Water Nutrition And Quality For Dairy Cattle

by David K. Beede
Dairy Science Department
University of Florida, Gainesville

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Introduction

Doubtless, water is the most important dietary essential nutrient. Loss of about 1/5 of body water is fatal. Lactating dairy cows need larger proportions of water relative to body weight (BW) than most livestock species because water comprises 87% of milk. Factors influencing daily water intake and requirements include physiological state, milk yield (MY), dry matter intake (DMI), body size, rate and extent of activity, diet composition including types of feedstuffs (e.g., concentrate, hay, silage or fresh forage), ambient temperature, and other environmental factors (e.g., humidity and wind velocity). Other factors affect how much of a particular water supply is consumed; included are salinity, and sulfate and chloride contents, dietary Na content, temperature of water, frequency and periodicity of watering, social or behavioral interactions of animalsn and other quality factors such as pH and toxic substances. This paper addresses practical considerations of water nutrition, needs during heat stress, effects of chilling drinking water, and factors affecting water quality.

Functions and Metabolism.

Water is ubiquitous within the body and is a great solvent. It is chemically neutral; thus, ionization of most substances occurs more freely in water than other media. Water serves as a medium for dispersion or suspension of colloids and ions within the body, and is necessary for maintaining osmotic balance. It functions as a medium for processes of digestion (hydrolysis), absorption, metabolism, milk and sweat secretion, and elimination of urine and feces. It provides a medium for transport of nutrients, metabolites, hormones, and gases and is a lubricant and support for various organ systems and the fetus. A special role is in heat exchange and maintenance of heat balance because of its high thermal conductivity, allowing rapid transfer of heat. High latent heat of vaporization allows cows to transfer significant heat from their bodies to the environment with only a small loss of water volume; high heat capacity provides a thermal buffer by conserving body heat in cold climates and conserving body water in warm environments.

Water balance is affected by total intake of water and losses arising from urine, feces, milk, saliva, sweating, and vaporization from respiratory tissues. Amounts lost via various routes are affected by amount of milk produced, ambient temperature, humidity, physical activity of the animal, respiratory rate, water consumption and dietary factors (e.g., Na or N contents).

The equation was:

water intake (lb/day)
= 0.90 x (MY, lb/d) + 1.58 x (DMI, lb/day)
+ 0.11 x (Na intake, g/day)
+ 2.64 x (oF/1.8 - 17.778, average minimum temperature) + 35.25

Water Intake and Requirements. Water requirements of dairy cattle are met from three sources: (1) that ingested as drinking water, (2) that contained on or in feed consumed, and (3) that resulting from metabolic oxidation of body tissues. Murphy et al. (1983) developed a prediction equation to estimate intake of drinking water. Data were from the first 16 wks of lactation of 19 multiparous Holstein cows (average BW 1276 lb) averaging 73 lb MY/day. Diet was approximately 40% corn silage and 60% concentrate, dry basis. Sodium intake varied because sodium bicarbonate was fed to part of the cows. Factors included in the prediction equation were DMI (lb/day), MY (lb/day), Na intake (g/day), and weekly average minimum environmental temperature (*F). Ranges and averages for independent factors from the data set used to develop the equation were: 7.7 to 112.3, 72.9 lb MY/day; 11.4 to 59.9, 41.8 lb DMI/day; 12 to 153, 74 g Na intake/day; and, 9.0 to 68.0, 46.5 °F, average minimum temperature.

Table 1 depicts relative influence of these factors on drinking water intake. Values of factors used generally are within ranges of data utilized to develop the prediction equation. Actual average minimum temperature (*F) was characterized within cool (Dec, Feb, and Apr) and warm (Jun, Aug, and Oct) season categories from weather data at Gainesville, FL (Whitty et al. 1991). Milk yield and DMI were estimated, with typical expected declines in DMI in warm season when MY was 60 lb/cow/day or more. Sodium intake (g/day) was calculated based on specified DMI and dietary Na concentrations of 0.18% (NRC, 1989) or 0.50% which would be typical of diets with supplemental Na-containing buffer. Water contained on or in feeds consumed was not considered in prediction; water con-

Table 1: Predicted daily water intake of dairy cattle as influenced by MY, DMI, Na intake, and average minimum temperature (season and month). 1,2

Cool Season					
		Dec	Feb	Apr	
min. mo temp		51.2	43.5	51.0	
max. mo temp		75.6	68.6	76.7	
avg. mo temp		63.4	56.1	63.8	
		MY (lb)	**DMI3 (lb)**	**Na4 (g)**	**water intake (gals/day)**
0	25	20	12.6	11.2	12.6
20	38	31	17.4	16.0	17.3
		86	18.1	16.7	18.0
40	40	33	19.9	18.6	19.9
		91	20.7	19.3	20.6
60	45	37	23.1	21.7	23.0
		102	23.9	22.6	23.9
80	50	41	26.2	24.9	26.2
		114	27.2	25.8	27.2
100	55	45	29.4	28.0	29.3
		125	30.4	29.1	30.4
120	60	49	32.5	31.4	32.5
		136	33.7	32.3	33.6
Warm Season					
		June	Aug	Oct	
min. mo temp		62.8	71.0	69.6	
max. mo temp		87.9	91.6	89.1	
avg. mo temp		75.2	81.3	79.3	
		MY (lb)	**DMI3 (lb)**	**Na4 (g)**	**water intake (gals/day)**
0	25	20	4.6	16.1	15.8
20	38	31	19.4	20.8	20.6
		86	20.1	21.6	21.4
40	40	33	22.0	23.4	23.1
		91	22.7	24.2	24.0
60	44	36	24.9	26.3	26.1
		100	25.8	27.2	27.0
80	46	38	27.5	28.9	28.7
		104	28.3	29.8	29.6
100	48	39	30.0	31.5	31.2
		109	30.9	32.4	32.2
120	50	41	32.6	34.0	33.8
		114	33.5	35.0	34.8

1: Drinking water intake predicted from equation of Murphy et al. (1983); equation uses average minimum temperature (*F).
2: Average minimum, maximum and average monthly temperatures are 70-year averages for specified months at Gainesville, FL (Whitty et al., 1991).
3: Estimated DMI.
4. First row within each MY by DMI by average minimum temperature category is with dietary Na % = 0.18 (NRC, 1989); second row is with Na % = 0.50, typical of feeding a Na-containing buffer.

tent of experimental diets to develop equation was about 38% (Murphy et al. 1983). Water intake in gallons per day can be calculated by multiplying lb/day by 0.1198.

The prediction equation indicates that intake of drinking water changes 0.90 lb for each 1.0 lb change in MY, 1.58 lb for each 1.0 lb change in DMI, 0.11 lb for each 1 g change in Na intake, and 1.47 lb for each 1°F change. Thus, DMI has the most relative influence on water intake. However, absolute magnitude of change of various factors has direct bearing on how much water intake will be affected. For instance, because possible range in MY is greater than DMI it could affect water intake more (Table 1). Based on the prediction equation, cattle consume 0.19 gallon of water for each lb increase of DMI and 0.11 gallon for each lb increase in MY when the other three independent variables of the equation are held constant.

Sodium has a relatively small influence (3-4% increase) on water intake when Na content is increased from 0.18 to 0.50% of diet DM (Table 1). Using 70-yr average minimum temperatures of Feb and Aug, water intake increased about 25% during the warmer month when DMI, MY and Na intake were the same. Winchester and Morris (1956) found a relatively constant ratio of 3 lb of water consumed/lb of DMI within temperature range of 0 to 41°F. However, water intake per unit of DMI accelerated rapidly as ambient temperature rose above 41°F, reaching over 7 lb of water/lb DMI at 90°F.

Other Factors Affecting Water Intake.

Diet Moisture Content. Dairy cattle consuming typical air-dry (about 90% DM) diets consume less than 1 gallon of water from feed daily, depending on feed intake. This quantity is small compared with drinking water (Table 1). By comparison, when cattle consume pastures, silages, and liquid feeds, a substantial portion of water needs is provided. A typical diet for lactating cows containing 50% water would result in intake of 50 lb (6 gallon) of water if feed intake was 100 lb as-fed; this would be equal to about 17-23% of predicted drinking water intake depending on MY and average minimum temperature, based on equation of Murphy et al. (1983). Belgium workers found a negative relationship between total water intake and DM content of ration when evaluated at constant DMI (Paquay et al. 1970). In an equation developed from several pasture experiments, total water intake was affected negatively by DM content of the ration, and positively by DMI and mean temperature (Stockdale and King, 1983). Davis et al. (1983) investigating feeding value of wet brewers grains, showed that total water consumed (drinking water intake plus that derived from the ration) decreased about 26% as total ration moisture content increased from 30.7 to 53.6%. Drinking water intake, per se, declined 37% over this range of ration moisture contents. However, this effect may have been more a function of actual DMI, because as total ration moisture content increased from 30.7 to 53.6%, actual DMI declined 24%. Substantial influence of DMI on drinking water intake was evident.

Metabolic Water. When organic compounds are oxidized by animals, hydrogen molecules go towards formation of metabolic water. During metabolic oxidation, water yields (ml/g tissue) are 1.07 from fat, 0.40 from protein, and 0.50 from carbohydrate. This can account for as much as 15% of total water intake (Chew, 1965), which is substantially more than from consumption of an air-dry ration. Although oxidation (e.g., protein catabolism) contributes metabolic water, there also are increased demands for water for respiration, heat dissipation and urine excretion associated with oxidative processes. Thus, generation of metabolic water is not adequate to cover other demands associated with oxidation. Additional sources of water (e.g., drinking or feed-borne water) are required for metabolic oxidation.

Drinking Behavior, Waterer Characteristics and Stray Voltage. Pattern of water consumption is associated with feeding pattern (Nocek and Braund, 1985). When four first lactation cows were fed one, two, four or eight times daily, peak hourly water intake was associated with peak times of DMI. Cows would alternate the intake of feed and water.

Given the opportunity, peaks of drinking can be associated with milking. Typically, greater consumption is observed immediately after milking. Therefore, it seems judicious to provide abundant water to cows immediately after milking such as in the return lanes. Some dairies provide water cups or troughs for cows in the milking parlor. However, field observations suggest intake at this location is not appreciable (D. K. Beede, personal observation). This may be because water was quite cool (about 55°F) and thus not as acceptable to cows (Wilks et al., 1990). A field observation in southeastern Georgia suggested that cows preferred warmer water (about 80°F) coming from a heat-exchange unit in the milking parlor compared with well water (about 65°F) in summertime. Water temperatures between 60 and 80°F appear most acceptable to dairy cattle.

The type of water receptacle may affect drinking behavior. Compared on a herd basis in Europe, cows drank less frequently from water troughs than from water cups (bowls) (Castle and Thomas, 1975). Total daily drinking time ranged from 2.0 to 7.8 min, with longest time found for a herd which had only water cups. Drinking rate ranged from 1.2 to 6.5 gallon per min. The lowest rate was with water cups. Total daily intake was highest with drinking cups, but this likely was biased by herd and diet differences.

Filling rate of water cups can affect water intake and is largely a function of pipe size and water pressure. Reid (1992) noted that during renovation of a tie-stall barn, 2-inch PVC water pipe replaced 1-inch galvanized pipe. Larger diameter pipe facilitated more rapid filling of water cups and MY increased 3 lb during summer in Wisconsin when cows were housed 14 hr/day. Actual flow rates into water cups before and after the change were not given. In Sweden, water intake behavior from cups with flow rates of .5, 1.8 and 3.2 gallon per min was examined (Anderrson et al., 1984). Time spent drinking decreased from 37 to 11 and 7 min/day as flow rate increased. Frequency of drinking episodes was 40, 28 and 30 times/day. As flow rate increased, total water intake increased from 20.4 to 22.0 and 23.3 gallons per day. However, MY and composition and DMI were not affected by flow rate into water cups. In this experiment, each cow of a pair sharing the same water cup was classified as dominant or submissive based on videotaped behavior of frequent confrontations in drinking episodes. Submissive cows consumed 7% less water and ate 9% less hay than dominant cows. Milk fat % and FCM yield also were lower for submissive cows.

Use of water cups in most large herds is relatively infrequent for obvious reasons. However, watering troughs with adequate accessibility and flow rates are important, because cows tend to drink in groups associated with other events (e.g., feeding or after milking). Therefore, adequate linear dimension and filling rate of the water receptacle are required to accommodate the group's needs. Otherwise, more submissive cows may not have adequate opportunities to consume water and may not return to the water trough at a later time.

Potential for stray voltage at or around water tanks or other receptacles is worth considering. In a recent study, lactating Holstein cows adapted to being subjected to 3 volts AC or less between the water bowl and the rear feet (Gorewit et al., 1989). About 91% of cows subjected to 4 to 6 volts adapted within 2 days so that there was no change in water intake. However, some cows refused to drink within the first 36 hrs of subjection to 4 volts or more and treatment was ended. There also was a direct relationship between amount of voltage applied and time required for cows to adapt and consume their first gallon of water. When 6 volts were applied, over 11 hrs were required before the first gallon of water was consumed. Probably stray voltage is not a prevalent problem. However, it should be evaluated if lactational performance and water intake are less than expectations. Use of water heaters in cold climates may contribute to stray voltage problems.

On a practical basis, it seems obvious that a fresh, clean, abundant, easily accessible supply of drinking water must be available at all times to dairy cattle. However, based on numerous farm visits, this is not always the case (D. K. Beede, personal observation). If a herd or group is not performing to expectations, one of the first factors that should be evaluated and monitored is the drinking water.

Water Nutrition of Young Calves.

During early life (0 to 3 wks), suckling calves consume 0.20 to 0.40 gallon of water daily via milk or milk replacer. Young calves fed liquid diets consume more water per unit DMI than do older cattle fed dry diets (ARC, 1980). Water intake accelerates as calves begin to consume larger amounts of dry feeds. Providing free access to drinking water increased DMI and BW gain (37% increase) of young calves fed a liquid diet (89% water) compared with calves fed only liquid diet (Kertz et al., 1984). There was no indication that offering free-choice drinking water produced scours. Some times producers do not offer free-choice drinking water to young calves. This practice appears detrimental and may be perilous, e.g. in heat-stressing environments when the physiologic demand for water to aid in thermoregulation may be higher. Additionally, the notion that restriction of free-choice drinking water enhances intake of liquid milk replacers seems equally dangerous when demands from stress are great. Performance and health of young calves is superior when fresh drinking water is offered free-choice at all times. Proper and timely sanitation of water receptacles obviously is extremely important.

Drinking Water During Hot Weather and Effects of Chilled Water.

Water Needs During Heat Stress. Many large dairy herds are located in warm climates. Water unequivocally is the most important nutrient for lactating dairy cows in heat-stressing environments. Water is the primary medium for dissipation of excess body heat through lungs and skin in addition to that required in milk. USDA research showed total water loss from the body increased by 58% in nonlactating cows maintained at 86°F compared with 68°F. Much of the increase was due to increased (176%) secretion of water through skin as sweat (McDowell and Weldy, 1967). Concomitantly, loss of water in feces decreased 25%, but increased 54% and 26% via respiratory and urinary routes at 86°F compared with 68°F. For lactating cows in climate chambers (64 vs 86°F), drinking water consumption increased 29% at the warmer temperature; fecal water loss dropped 33%, but loss of water via urine, skin surface and respiratory evaporation increased 15, 59 and 50% (McDowell, 1972). Marked increases in water intake were observed starting at 81 to 86°F with lactating cows (Winchester and Morris, 1956; NRC, 1981). Cows also consumed less water in high humidity than lower humidity environments, probably because of reduced DMI and dampened ability to employ evaporative heat loss mechanisms.

Surprisingly little is known about actual requirements for water during heat stress. Numerous factors, such as rate of feed intake and physical form of the diet, physiological state, breed of animal, and quality, accessibility and temperature of water, likely affect intake during heat stress (NRC, 1981). Studies in climate chambers suggested that water needs under heat stress are 1.2- to 2-fold higher than required of cows producing in the thermal comfort zone. Using the prediction equation of Murphy et al. (1983), intake of drinking water increased 1.25-fold in Aug compared with Feb for the same MY by DMI by Na intake category (Table 1). Under natural conditions, particularly with potential for plentiful natural ventilation and sweating, water expenditure may be even greater.

Inadequate provision of water decreases milk production faster and more dramatically than any other nutritional factor. If milk production drops dramatically, particularly during summer, water supply should be evaluated. All too often, dirty water tanks or improper placement of waterers may be the culprit. A good guideline is, "Based on appearance of cleanliness, would you be willing to drink from the tank? If the answer is no, it is not clean enough for cows." A second frequent problem is that waterers or tanks are placed too far away from shade where cows spend their time during the hottest part of the day. If cows must choose between shade and walking to an unshaded watering station, they stay in the shade. During this time cows use much of their available body water to dissipate heat through evaporation, reducing that available for synthesis of milk. Waterers should be placed in shade in close proximity to cows; this also keeps water from getting hot from solar radiation which can reduce water intake.

Drinking Water Temperature.

Researchers at Texas A&M University compared cooling effects of chilled drinking water (50, 61, 72 and 82°F; Stermer et al., 1986). All water was withheld for 6 hrs before offering to cows. Inner ear temperature was reduced more with 50°F water than 82°F water. However, 50°F water was only 32% effective in reducing body temperature and authors were doubtful if the effect was maintained long enough (about 2.2 hr) to keep body temperature from rising above the upper critical temperature. There were no differences in MY of cows offered drinking water at various temperatures. This, coupled with estimated cost to chill water from 82 to 72°F ($.049/cow/day) or to 50°F ($.125/cow/day) led to the conclusion that there probably was no advantage to chilling drinking water for lactating cows. In another study, cows offered chilled (50°F) water had greater DMI (15% increase) and produced more 3.5% FCM (11% increase) than those drinking 82°F water (Milam et al., 1986).

Cows were offered 51° or 81°F water on a 24 hr basis in a switchback design (Wilks et al., 1990). Cows offered cooler water consumed more feed (3%), drank more water (7.7%) and had reduced respiration rates and rectal temperatures. Milk yield was increased 4.8% for cows consuming chilled water. An alternative to chilling water may be to insulate water tanks to maintain a lower water temperature if it comes from the well (or other source) relatively cool. Measurements in Florida indicated a temperature range of well water of 73-79°F immediately after pumping, considerably cooler than the high temperature treatments used in most of the Texas A and M University experiments. The practical approach seems to be to prevent well water from warming after it is pumped and stored above ground.

Cows exhibited preference when offered 50° or 86°F drinking water cafeteria-style (Wilks et al., 1990). Respiration rates and rectal temperatures were reduced with cooler water. However, cows preferred to drink warmer water given the choice, with over 97% of total water consumed being warmer water. Over 70% of cows drank only warm water. It was concluded that if chilled drinking water was offered as way to cool cows, it must be the only source of drinking water available. Otherwise, cows may wait to drink until a time when warmer water is available.

Well water (77°F) or chilled (59°F) drinking water was offered on a large Florida dairy (Bray et al., 1990). Cows were kept in open lots with cooling ponds and two shade structures per lot. Cows did not have access to feed and water under shades. Four watering stations (unshaded) were in each lot. Over 1,100 cow-period observations were collected in a reversal design from June through September. Mean daily minimum, maximum, and average ambient temperatures and mean daily minimum relative humidity were 68.4, 91.0 and 79.7°F, and 58%. Under these conditions there was no difference in MY (61.4 vs 61.8 lb/day) for cows offered well or chilled water.

A similar experiment was performed the following year on another commercial dairy where cows were kept in feeding barns with fans and sprinklers, and had access to feed and water continuously (Bray et al., 1991). Mean daily minimum, maximum, and average ambient temperatures and mean daily minimum relative humidity were 66.3, 91.3 and 78.8°F, and 50.5%. There were about 175 cows per treatment and drinking water temperatures were well water (75-80°F) and chilled water (52-57°F) in a 2-mo. reversal experiment. Water consumption from total group measurements averaged 21.7 and 23.2 gallons per cow per day for well water and chilled water. There was no difference in intravaginal temperatures as detected by thermal couples with radio transmitters. Average MY was 63.1 and 64.2 lb/d, for well and chilled water treatments, but were not significantly different.

In a survey of over 200 drinking water tanks on 31 dairies in central Florida in summer (Giesy, 1990 cited by Bray et al., 1991), overall average water temperature was 86°F, and ranged from 77-97°F. Shading tanks lowered temperatures somewhat with average water temperatures of 87, 85, 81 and 81 when tanks were unshaded, shaded during the morning, shaded during the afternoon or continuously shaded. Average temperature of fresh water at the tank inlet was 82°F, and was affected by the distance water traveled before entering the tank. Fresh water inlet temperature to the tank was higher (82°F) if pipe servicing the tank was above ground for 200 ft or more, compared with less than 100 ft (79°F). Volume capacity of tank relative to number of cows it serviced affected tank water temperature. When tank capacity was less than 1 gallon per cow, water temperature was 82°F. At tank capacities of 1-3, 4-9, 10-19, 20-39 and over 40 gallons per cow, temperatures of water in tanks were 85, 86, 87, 88 and 91°F. This information emphasizes the benefit of relatively small volume, rapidly filling tanks for cows in warm climates. Access to sufficient linear space of an abundant water supply probably is more important than tank capacity.

Main consideration for water nutrition during hot weather is to provide an easily accessible source of clean drinking water in close proximity to cows. This should be in the shade so that water in the tank or waterer is not heated excessively above that temperature which it comes from the well. Additionally, chilling drinking water probably is not warranted except where water comes from the well at temperatures above 86°F or where water cannot be kept reasonably cool by shade, specifically designed drinking water receptacles, and (or) insulation.

Water Quality and Factors Affecting Performance

The most extensive review of water quality factors was by the NRC (1974) subcommittee on nutrients and toxic substances in water for livestock and poultry. Water quality is an extremely important issue both in terms of quality of drinking water provided to livestock and in terms of quality of water leaving production units as a potentially renewable resource. The latter is not considered in this paper.

Five criteria can be considered when evaluating drinking water quality: organoleptic, physio-chemical, substances present in excess, toxic compounds, and microorganisms (primarily bacteria). Organoleptic factors (e.g., odor and taste) may be readily detectable by the animal, but are of little direct consequence to health or productivity unless water consumption is affected dramatically. Physio-chemical properties, i.e. pH, total dissolved solids, hardness, and total dissolved oxygen are used to classify broadly water sources and generally do not present direct health risks but may indicate underlying problems. Excess of some chemicals normally found in water (i.e. nitrates, Fe, Na, sulfates, and Fl) may be health risks or depress water consumption. Toxic substances may be common in water but generally are below dangerous concentrations; examples are As, cyanide, Pb, Hg, hydrocarbons, organochlorides, and organophosphates. Maximum bacterial concentrations of potable water for humans are regulated; however, less control is exercised for drinking water for livestock, but potential hazards might exist in some circumstances.

Table 2: Guide to use of saline waters for dairy cattle; total dissolved solids equals TDS.

TDS (mg/l or PPM)	comment
less than 1000 (fresh water)	Presents no serious burden to livestock.
1000-299 (slightly saline)	Should not effect health or performance, but may cause temporary mild diarrhea.
3000-4999 (mod. saline)	Generally satisfactory, but may cause diarrhea especially upon initial consumption.
5000-6999 (saline)	Can be used with reasonable safety for adult ruminants. Should be avoided for pregnant animals and baby calves.
7000-10000 (very saline)	Should be avoided if possible. Pregnant, actating, stressed or young animals can be affected negatively.
over 10000 (nearing brine)	Unsafe. Should not be used under any conditions.

Salinity and Total Dissolved Solids. Salinity refers to the amount of dissolved salts present in water. First consideration generally is sodium chloride, but other dissolved inorganic constituents such as carbonates, sulfates, nitrates, K, Ca, and Mg are in the same category. These constituents may affect osmotic balance of animals and generally are measured as total dissolved solids (TDS). Table 2 adapted from NRC (1974) provides a guide to use of saline waters.

Jaster et al. (1978) studied effects of water salinity on lactation. Tap water (196 ppm) was compared with drinking water containing 2,500 ppm dissolved sodium chloride offered to 12 lactating cows averaging 82 lb MY/day at the beginning of the experiment. Water intake was 7% greater, but feed intake and MY tended to be less for cows offered high saline water. Minerals in blood and milk, and diet digestibilities were similar between treatments, but urine and fecal Na, and urine Cl were higher for cows offered drinking water containing high amounts of salt. Other studies suggested no effect of drinking water containing 15,000 ppm (Heller, 1933) and 10,000 ppm (Frens, 1946) sodium chloride, or 5,895 ppm sodium sulfate. However, Frens (1946) reported reduction in MY with 15,000 ppm sodium chloride. Also in Arizona, Holstein heifers showed an increasing preference for drinking water as salinity approached 2,000 ppm, but water consumption dropped dramatically when salinity was greater than 2,500 ppm (Wegner and Schuh, 1974). In growing beef heifers, consumption of drinking water with 12,500 to 20,000 ppm sodium chloride caused symptoms of salt toxicity (Weeth and Haverland, 1961).

In a recent study in Saudi Arabia during warm weather, Challis et al. (1987) found that desalination of drinking water originally containing about 4,400 ppm TDS, of which 2,400 ppm were sulfates, improved MY by 28% (77 vs 60 lb/day), increased water intake 20% and increased grain intake 32% compared with high saline water. Desalinated water contained 441 ppm TDS. When high saline water was reintroduced, MY dropped 13.2 lb/day during the first week. This study suggests that a combination of high TDS in drinking water and hot weather can be particularly deleterious for lactating cows.

Maximum tolerable concentrations of sulfates in drinking water were investigated in Nevada. Growing cattle were affected adversely by 3,493 ppm sulfate in their drinking water. Feed and water intakes were reduced and methemoglobin concentration was increased (Weeth and Hunter, 1971). In a subsequent study, 1,462 ppm or 2,814 ppm sulfate-water made by adding sodium sulfate to tap water reduced hay intake, but not water consumption of Hereford heifers compared with controls (110 ppm sulfate in drinking water) (Weeth and Capps, 1972). Rate of BW gain was reduced by water containing the highest sulfate concentrations. Drinking water with 2,814 ppm sulfate increased methemoglobin concentrations and significantly altered renal function. These researchers concluded that the tolerable concentration of sulfate in drinking water for growing beef cattle in summer in Nevada was near 1,450 ppm.

In a follow-up study designed to define more accurately maximum tolerable concentrations of inorganic sulfate in drinking water, Digesti and Weeth (1976) offered 110, 1,250 or 2,500 ppm sulfate in drinking water, with higher concentrations added as sodium sulfate. Feed consumption, water intake and growth rate of beef heifers were not affected by higher sulfate drinking water during the 90-day experiment. No overt toxicity was detected. However, heifers given water with 1,250 or 2,500 ppm sulfate tended to accumulate more methemoglobin and sulfhemoglobin without a decrease in concentration of total blood hemoglobin. Sulfate loading did not cause diuresis, although renal filtration of sulfate was increased by the highest sulfate treatment. It appeared that 2,500 ppm sulfate in drinking water was tolerated by these heifers without adverse effects, and it was suggested to represent a safe tolerance concentration. In a companion study, sulfate (3,317 ppm estimated rejection threshold) in drinking water was found to be more unpalatable than Cl (5,524 ppm estimated rejection threshold). Recent evidence suggests that high dietary intakes of the anions, sulfate and Cl, can perturb acid-base balance of cattle (Wang and Beede, 1992). Abnormally high intakes of these anions in drinking water likely are responsible for detrimental effects on animal health and productivity. Their negative influence likely is more marked than that of high Na intake.

If anti-quality factors (e.g., high TDS, Cl or sulfates) are suspected of affecting animal performance, concentrations in drinking water should be determined. Water intake can be estimated from equation of Murphy et al. (1983) or by using water meters. It may be feasible to adjust amounts of minerals supplemented in the diet so that total intake (from water plus feed) is more nearly those recommended. Alternatively, processes to reduce concentrations of minerals in water (e.g., dilution, ion exchange or distillation), may be possible, though possibly costly.

Nitrates (nitrites). Nitrate poisoning (nitrite poisoning) results from conversion of nitrate to nitrite by ruminal microorganisms and subsequent conversion of hemoglobin to methemoglobin by nitrite in blood. This reduces dramatically the oxygen carrying capacity of blood and can result in asphyxiation in severe cases.

One 35-mo study in Wisconsin compared reproductive efficiency and lactational performance of a 54-cow herd in which drinking water contained 19 ppm or 374 ppm nitrate (added as potassium nitrate; Kahler et al., 1975). During the first 20 mo of study there were no effects on reproductive function as assessed by incidences of abortions, retained fetal membranes, cystic ovaries, observed heats, services per conception, and first-service conception rates. During the latter 15 mo of study cows drinking higher nitrate-containing water had higher services per conception (1.7 vs 1.2) and lower first-service conception rates. Average MY was not different between groups but, total MY during the 36-mo study was somewhat lower for cows drinking higher nitrate-containing water, likely due to increased dry period length resulting from lower conception. No effects on blood hemoglobin, methemoglobin, vitamins A or E, or liver vitamin A concentrations were detected.

Table 3: Concentrations of nitrates and nitrate-nitrogen in drinking water and expected response.

(ion in water, ppm) NO3	NO3-N	comment
0-44	10	No harmful effects.
45-13	10-20	Safe if diet is low in nitrates and is nutritionally balanced.
133-220	20-40	Could be harmful if consumed over a long peri od of time.
221-660	40-100	Dairy cattle at risk; possible death losses.
661-800	100-200	High probability of death losses; unsafe.
800+	200+	Do not use; unsafe.

Though nitrates have not been a major concern in drinking water of dairy cattle in the past, it may be an important future consideration. This poisoning has been reported when cattle drink from ponds or ditches contaminated by runoff from heavily fertilized crop land or pastures. Drinking water with above normal nitrate concentrations in combination with feeds containing high nitrate concentrations may pose an important practical concern in specific situations. There is a lack of information upon which to base definitive standards. Table 3 gives general guidelines (NRC, 1974).

Water Hardness and pH. Hardness often is confused with salinity or TDS, but the two are not necessarily related meaningfully. For example, high saline waters may contain an abundance of Na salts of Cl and sulfate and yet be quite soft if relatively low concentrations of Mg and Ca are present. Concentrations of these two cations primarily are responsible for degree of hardness of water. Hardness (Ca plus Mg) classifications include: soft (0-60 ppm), moderate (61-120 ppm), hard (121-180 ppm) and very hard (181 ppm and greater; NRC, 1974). Some laboratory analyses may list hardness in terms of grains; 1.0 grain per gallon is equal to 5.8418 x 10-3 ppm.

Table 4: Safe upper limit concentrations of some potentially toxic substances in drinking water of livestock (NRC, 1974)[1]

substance	Upper Limit mg/liter (ppm)
As	0.2
Ba	not defined
Cd	0.05
Cr	1.0
Co	1.0
Cu	0.5
Cyanide	not defined
Fl	2.0
Fe	not defined2
Pb	0.1
Mn	not defined
Hg	0.01
Mo	not defined
Ni	1.0
V	0.1
Zn	25.0

1: These concentrations generally are far below that required to cause death of half the test subjects (LD50) administered these substances.
2: Experimental evidence not available to make definitive recommendations.

Water nutrition of young calves fed liquid diets is important and there is no justifiable reason not to provide free-choice drinking water. Feed intake and growth rate have been increased by offering free-choice drinking water. Under heat-stressing conditions, water needs are increased 1.2- to 2-fold. Chilled drinking water did not consistently improve lactational performance under commercial conditions and was not economically advantageous. Drinking water temperature above 86°F may reduce consumption.

Several factors should be evaluated if problems with the drinking water supply are a suspicion. Abnormally high concentrations of Cl and sulfate are often times of most concern. Nitrates and hardness of water have not been detrimental factors.

An abundant, continuous, clean source of drinking water for all classes of dairy animals is crucial!

Apparently, degree of hardness does not affect animal health or productivity. Over 30 years ago researchers in Washington compared influence of hard (116.4 ppm of calcium carbonate equivalents) and soft (8.4 ppm) water on MY of dairy cows (Blosser and Soni, 1957). Calcium plus Mg concentrations were 33 ppm for hard water and about 1.2 ppm for soft water. No differences were detected due to degree of hardness in 4% FCM yield, water intake or water consumed/lb MY. Similarly, Graf and Holdaway (1952) in Virginia found no effects of hard water (290 ppm of Ca plus Mg) on MY, BW changes, water intake or ratio of water intake to MY compared with soft (0 ppm) water offered for 57 days.

Drinking water with pH between 6 to 9 is thought to be acceptable to livestock (NRC, 1974). Information on potential deleterious effects outside this range was not found.

Other Potentially Toxic Compounds and Organisms. NRC (1974) provided guidelines of upper limit concentrations of potentially toxic substances in drinking water. Studies are limited on effects of these compounds on lactation and secretion into milk. Clinical cases have been reported where Pb and Hg were determined to cause toxicity. Table 4 gives safe upper limits of several toxic substances.

Chlorinating water can increase intake because bacteria present in pipes and waterers are reduced. Commercial dry pellet chlorinators are available which can be connected at the well to service the whole dairy. Reid (1992) recommended in certain situations that all water receptacles be chlorinated weekly. Household bleach at 2 to 3 ounces per 50 gallon water capacity was recommended.

Gorham (1964) reported that at least six species of blue-green algae poisoned cattle drinking water from a lake. However, the causative agents were not identified specifically. It was recommended that water with plentiful algae growth not be offered to cattle. Shading of water troughs and frequent sanitation also can help minimize algae growth.

Summary and Conclusions

Water is indispensable for life and is the most important dietary essential nutrient for dairy cattle. Lactating cows require a larger portion of water relative to their BW because milk is 87% water. Water intake and requirements are influenced by physiological state, rate of MY and DMI, BW, composition of diet and environmental factors. The water intake prediction equation of Murphy et al. (1983) is useful to estimate water intake requirements. Dry matter intake and MY have large influences in the equation. Diet moisture content, cow behavior, physical characteristics of water receptacle, and ambient temperature also affect water intake.

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