO ₃) or 10 (as N) for MUN	-
	Groundwater	210-1,260 ^(gg)	-	180 (MUN)	500 (MUN)	500 (MUN)		1-13 (as total inorganic nitrogen)	
				9 (SAR for AGR) ^(hh)			10-30 ^(gg)	20-40 ^(gg)	45 (as NO ₃) or 10 (as N) (MUN)
				20-65 ^(gg)			1.0-10.0 (Nitrate as N)		
San Diego Region (Region 9)	Inland Surface Waters ^{(ii) (jj)}	300-2,100	-	60% (as % Na)	50-500	65-500	0.75-1.0	-	0.1 (stream entering standing water); 0.025 (standing water) as (P)
	Groundwater ^(kk)	350-3,500	-	60% (as % Na)	60-800	60-600	0.75-2.0	5-45	-

Table 2 Notes:

- (a) The ranges represent the lowest and highest waterbody-specific water quality objectives in the Region 1 Basin Plan.
- (b) Source: Table 3-1 of the Region 1 Basin Plan. As noted in the Basin Plan, 90% upper and lower limits represent the 90 percentile values for a calendar year. 90% or more of the values must be less than or equal to an upper limit and greater than or equal to a lower limit.
- (c) Source: Table 3-1 of the Region 1 Basin Plan. As noted in the Basin Plan, 50% upper and lower limits represent the 50 percentile of the monthly mean values for a calendar year. 50% or more of the values must be less than or equal to an upper limit and greater than or equal to a lower limit.

- (d) Based on Table 3-1 of the Region 1 Basin Plan, listed as specific conductance (micromhos at 77°F).
- (e) Source: Table 3-6 of the Region 2 Basin Plan; Note: Basin Plan does not explicitly define “limit” or “threshold”. Based on usage it is assumed that “threshold” means the concentration where an effect is observed, while “limit” is the maximum acceptable concentration
- (f) Source: Table 3-6 of the Region 2 Basin Plan. Adjusted SAR = $\{ \text{Na}/[(\text{Ca} + \text{Mg} + 2)^{0.5}] \} \{ 1 + [8.4 - \text{pHc}] \}$, where pHc is a calculated value based on total cations, Ca + Mg, and CO₃ + HCO₃, in milliequivalents per liter (meq/L). Exact calculations can be found in “Guidelines for Interpretations of Water Quality for Agriculture” prepared by the University of California Cooperation Extension.
- (g) For sensitive crops, values are actually for NO₃-N +NH₄-N.
- (h) Source: Table 3-7 of the Region 2 Basin Plan. Represent water quality objectives for the Alameda Creek Watershed above Niles.
- (i) Source: Table 3-7 of the Region 2 Basin Plan. Represent water quality objectives for Alameda Creek and tributaries.
- (j-1) Source: Table 3-4 of the Region 3 Basin Plan with a publication date of June 8, 2011. Represent maximum values that are considered as 90 percentile values not to be exceeded. Values based primarily on “Water Quality Criteria 1972” National Academy of Sciences- National Academy of Engineers, Environmental Study Board, ad hoc Committee on Water Quality Criteria furnished as recommended guidelines by the University of California Agriculture Extension Service, January 7, 1974.
- (j-2) Table 3-3 in the Basin Plan establishes range of values to be used as “Guidelines for Interpretation of Quality of Water for Irrigation”. These ranges are not reproduced here; however, they may be found in Appendix A of CV-SALTS technical memorandum, “Salinity Effects on Agricultural Irrigation-Related Uses of Water”.
- (k) Values provided will normally not adversely affect plants or soils.
- (l) Source: Table 3-8 of the Region 3 Basin Plan. Objectives shown are median values based on data averages; objectives are based on preservation of existing quality or water quality enhancement believed attainable following control of point sources. Values vary for specific sub-basins and sub-areas. The ranges represent the lowest and highest water quality objectives in Table 3-8.
- (m) As noted in Table 3-8 of the Region 3 Basin Plan, upper range objective for a specific waterbody exceeds California Secondary Drinking Water Standards contained in Title 22 of the Code of Regulations. Water quality standard is based upon existing water quality. If water quality degradation occurs, the Regional Board may consider salt limit on appropriate discharges.
- (n) Source: Table 3-7 of the Region 3 Basin Plan. The ranges represent the lowest and highest waterbody-specific water quality objectives in Table 3-7. Per the table, the water quality objectives represent “annual mean values”. Per the Basin Plan text (page III-12), the water quality objectives represent “median values”. Objectives are based on preservation of existing quality or water quality enhancement believed attainable following control of point sources.
- (o) Source: Table 3-8 of the Region 4 Basin Plan. Ranges represent the lowest and highest water quality objectives for waterbodies specifically listed in the Region 4 Basin Plan. Water quality objectives are applied to all waters tributary to those specifically listed in the Basin Plan. Where waterbody-specific objectives have not been established, footnote to Table 3-8 establishes guidelines for TDS, Cl, SO₄ and B for establishment of effluent limits to protect the AGR use.
- (p) Source: Table 3-8 of the Region 4 Basin Plan. SAR predicts the degree to which irrigation water tends to enter into cation-exchange reactions in soil. SAR = $\text{Na}/[(\text{Ca}^{++} + \text{Mg}^{++})/2]^{1/2}$
- (q) As noted in Table 3-8 of the Region 4 Basin Plan, where naturally occurring boron results in concentrations higher than the stated objectives a site specific objective may be determined on a case-by-case basis.
- (r) Source: Table 3-10 of the Region 4 Basin Plan. The ranges represent the lowest and highest water quality objectives for ground waters specifically listed in the Region 4 Basin Plan.
- (s) Source: Table 2 of the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary. The range represents the values at different inland water compliance stations specifically listed in the table for different water year types and seasons. The EC values represent the maximum 14-day running average of mean daily EC. Additional criteria established for salt marshes.
- (t) Source: Table III-3 of the Region 5 Basin Plan for the Sacramento and San Joaquin River Basins. The range represents the lowest and highest 90th percentile waterbody-specific water quality objectives in the Basin Plan.
- (u) Source: Table III-3 of the Region 5 Basin Plan for the Sacramento and San Joaquin River Basins. The range represents the lowest and highest 50th percentile reported for waterbodies specifically listed in the table.
- (v) Source: Table III-3 of the Region 5 Basin Plan for the Sacramento and San Joaquin River Basins. EC values reported at 25°C.

- (w) Source: Table III-1 of the Region 5 Basin Plan for the Sacramento and San Joaquin River Basins. The range represents water quality objectives set for specific waterbodies based on season; one exception is a maximum objective of 5.8 mg/L set for specific waterbodies.
- (x) Source: Table III-1 of the Region 5 Basin Plan. The range represents the monthly mean for 16 September through 14 March for waterbodies specially listed in the table.
- (y) Source: Table III-3 of the Tulare Lake Basin Plan. The range represents the lowest and highest objectives at selected streamflow stations specifically reported in the table. Table also includes maximum median and mean values for same waterbodies.
- (z) Source: Table III-2 of the Tulare Lake Basin Plan. The range represents the lowest and highest maximum values that apply to the waterbodies specifically reported in the table. Some of these waterbodies have additional objectives based on other criteria such as 10-year averages.
- (aa) Source: Table III-4 of the Tulare Lake Basin Plan. Water quality objectives for groundwater salinity control the rate of increase. The range represents the maximum average annual increase in EC for hydrologic units specifically reported in the table.
- (bb) Source: Region 6 Basin Plan, Tables 3-7 through 3-21. The ranges represent the lowest and highest water quality objectives reported for various surface waters specifically listed in the Basin Plan. Measurement varies by Hydrologic Unit: objectives vary among annual average, 90th percentile and monthly average.
- (cc) Source: The Region 7 Basin Plan.
- (dd) The range represents the lowest and highest values reported for surface waterbodies specifically reported in the Basin Plan. Any discharge, excepting discharges from agricultural sources, shall not cause concentration of TDS in surface waters to exceed the ranges reported.
- (ee) Represent the flow-weighted average annual; water quality objectives established by the Colorado Salinity Control Forum and incorporated into Basin Plan.
- (ff) The range represents the lowest and highest values reported for surface waterbodies specifically reported Table 4-1 in the Basin Plan.
- (gg) Source: Table 4-1 of the Region 8 Basin Plan. The ranges represent the lowest and highest values reported for various groundwater management zones.
- (hh) $SAR = Na/[1/2 (Ca + Mg)]^{1/2}$ where sodium (Na), Calcium (Ca), and Magnesium (Mg) are expressed in meq/L.
- (ii) Table 3-1 in the Basin Plan establishes range of values to be used as "Guidelines for Interpretation of Quality of Water for Irrigation". These ranges are not reproduced here; however, they are the same values as may be found in Appendix A of CV-SALTS technical memorandum, "Salinity Effects on Agricultural Irrigation-Related Uses of Water".
- (jj) Source: Table 3-2 of the Region 9 Basin Plan identifies ranges of waterbody-specific water quality objectives established for inland waters not to be exceeded more than 10% of the time during any one year period.
- (kk) Source: Table 3-3 of the Region 9 Basin Plan identifies ranges of waterbody-specific water quality objectives established for ground waters not to be exceeded more than 10% of the time during any one year period.

Table 3. Water Quality Guide For Livestock and Poultry Uses

Total Soluble Salts Content of Waters (mg/L)	Remarks
<1,000	Relatively low level of salinity. Excellent for all classes of livestock and poultry.
1,000-2,999	Very satisfactory for all classes of livestock and poultry. May cause temporary and mild diarrhea in livestock not accustomed to them or watery droppings in poultry.
3,000-4,999	Satisfactory for livestock, but may cause temporary diarrhea or be refused at first by animals not accustomed to them. Poor waters for poultry, often causing water feces, increased mortality and decreased growth, especially in turkeys.
5,000-6,999	Can be used with reasonable safety for dairy and beef cattle, for sheep, swine and horses. Avoid use for pregnant or lactating animals. Not acceptable for poultry.
7,000-10,000	Unfit for poultry and probably 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.
>10,000	Risks with these highly saline waters are so great that they cannot be recommended for use under any conditions.

Source: Table V-3 from NAS and NAE 1973.

Table 4. National Recommended Water Quality Criteria for Salts and Nutrients for Uses Other Than Stock Drinking Water

Constituent	Criteria^(a)	Target Beneficial Use
Boron	0.75 mg/L	Agriculture – crop irrigation
Chloride	250 mg/L	Domestic water supply
Nitrate-N	10 mg/L	Domestic water supply
Phosphate-Phosphorus ^(b)	50 µg/L 25 µg/L	Aquatic protection for streams and reservoirs
Sulfate	250 mg/L	Domestic water supply

Notes:

(a) Source: US EPA 1986

(b) Not recommended criteria, but are values to be considered in setting state standards

Table 5. Colorado Water Quality Standards for Salinity and Nutrients in Groundwater and Surface Water

Constituent	Waterbody Type	Limit (mg/L)
Dissolved Minerals		
Chloride	Groundwater and Surface water	250
Sulfate	Groundwater and Surface water	250
Trace Elements		
Boron	Groundwater and Surface water	0.75
Nutrients		
Nitrate + Nitrite as N	Groundwater and Surface water	100 ^(a)
Nitrite N	Groundwater	10 ^(a)
	Surface water	5 ^(a)

Notes:

(a) Agricultural standards

Table 6. Colorado Water Quality Guidelines for TDS in Groundwater

Waterbody 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

Source: Colorado Department of Public Health and Environment, Water Quality Control Commission. 5 CCR 1002-41, Regulation 41 - The Basic Standards for Ground Water

Table 7. Water Quality Guide for Livestock and Poultry Uses

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

Source: Water Quality for Agriculture (Ayers and Westcot 1985)

Table 8. Water Quality Guidelines for Additional Salinity and Nutrient Parameters

Constituent	Maximum Concentration (mg/L)	Species
Dissolved Minerals		
	< 250	Poultry and swine
Magnesium	250	Horses, lactating cows, ewes with lambs
	400	Beef cattle
	500	Adult sheep on dry feed
Trace Elements		
Boron	5.0	All
Nutrients		
Nitrate + Nitrite (N)	100.0	All
Nitrite (N)	10.0	All

Source: From AWRC, 1969 as cited in Water Quality for Agriculture (Ayers and Westcot 1985)

Table 9. Canadian Water Quality Guidelines and Recommendations for Livestock

Constituent	Livestock Maximum Recommended Limit (mg/L) ^(a)	Poultry Recommended Limits (mg/L) ^(b)	Horses Recommended Limits (mg/L) ^(c)	Additional Information
Dissolved Minerals				
TDS	3,000	1,500 - 4,000	6,500	-
Hardness	-	180	200	Poultry levels
Calcium	1,000	600	500	-
Magnesium		125	125	Based on other constituents in water
Sodium	-	50	2,500	Based on other constituents in water, specifically sulfate or chloride
Chloride	-	250 ^(d)	3,000	-
Sulfate	1,000	250	2,500	-
Trace Elements				
Boron	5	-	-	-
Nutrients				
Nitrate	10 ^(d)	-	10 ^(d)	-
Nitrate (as NO ₃)	-	25 ^(e)	-	-
Nitrate plus Nitrite	100 ^(d)	-	100 ^(d)	Horses - 400 mg/L nitrate Swine - maximum level 750 mg/L nitrate
Nitrite	-	4 ^(f)	-	-

Notes:

- (a) Canada (2012)
- (b) Canadian Plan Service (2001) (Adapted from Carter and Sneed 1987).
- (c) Olkowski 2009
- (d) As nitrogen
- (e) As nitrate
- (f) As nitrite

Table 10. Australia and New Zealand TDS Guidelines for Various Types of Livestock as Established Under the National Water Quality Management Strategy

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)

Table 11. Australia and New Zealand Water Quality Guidelines for Stock Drinking Water as Established Under the National Water Quality Management Strategy

Constituent	Livestock Maximum Recommended Limit (mg/L)	Additional Information
Dissolved Minerals		
Calcium	1,000	
Magnesium	None	No health effect has been determined to date
Sodium	-	
Chloride	-	
Sulfate	1,000	
Trace Elements		
Boron	5	Can be tolerated at higher concentrations for a short period of time
Nutrients		
Nitrite (NO ₂)	30	
Nitrate (NO ₃)	400	Based on nitrate levels in feed stocks

Source: ANZECC/ARMCANZ (2000)

Table 12. South Africa Water Quality Guidelines for Stock Drinking Water

Parameter	Target Water Quality (mg/L)	Additional Information
Dissolved Minerals		
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
Sodium	2,000	Mild health effects in cattle and sheep; severe health effects in other livestock at > 2,000 mg/L
Calcium	1,000	Ruminants may handle higher levels
Magnesium	500	
Chloride	1,500	Poultry most sensitive
Sulfate	1,000	Young livestock less tolerant
Trace Elements		
Boron	5	
Nutrients		
Nitrate (NO ₃)	100	Other livestock tolerate higher levels
Nitrite (NO ₂)	NA	

Source: Republic of South Africa, Department of Water Affairs and Forestry (1996)

Table 13. TDS and EC for Stock Drinking Water

TDS (mg/L)	EC (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 14. Health Effects of Sodium in Stock Drinking Water Shown in Selected University Extension Service Bulletins

Sodium (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	-
~ 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)

Table 15. Health Effects of Sulfate in Stock Drinking Water as Shown in Selected University Extension Service Bulletins

Sulfate (mg/L) ^(a)	Livestock	Cattle	Poultry
< 50	Safe	Safe	Safe for poultry ^(b)
< 250	Safe, but may have laxative effect	Safe, but 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	Significant laxative effect; substantial reduction in copper availability	Significant laxative effect; substantial reduction in copper availability; sporadic PEM	Not recommended, especially for turkeys
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

Notes:

(a) Sources: German et al. (2008); Higgins et al. (2008)

(b) 50 mg/L represents the critical number where potential health risks may begin (Blake and Hess 2001)

Table 16. Health Effects of Nitrate in Stock Drinking Water as Shown in Selected University Extension Service Bulletins

Nitrate (NO ₃) ^(a) (mg/L)	Nitrate-Nitrogen ^(b) (NO ₃ -N) (mg/L)	Livestock	Cattle	Poultry
< 44	0-10	Safe	Safe	Safe
45-132	11-30	Safe with low nitrate feeds	Safe with low nitrate feeds	Safe
133-220	31-50	Harmful with long periods of exposure	Harmful with long periods of exposure	-
< 440	< 100	Safe	Safe	Safe
221-660	51-150	-	Risk of death ^(c)	-
440-1,300	100-300	Safe with low nitrate feeds	Safe with low nitrate feeds	Safe
500	110	-	Safe with low nitrate feeds	-
> 660	> 150	-	Unsafe for consumption	-
>1 ,300	> 300	Swine - Avoid due to nitrate contribution to total salt content; Ruminants and horses - Nitrate poisoning	Nitrate poisoning	Avoid due to nitrate contribution to total salt content

Notes:

- (a) Sources: Faries et al. (1998); Higgins et al. (2008); German et al. (2008); Raisbeck et al. (2008)
- (b) 1 mg/L nitrate-nitrogen (NO₃-N) equivalent to 4.4 mg/L nitrate (NO₃). Values adjusted as required
- (c) Based on NRC (1974) (Note: this reference are derived from older, fragmented studies and may be outdated)

Table 17. Boron Guidelines for Stock Water Supply from Various References

Concentration (mg/L)	Remarks	Reference
5.0 mg/L	Concentration in water used by livestock should not exceed 5.0 mg/L	NAS & NAE (1973)
5.0 mg/L	Concentration in water used by livestock should not exceed 5.0 mg/L	Canadian Task Force on Water Quality (1987)
5.0 mg/L	Concentration in water used by livestock should not exceed 5.0 mg/L	Williamson (1983)
5.0 mg/L	Maximum allowable	Weeth et al (1981); NAS (1980); Seal and Weeth (1980); Green and Weeth (1977) in Eisler (1990)
5.0 mg/L	If the boron concentration 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	ANZECC/ARMCANZ 2000
< 5.0 - 30 mg/L	Recommended maximum levels for livestock	Puls (1994)
40 mg/L	Maximum tolerated	Seal and Weeth (1980) in Eisler (1990)
40 - 150 mg/L	“Safe”	Green and Weeth (1977) in Eisler (1990)
>150 mg/L	Adverse effects	Nielsen (1986) in Eisler (1990)

Table 18. Summary of Calculations Used to Develop a Guideline for Boron in Stock Drinking Water

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

Source: ANZECC/ARMCANZ (2000)

Table 19. Generally Accepted NRC Guidelines for Nitrate and Nitrate Nitrogen Concentrations in Stock Drinking Water

Nitrate (mg/L)	Nitrate Nitrogen ^(a) (mg/L)	Guidelines
0–44	0–10	Safe for consumption by ruminants
45–132	10– 30	Generally safe in balanced diets with low nitrate feeds
133–220	30–50	Could be harmful if consumed over long periods
221–660	50–150	Cattle at risk; possible death
> 661	> 150	Unsafe, possible death; should not be used as a source of water

Source: National Research Council (NRC 1974; 2001); **Bold values** represent recalculated values to be consistent with conversion factor (0.226) from nitrate to N.

Notes:

(a) Guidelines in this reference are derived from older, fragmented studies and may be outdated. Newer references indicate greater tolerances for some stock (see text).

Table 20. Summary of Key Tolerable Salinity, Boron, and Nutrient Concentrations for Stock Drinking Water

Constituent	Livestock Type – Tolerable Concentration (mg/L)	Key Reference(s)
Dissolved Minerals		
Total Dissolved Solids ^(a)	Dairy cattle – 2,500 Beef cattle – 4,000 Sheep and Goats – 5,000 Poultry – 2,000 Horses - 4,000 Swine – 4,000	Olkowski (2009)
Sodium	Dairy cattle - 975	Jaster et al. (1978)
	Dairy cattle – 1,000 to 5,000	Canada (1987)
	All livestock (including poultry) – 2,000	South Africa (1996)
Calcium	No research found directly relating calcium in drinking water to livestock/poultry health and performance.	
Magnesium	Sheep and goats Young - 250 Lactating - 400 Adult - 500	Pierce (1959, 1968)
Chloride	Beef cattle – 3,000 Sheep and goats – 3,000 Poultry – 1,500 Horses – 1,500	South Africa (1996)
Sulfate	Beef cattle - 539 Poultry – 1,000	Longeragan et al. (2001); South Africa (1996); Canada (1987)
Trace Element		
Boron	Dairy cattle - 7 Beef cattle - 7 Sheep and Goats – 6.2 Poultry – 11.3 Horses – 8.6 Swine - 5.8	Moss and Nagpal (2003); ANZECC/ ARMCANZ (2000)
Nutrients		
Nitrate (NO ₃) N	Dairy & beef cattle - 110	Raisbeck et al (2008)
	Dairy Cattle - 100	NAS (1974); NRC (2005)
	Livestock general - 100	Canada (1987); ANZECC/ARMCANZ (2000)
	Sheep and Goats – 200	NRC (2005)
	Pigs – 2,000	Sørensen et al. (1994)
Nitrite (NO ₂) N	Dairy cattle - 10	NAS (1974); NRC (2005)
	Beef cattle - 30	Raisbeck et al. (2008)
Other Constituents: Total Nitrogen, Total Kjeldahl, Organic Nitrogen, Ammonia, Total Phosphorus, Dissolved Phosphorus	No research found directly relating any of these parameters in drinking water to livestock/poultry health and performance.	

Notes:

(a) EC in units of dS/m can be estimated by multiplying TDS by 0.015

Table 21. Guidelines for Stock Drinking Water

Constituent	Range of Tolerable Levels ^(a)		Sensitive Stock
	Lower Value (mg/L)	Upper Value (mg/L)	
Dissolved Minerals			
TDS ^(b) (EC) ^(b)	< 2,000 mg/L (< 3.0 dS/m)	< 5,000 mg/L (< 7.5 dS/m)	Poultry, especially turkeys
Sodium	1,000 mg/L	2,000 mg/L	Poultry
Chloride	1,500 mg/L	3,000 mg/L	Poultry, horses
Sulfate	1,000 mg/L	2,000 mg/L	Cattle
Trace Elements			
Boron	5.0 mg/L	7.0 mg/L	All
Nutrients			
Nitrate + Nitrite as N	100 mg/L	300 mg/L	Ruminants and Horses
Nitrite as N	10 mg/L	30 mg/L	Ruminants and Horses

Notes:

- (a) Primarily based on government guidelines rather than individual published studies.
- (b) TDS (EC) is a general indicator of salinity; concentrations of individual ions may be more important than TDS criteria. Per the literature (e.g., Raisbeck et al. 2008), it is recommended that if TDS exceeds 500 mg/L (EC above 0.75 dS/m), the individual constituents contributing to TDS should be identified, quantified, and evaluated.