

## Variability of Water Composition and Potential Impact On Animal Performance

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### Introduction:

Water is often overlooked as an important nutrient in diets of livestock (Adams and Sharpe, 1995). Animals need a plentiful supply of good, clean water for normal rumen fermentation and metabolism, proper flow of feed through the digestive tract, good nutrient absorption, normal blood volume and tissue requirements (Adams and Sharpe, 1995). Despite the importance of water to livestock, limited research has examined the variability of water composition and the impact on animal performance. In most cases, nutrition advisors must rely upon their own anecdotal experiences to assess whether water is limiting performance of livestock. As quoted by Pennsylvania State University Publication DAS 95-8, "Lack of good data on effects of (water) quality problems. Must depend largely on experiences, and further research is encouraged." This paper will examine the variability of mineral content of water and the limited research that examines the impact of water composition on animal performance.

### Good Basic Water Management:

While quality of water entering the watering system appears to be of importance, assessing water quality on dairies not adhering to good basic water management practices, in most cases, is inappropriate use of time and resources. Sound water management practices include:

1. cleaning water devices on a weekly, if not daily basis;
2. insuring that water systems provide adequate volume to meet water needs even during peak demands;
3. water devices are designed and located to allow animals to comfortably drink from the device (please see McFarland, 1998 for a more extensive review); and
4. at least 2 ft. (0.61 m) of accessible linear waterer space is provided for every 10 to 20 cows (McFarland, 1998).

Failure to adhere to sound water management practices can impede animal performance. For instance, research has shown that increased frequency of cleaning increases milk production (Ensley, 2000). Furthermore, increasing linear inches of available waterer space/cow has been found to have a positive impact on milk production, while increasing the distance from the feed bunk to first available water source had a negative effect on milk production (Ensley, 2000).

### What is Good Quality Water?

Good quality water can be defined by a number of factors including taste, smell, turbidity, electrical conductivity and presence or absence of certain substances. This review will focus mainly on the impact of mineral content of water on acceptability and animal performance.

Presented in Table 1 are guidelines for assessing water quality. These guidelines are a composite of several sources (Bergsrud and Linn, 1990; Hutcheson, 1996; NAS, 1974; NAS, 1980; Puls, 1994). For most substances, the upper desired level for livestock is the U. S. EPA or the U. S. Public Service Guideline's recommended limits for livestock and/or humans. However, it should be noted that values published as the upper desired levels can vary. For instance, the National Academy of Sciences lists the safe upper limit for nitrates at 440 ppm, while the U. S. EPA lists the safe upper limit for livestock at 100 ppm. Part of the variation in standards is due to the limited amount of data available on the impact of varying substance concentrations in water on animal performance. Furthermore, there may be additive effects of

increasing levels of substances in the water on animal performance. More resources need to be devoted towards understanding the impact of varying levels of substances in water on animal performance.

**Table 1. Water quality guidelines.**

Item	Upper Levels, Livestock	Maximum Upper Levels
Aluminum, ppm	5.0	10.0
Arsenic, ppm	0.2	0.2
Barium, ppm	1.0	1.0
Bicarbonate, ppm	1000.0	1000.0
Boron, ppm	5.0	30.0
Cadmium, ppm	0.005	0.05
Calcium, ppm	100.0	150.0
Chloride, ppm	100.0	300.0
Chromium, ppm	0.1	1.0
Copper, ppm	0.2	0.5
Fluoride, ppm	2.0	2.0
Iron, ppm	0.2	0.4
Lead, ppm	0.05	0.1
Magnesium, ppm	50.0	100.0
Manganese, ppm	0.05	0.5
Mercury, ppm	0.01	0.01
Molybdenum, ppm	0.03	0.06
Nickel, ppm	0.25	1.0
Nitrate-Nitrogen, ppm	20.0	100.0
pH	6 - 8.5	8.5
Phosphorus, ppm	0.7	0.7
Potassium, ppm	20.0	20.0
Selenium, ppm	0.05	0.1
Silver, ppm	0.05	0.05
Sodium, ppm	50.0	300.0
Sulfates, ppm	50.0	300.0
Total dissolved solids, ppm	960.0	5000.0
Vanadium, ppm	0.1	0.1
Zinc, ppm	5.0	25.0
Coli form, #/100 mL	0.5	0.5
Fecal coliform, #/100 mL	0.1	0.1
Total Bacteria, #/100 mL	1000.0	1000.0

#### **Is Water, Water?**

Recently over 3600 water samples were collected from livestock operation throughout the United States (Socha et al., 2001). Results of this survey indicate that water composition varies not only across the United States, but also within a geographical region. In some cases water composition within a geographical region can not only vary significantly; it can also have a significant impact on dietary mineral intake and availability.

In the survey, the average concentration in water did not exceed the upper desired level for Ca, Cl, Cu, Mg, Na, SO<sub>4</sub> and Zn (Table 2). However, 15 to 30% of the samples exceeded the desired livestock levels for calcium, sodium and sulfates. The average iron and manganese content of samples exceeded the desired livestock levels with greater than 40% of samples containing iron and manganese concentrations above desired levels (Table 2).

Locally, the average mineral content of California water samples did not exceed desired levels for any of the minerals measured. Iron appeared to be a problem in less than 10% of California samples, while sulfates and chlorides were a concern in 15 to 25% of samples (Table 3). The minerals that tended to be of greatest concern in California water were

manganese and sodium, which exceeded desired livestock levels in 40.8 and 64.0% of samples, respectively (Table 3).

**Table 2. Variation in water composition, 3651 samples collected throughout the United States.**

Item	Number of Samples Analyzed	Average Concentration, ppm	Maximum Concentration, ppm	% of Samples Exceeding Upper Level for Livestock
Calcium	2517	65	590	15.6
Chloride	446	59	727	12.6
Copper	1537	0.07	11	4.8
Iron	2437	0.79	123	41.1
Magnesium	2524	24	682	7.6
Manganese	2158	0.17	12.7	44.8
Potassium	275	4	33	1.1
Sodium	2941	46	1556	20.2
Sulfate	2693	81	3595	29.6
Zinc	2386	0.12	10.0	0.1

The results of this survey indicate that water quality on a number of dairies could be limiting animal performance. However, nutrition advisors need to be cautioned that a limited amount of research was available for development of upper desired levels for livestock. Furthermore, point of collection and source of water (surface, well, spring, etc.) were not recorded in this survey. Well water samples are commonly collected as close to the well head as possible. However, it may be beneficial to collect a sample close to the waterer to accurately assess the quality of water the cow is actually drinking. A study by Ensley (2000) indicated a difference in the concentration of iron and coliform from the well head to the drinking waterer. Iron content of water declines when water mixes with air, oxidizing from the soluble ferrous state ( $Fe^{+2}$ ) to the less soluble ferric state ( $Fe^{+3}$ ), resulting in iron precipitating. In order to accurately determine the iron concentration of drinking water, a separate collection vial that provides 0.3 mL 50% nitric acid/100 mL of sample water needs to be used to prevent oxidation and precipitation of iron.

**Table 3. Variation in water composition, 101 samples collected from throughout California**

Item	Number of Samples Analyzed	Average Concentration, ppm	Maximum Concentration, ppm	% of Samples Exceeding Upper Level for Livestock
Calcium	97	53	341	14.4
Chloride	69	73	437	18.8
Copper	76	0.01	0.16	0.0
Iron	86	0.08	1.50	8.1
Magnesium	97	14	79	6.2
Manganese	76	0.16	1.24	40.8
Potassium	38	1	6	0.0
Sodium	100	98	559	64.0
Sulfate	73	54	335	25.3
Zinc	83	0.10	1.40	0.0

**How Much Mineral is Supplied By Water?**

Predicting water intake using the Murphy et al. (1983) equation corrected for dry matter content of the diet (DM% of diets fed in the

Murphy et al. (1983) study was 68%), the mineral contribution of water to total mineral intake can be calculated. Despite the average water sample containing levels of iron and manganese that exceeded the desired levels for livestock, the average water sample collected in the United States still only contributed 83 and 18 mg of iron and manganese, respectively (Table 4). If we assume that the average dairy diet contains 200 ppm of total iron and 80 ppm of total manganese, water contributes only 1.8 and 1.0% of iron and manganese intake respectively. In California, the average contribution of water to total iron and manganese intake showed similar trends (Table 5).

If level of iron and manganese in water negatively impact animal performance, how it impacts animal performance is heavily debated, even among the authors of this paper. Some believe that the iron in water is more reactive and more available to the animal than iron found in feedstuffs and supplements and thus even small amounts negatively impact animal performance and availability of minerals. These researchers believe that cows acclimate to the taste of the water and once acclimated, mineral content of water does not have a sizeable impact on water consumption. Others believe that even if the iron found in water has greater availability and reactivity, the amount supplied by most water is relatively minute. This group believes that the primary reason for reduced animal performance when animals are consuming water containing 5 ppm or less of iron is reduced palatability and hence reduced water consumption.

Similar to iron and manganese, water that contained an average amount of mineral contributed a relatively small amount to total mineral intake. Less than 10% of Ca, Cl, Cu, Mg, Na, S and Zn intake of dairy cattle would have been supplied by U. S. and California water samples containing average amounts of mineral, based upon the assumption that the average dairy diet supplies 225 g Ca, 80 g Cl, 450 mg Cu, 80 g Mg, 100 g Na, 55 g S and 1800 mg Zn (Tables 4 and 5). The average water would also have minimal impact on DCAD of the diet.

In contrast, water can be a significant source of minerals when one considers the amount contributed when the maximum mineral content was observed. For instance, U. S. water samples with the maximum observed Cu, Fe, Na and S content would contribute 257, 284, 163 and 275%, respectively, of that contributed by the diet and would reduce the dietary DCAD by 192.9 meq/kg DM (Table 4). In California, water with the maximum observed mineral content would contribute an additional 36 g Ca, 46 g Cl, 17 mg Cu, 157 mg Fe, 8 g Mg, 130 mg Mn, 59 g Na, 14 g S and 147 mg Zn and would increase the dietary DCAD by 18.0 meq/kg DM (Table 5). The impact of water on DCAD should be interpreted with caution as only 275 of the 3651 water samples were analyzed for potassium content.

**Table 4. Amount of Mineral Supplied By the Water Sources In The United States, Based Upon Analysis of 3651 Samples**

Item	Average Concentration, ppm	Amount of Mineral Supplied Daily By The Average Water Source <sup>a</sup>	Maximum Concentration, ppm	Amount of Mineral Supplied By Water Containing the Maximum Concentration of Mineral <sup>a</sup>
Calcium	65	7 g	590	62 g
Chloride	59	6 g	727	76 g
Copper	0.07	7 mg	11	1155 mg
Iron	0.79	83 mg	123	12910 mg
Magnesium	24	3 g	682	72 g
Manganese	0.17	18 mg	12.7	1333 mg

<b>Potassium</b>	4	0 g	33	3 g
<b>Sodium</b>	46	5 g	1556	163 g
<b>Sulfur</b>	27	3 g	1197	151 g
<b>Zinc</b>	0.12	13 mg	10.0	1050 mg
<b>DCAD</b>	--	-6.0	--	-192.9

<sup>a</sup>Estimated water intake, 231.4 lbs/d. Assumptions: DMI, 50 lbs/d; dietary sodium, 0.5% DM; diet DM, 60%; minimum daily temperature, 60° F; milk production, 75 lbs/d

<sup>b</sup>(Na+K)-(Cl+S), meq/kg

Similar to the results of this survey, a summary of water samples collected from 1957 to 1969 from 140 locations (NAS, 1974) indicated that surface water can vary substantially in mineral content and that some sources of water can contribute a significant amount of mineral towards meeting the animal's mineral requirements (Table 6). In comparison to the survey of U. S. water by Socha et al. (2001), maximum observed values for K, Cl and Na were considerably higher and would have a greater impact on the DCAD of the diet (Table 6).

In some cases nutritionists have not recognized minerals supplied by water during diet formulations due to concerns that minerals in water may have a low bioavailability. The merits of this practice need to be reconsidered. According to NAS (1974), "availability of elements in water solution is at least equal to that present in solid feeds or dry salt mixes." In some cases, minerals dissolved in water may be more available than minerals found in feedstuffs. For instance, copper dissolved in water solution has been shown to be more available to cattle than copper incorporated into dry feed (Chapman et al. (1962).

**Table 5. Amount of Mineral Supplied By the Water Sources In California, Based Upon Analysis of 101 Samples**

<b>Item</b>	<b>Average Concentration, ppm</b>	<b>Amount of Mineral Supplied Daily By The Average Water Source<sup>a</sup></b>	<b>Maximum Concentration, ppm</b>	<b>Amount of Mineral Supplied By Water Containing the Maximum Concentration of Mineral<sup>a</sup></b>
<b>Calcium</b>	53	6 g	341	36 g
<b>Chloride</b>	73	8 g	437	46 g
<b>Copper</b>	0.01	1 mg	0.16	17 mg
<b>Iron</b>	0.08	8 mg	1.50	157 mg
<b>Magnesium</b>	14	1 g	79	8 g
<b>Manganese</b>	0.16	17 mg	1.24	130 mg
<b>Potassium</b>	1	0 g	6 ppm	1 g
<b>Sodium</b>	98	10 g	559	59 g
<b>Sulfur</b>	18	2 g	112	14 g
<b>Zinc</b>	0.10	11 mg	1.40	147 mg
<b>DCAD</b>	--	+3.9	--	+18.0

<sup>a</sup>Estimated water intake, 231.4 lbs/d. Assumptions: DMI, 50 lbs/d; dietary sodium, 0.5% DM; diet DM, 60%; minimum daily temperature, 60° F; milk production, 75 lbs/d

<sup>b</sup>(Na+K)-(Cl+S), meq/kg

Nutrition advisors also need to recognize that substances found in water can affect availability of other dietary elements. High dietary nitrate intakes may inhibit iodine uptake by the thyroid (Puls, 1994). High intakes of Fe and S would affect the availability of Zn, Mn, Cu and Se (NRC, 2001; Puls, 1994). Increasing dietary S concentration from 0.2%

to 0.4% due to consumption of high sulfate water reduces copper's absorption coefficient from 4.6% to 3.1%. If nutritionists were not feeding complexed copper, dietary copper levels would need to be increased by 32.6% in order to meet the copper requirements of the animal.

In some of these cases, water can contribute enough mineral to create mineral toxicity. The Nutrient Requirements of Dairy Cattle (2001) lists the maximum tolerable level for S to be 0.4%. If cattle are consuming 230 lbs of water containing 1000 ppm of S (3000 ppm sulfate), they would be consuming 104 g of S from water. Water's contribution to dietary intake of S alone would result in a dietary S concentration of 0.46% DM, assuming cows are consuming 50 lbs of DM.

**Table 6. Composition of United States surface water, 1957-1969, collected at 140 stations.**

Item	Average Concentration, Ppm	Amount of Mineral Supplied Daily By The Average Water Source <sup>a</sup>	Maximum Concentration, ppm	Amount of Mineral Supplied By Water Containing the Maximum Concentration of Mineral <sup>a</sup>
Calcium	57	6 g	173	18 g
Chloride	478	50 g	19000	1994 g
Copper	0.01	1 mg	0.28	29 mg
Iron	0.04	4 mg	4.60	483 mg
Magnesium	14	1 g	137	14 g
Manganese	0.03	3 mg	3.23	339 mg
Potassium	4	0 g	370	39 g
Sodium	55	6 g	7500	787 g
Sulfur	45	6 g	1127	47 g
Zinc	0.05	5 mg	1.18	124 mg
DCAD <sup>b</sup>	--	-66.3	--	-1050

<sup>a</sup>Estimated water intake, 231.4 lbs/d. Assumptions: DMI, 50 lbs/d; dietary sodium, 0.5% DM; diet DM, 60%; minimum daily temperature, 60° F; milk production, 75 lbs/d

<sup>b</sup>(Na+K)-(Cl+S), meq/kg

#### **Impact of Water Quality on Animal Performance:**

Most producers assume that water quality affects dairy cow performance. It is unclear whether subtle and persistent problems that decrease production or health of a dairy cow could be related to water quality. There has been little research of the impact of water quality on animal performance. The work that has been done indicates that elevated drinking water nitrate, sulfate, zinc and total dissolved solids will negatively impact milk production (Blosser, 1957; Campbell, 1975; Challis, 1987; Coup, 1964; Crowley, 1974; Digesti, 1976; Frens, 1946; Graf, 1952; Heller, 1933; Jaster, 1978; Smith, 1980; Solomon, 1995; Wang, 1992; Weeth, 1972; Wegner, 1974). For a more extensive review of this data, the reader is referred to a review article by Beede and Myers, 2000.

Ensley (2000) collected water samples from 128 dairies in Iowa to assess the effect of water quality on dairy cow performance. Drinking water coliform, nitrate, sulfate, total dissolved solids and 21 additional minerals were measured in the drinking water and correlated with 26 production parameters.

Results of this study indicate that an elevation in the nitrate concentration of drinking water increased length of calving intervals. The findings in this study substantiate Crowley's report of a negative

impact of elevated drinking water nitrate on reproduction (Crowley, 1974). There was also a negative relationship between nitrate concentration of drinking water and the Rolling Herd Average for Milk Production (RHAmilk) and Rolling Herd Average for Protein Production (RHApotein).

Ensley (2000) observed a small but significant, positive correlation between sulfate concentrations in water and RHAmilk, RHApotein and somatic cell count score. In this study, the maximum sulfate content of water was 1589 ppm and water sulfate concentrations up to 1500 ppm had a positive effect on dairy cattle milk production. In contrast, Weeth (1972) found that providing water containing 1462 ppm of sulfates had an adverse effect on animal performance.

Loneragan et al. (2001) found that sulfate concentrations greater than 583 ppm decreased feedlot performance as indicated by a reduction in average daily gain, feed conversion and carcass characteristics. Reduction in performance was largest at the beginning of the 116 day study. However, in the latter stages of this trial, cattle supplied higher sulfate water had higher average daily gain and feed conversion. It should be noted that this Colorado trial began in July and ended in early November. The response in the latter stages of the trial can be attributed to either compensatory gain with decreased ambient temperature and water requirements or adaptation of cattle to the high sulfate water. In the Ensley (2000) study, most of the cattle in the surveyed herds would have been receiving the high sulfate water for an extensive period of time prior to data collection for the trial.

Improved milk production with increased sulfate content of water is perplexing. However, if sulfur is limiting in diets of high producing dairy cattle, a moderate elevation in drinking water sulfate may provide sulfur for ruminal synthesis of methionine and cysteine production.

Other factors found in the Ensley study (2000) to have a significant positive relationship with RHAmilk were decreasing nitrate, increasing sulfate, increasing phosphorus and increasing boron content of water. Water availability factors that were identified as having a significant positive effect on RHAmilk were increasing linear available waterer space/cow, decreasing distance from feed bunk to first water device, increasing frequency of cleaning and the use of cups as water devices.

**Summary:**

Although water is considered one of the most important nutrients if not the most important nutrient in diets of animals, there is a limited amount of data on the variability of water quality and its effect on animal performance. Recent survey work indicates that water quality can vary substantially and that water quality can have an impact on animal performance. However, before dairy producers spend significant amounts of money on water treatment systems to correct water quality problems, dairy producers must have implemented good sound water management practices including routine cleaning of water devices, providing ample amounts of available waterer space per cow, place waterers close to feed bunks and provide adequate volumes of water to meet water needs even during peak demands.

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