

Microbiological Water Quality for Optimal Livestock Production and Health: *An absence of data?*

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Abstract

Relative to standards for humans, water in the cattle environment is often of poor or unknown microbiological quality, whether it is surface drinking water, recycled flush water, wash water, cooling water or drinking water in troughs. The microbial ecology is complex and not well understood. Microbial contamination originates from the environment, the feces of cattle or other animals, and, due to oral residues, even the normal act of drinking. In many circumstances, the quality is regarded as uncontrollable at best. Although pathogenic bacteria and zoonotic foodborne pathogens are found in cattle water with some frequency, the health, production and food safety risks associated with cattle drinking or contacting water contaminated with these microorganisms remains largely undefined. As production and health consequences from the presence of these agents are certainly biologically plausible and some evidence suggests that they do exist, additional research is needed to quantify these risks. If these risks prove to be unacceptable under current management conditions and consumer expectations, methods to ensure microbiologically cleaner water for livestock will need to be identified.

Introduction

For humans, provision of pure, clean drinking water has long been one of the most important public health objectives. Well before John Snow's classical epidemiological investigation identifying an association between cholera and water contamination in London (1846-61) and before Pasteur's Germ Theory of Disease

(1870), civilizations made special efforts to protect against water contamination. Today, the impact of poor microbiological water quality on human health continues and is undisputed. Numerous studies have shown the adverse health consequences of consuming drinking water that fails to meet basic microbiological standards. To this end, the World Health Organization publishes comprehensive guidelines on the risk assessment and control of water contamination.⁴⁷ Despite this long history, new water-borne pathogens continue to emerge and standards evolve as the microbial ecology of drinking water, such as the role of biofilms, is better understood.⁴⁰ In contrast, few studies of the effects of microbiological quality of livestock drinking water or of other water to which the livestock are exposed have been done. The general lack of concern about the quality of livestock drinking water is not the result of ignorance but either unquestioned acceptance of the commonplace or resignation to the apparent lack of control. This review focuses on the effects of microbiological water quality on cattle production and health.

As water is becoming an increasingly scarce resource, its conservation and reuse are becoming larger issues for agriculture. Compared to most other livestock farms types, dairy farms use a comparatively large amount of water per cow and cattle are exposed to the water in unique ways. Besides drinking, water on dairy farms is often used in wash pens and in the parlor for cleaning cow udders prior to milking, cleaning of milking equipment during and after milking, flushing of manure from alleyways, mixing powdered calf milk replacer, evaporative cooling of cows, as cooling ponds and even as a heat transfer agent for thawing frozen semen and cooling milk.

Wastewater is commonly collected in lagoons and applied to crop and grazing land from which harvested or grazed crops can plausibly transmit infectious agents originally contaminating the water back to cattle. Even when presented with drinking water of controlled quality, cows may deliberately consume poor quality water intended for other purposes, such as alley flushing, or other water in the environment. A Florida study found that water use averaged 175 gallons per lactating cow per day, with some dairies averaging 400 gallons per lactating cow per day.⁴¹ Of this, the highest use was for flushing manure from alleyways (60 to 80 gallons per lactating cow per day). Cows drank an average 25 gallons per day through the year and approximately the same amounts were used for cow cooling, cleaning cows prior to milking and cleaning the milking parlor. In a study of Arizona dairies cited by Martin *et al*,³³ water usage ranged from 80 to 240 gallons per lactating cow per day.

Water is described in the National Research Council (NRC) "Nutrient Requirements of Dairy Cattle" as being the most important nutrient.² The amount of water per unit of body mass required by the lactating dairy cow is greater than for any other land-based mammal.⁶ In the NRC water intake prediction equation, the predicting factors are dry matter intake, milk yield, sodium intake and minimum daily temperature, all being positively correlated with intake. Martin *et al*³³ stated that a high producing cow drinks 30 to 50 gallons of water per day, drinking is likely the largest and most direct exposure to microbial contaminants in water.

Numerous publications address standards and acceptable levels of chemical contaminants and mineral concentrations in cattle water.^{2, 5, 6, 10, 39} However, little information is available on the effects of microbial contamination or on acceptable levels. Again, this is not because of a lack of the awareness of the role of water in the transmission of infectious diseases. Over 100 years ago, the role of water in the dissemination of several viral and parasitic infections of livestock was clearly outlined.⁷ Poor livestock water quality was of such concern in early days at the Chicago Stock Yards that the first commercial large-scale water chlorination facility in the US was constructed to purify the water offered to cattle.⁴⁶

General guidelines on microbiological water quality for cattle have been proposed but the empirical evidence to support these standards is lacking. The current NRC states that coliforms greater than 0 MPN (Most Probable Number) is "unsatisfactory" and greater than 9 MPN is "unsafe" but that "the effect of coliforms in water on health of cattle or ruminal microorganisms is unknown."² Dairy extension specialists in the Midwest have proposed that water be classified as acceptable for dairy cattle if it contains less than 1,000 total bacteria

per mL and less than 50 coliform bacteria per 100 mL.³⁰ Dairy extension specialists in the Southwest have proposed that both total and fecal coliform counts should be under 1 per 100 mL for calves.⁴³ For adult cattle, they proposed that total coliform counts should be under 15 per 100 mL and fecal coliforms under 10. They also recommend that fecal streptococci should not exceed 3 per 100 mL of water for calves or 30 per 100 mL for adult cattle. They state that water with total bacteria counts exceeding one million should be avoided for all classes of livestock, and that most water supplies will have total bacteria counts below 200 per 100 mL. Others have arbitrarily set acceptable levels of bacterial contamination of livestock drinking water as being below 5×10^3 CFU *E. coli* per 100 mL of drinking water.^{14, 31} In a survey of dairy water troughs, *E. coli* counts (a fecal coliform) in trough water averaged 1,000 per 100 mL.²⁹ *E. coli* in intensively used feedlot water troughs were higher, averaging 25,000 per 100 mL (LeJune, unpublished data). From this, the total daily intake of *E. coli* by dairy and beef cattle can be estimated based upon average water consumption and may be as high as 10^6 to 10^7 CFU each day. Note that this dose of *E. coli* is comparable to that from the daily consumption 0.1 to 1 kg of typical fresh bovine feces, which most would regard as excessive.

Any dairy farm water use that could contaminate raw milk falls under specific regulatory guidelines and requirements maintained by the FDA. The Grade A Pasteurized Milk Ordinance (PMO), 1999 revision, requires that all water used in the milkhouse and milking operations be obtained from a proper supply, which is defined in appendix D of the PMO, and be of a tested safe and sanitary quality as defined in appendix G of the PMO.¹ The criterion for the latter is a Most Probable Number (MPN) of coliforms less than 1.1 per 100 mL as tested every three years or after repair, modification or disinfection of the water delivery system. As the PMO does not apply to water used outside of the milkhouse, water quality may be impacted by flaws in the distribution system beyond the milkhouse.

Microbiological Risk Analysis

Risk analysis is a systematic approach to quantifying the risk associated with microbiological agents. Driven by recent concerns about emerging microbial food safety risks, quantitative microbiological risk assessment methodology is maturing rapidly. Although focused on human foodstuffs, several recent reviews provide excellent overviews of the methods.^{9, 25, 26} Risk analysis consists of three components: 1) risk assessment, 2) risk management, and 3) risk communication. The risk assessment step of risk analysis attempts to answer the following questions: What are the hazards? What is the

likelihood that it will occur? What is the result if the risk occurs?

Risk Assessment

Hazard Identification

Cattle drinking water is easily (and frequently) contaminated with microbes and organic matter from the normal act of drinking and often with fecal material from cattle or other animals.^{29, 38} Outflow water from flushing manure is certainly heavily contaminated and flush inflow water is likely contaminated if it was recycled. Furthermore, some water entering the trough or reservoir is contaminated at the source, thereby exposing animals to microorganisms regardless of the hygiene of the drinking trough.²³ As summarized by Bauder *et al*⁴ and Goss *et al*,¹⁷ multiple studies have found that a considerable fraction of rural human drinking water wells are contaminated with coliforms at levels that exceed quality standards (Table 1). Livestock drinking water obtained from these wells is also likely contaminated at a similar frequency.

The list of potential microbiological hazards in livestock water is long. Virtually any virus, algae, bacterium, fungi or protozoa that can survive, even transiently, in the aquatic milieu could be included on such a list. Unless microbial predation is occurring, the survival of most infectious agents is often prolonged in water compared to other environments. Livestock drinking water quality studies have specifically identified *Leptospiras* (occasionally),¹⁹ *E. coli* O157 and other shiga toxin-producing *E. coli* (3-20% of troughs tested),^{29, 35, 37} *Salmonella* sp (approximately 2% of troughs),⁴² *Campylobacter* sp²⁰ and *Aeromonads*.¹⁸ In a 1989 survey of veterinarians, 38% of respondents reported that problems associated with poor water quality were very frequently encountered.³⁴ Among problems attributed to poor water quality were mastitis (particularly coliform), abortions, metritis, infertility and diarrhea. Due to the consumer and public health con-

cerns that developed during the last decade, this list now would likely include the transmission to cattle of foodborne pathogens and antibiotic resistant commensal flora.

Contaminated water is associated with the presence in or the transmission of enteric agents to cattle in a number of reports. Wray and Sojka reviewed a number of clinical salmonellosis outbreak reports where drinking contaminated water from rivers, streams and ponds was associated with the outbreak.⁵⁰ In the 1996 USDA NAHMS studies, dairies that used water for alley flushing were 8 times more likely to have cows shedding *E. coli* O157:H7¹⁵ and to have a significantly higher proportion of cows shedding *Arcobacter* spp⁴⁵ than dairies that did not. Although not statistically significant in the presence of low study power, dairies that used water for alley flushing were 3.5 times more likely to have *Salmonella*-infected cows than dairies that did not.²⁴ Contaminated recycled flush water was associated with the long-term perpetuation of *Salmonella* infections on a large California dairy.¹⁶ In a study of 231 British herds engaged in a John's disease vaccination program, the use of a piped water supply at pasture compared to ponds or ditches was associated with reduced time to freedom from clinical disease.⁴⁸ This suggests that investigating the role of drinking water contamination in the transmission of John's disease is warranted. Seasonal fecal shedding of *Campylobacter jejuni* by dairy cows was shown to be associated with drinking from a contaminated pond.²⁰ Also worthy of note is that two of these enteric agents, *Salmonella* spp and *Campylobacter* spp, account for the majority of human food-borne disease cases in the US.

Dairy cattle are exposed to microbial contaminants in water through exposure routes other than drinking, particularly in association with the milking process. Numerous herd outbreaks of *Pseudomonas aeruginosa* mastitis due to the use of contaminated water for udder washing have been documented.^{11, 12, 32} In a survey of

Table 1. Summary of human drinking water wells exceeding coliform standards.

Rural well region	Survey year	No. wells sampled	% exceeding coliform stds.	% with fecal coliforms present
Alberta	1994	420	68	-
Iowa	1989	686	-	37
Midwest	1995	5,530	41	-
Montana	1990	1,259	39	-
Nebraska	1982	268	-	37
Nebraska	1994	1,808	15	-
Ontario	1992	1,292	34	22
Quebec	1976	216	27	-
US	1988	3,690	31	-

(Adapted from Bauder JW, *et al*, 1991 and Goss MJ, *et al*, 1998)

wash hoses in 22 milking parlors, Erskine and co-workers found that 23% contained *P. aeruginosa*, suggesting that it may be a relatively common contaminate of parlor water even though the water and the supply system met PMO standards.¹² Contaminated aerosols have also been associated with the transmission of salmonellae in calves on farms²¹ and experimentally.⁴⁴

Likelihood of transmission

The likelihood of waterborne transmission of microorganisms from water to cattle is more difficult to quantify and may be influenced by both animal factors and environmental effects on the organism, both of which are complex. For example, the probability of a water source being contaminated with a particular microorganism is often a complex function of the number of animals harboring the organism, the typical amount of contamination and frequency with which it is delivered to the water source and the microecology of the particular water system. Once in the water, the degree to which the aquatic environment provides a suitable niche for the survival and/or proliferation will influence the concentration of the potential pathogen in the water. Depending on the number of competing microbial species and whether or not protozoal predation is occurring, many bacterial species are able to proliferate in the presence of remarkably low nutrient concentrations.

Unlike municipal water mains, cattle water systems are usually not routinely flushed to remove sediments and impurities. Biofilms and accumulated sediments at the bottom of water troughs provide an ideal environment for survival of microorganisms, protecting them from sunlight and disinfectants. The concentration of bacteria in aquatic sediments is often 2 to 3 orders of magnitude greater than the bacterial concentration in the overlying water column. Coliforms that persist in aquatic sediments and biofilms can proliferate under appropriate environmental conditions, such as increased summer temperatures and the absence of direct sunlight, which results in increased coliform levels in the water.^{22, 29} Studies of municipal water distribution systems have clearly demonstrated that coliform growth in water is seasonal, peaking in the summer when the water temperatures are warmer.²⁷ In addition, disturbing or mixing of the sediments may transiently increase the concentration of potential pathogens in the water column.

An association between water contamination by a specific microorganism and the prevalence of infection or disease in cattle is not sufficient evidence of causality in itself. The contaminated water may simply reflect the total environmental contamination by an organism. Experimental studies have demonstrated the possibility of transmission of *E. coli* O157 from a contaminated water trough after a prolonged period of environmental

persistence.²⁸ However, it remains to be determined how frequently waterborne transmission occurs and what precautions can be used to prevent such events from occurring.

Implications of Infection

This aspect of risk analysis falls within the realm of traditional clinical veterinary medicine. Briefly, waterborne infections can result in a spectrum of outcomes, ranging from life-threatening septicemias in calves to clinical enteric disease in adults to subclinical production losses to asymptomatic infections of adult animals with zoonotic foodborne pathogens. For example, *E. coli* can cause mastitis, *Leptospira* spp can cause abortion, and salmonellosis can be manifested clinically as diarrhea. Furthermore, in the case of human foodborne pathogens, cattle may have intestinal colonization with *Campylobacter jejuni*, *E. coli* O157 or *Salmonella* and remain asymptomatic.

Risk Management

This step of risk analysis attempts to answer the following questions: What can be done to control the hazards? What are the costs of the proposed mitigation strategies in relation to the expected benefits? In theory, simply providing *only* clean water would eliminate waterborne infections in cattle, but this goal is not achievable even for human drinking water. To establish future water quality criteria for human consumption, the EPA has defined the acceptable risk as one case per 10,000 people exposed per year.⁴⁰ Even if the incoming water meets a standard, most cattle water troughs are contaminated each and every time they are used. Frequent cleaning, even as frequent as twice daily, doesn't appear to be an effective method to control the microbial contamination in water troughs (LeJeune, unpublished data).^{29, 38} Paradoxically, episodic trough cleaning and disinfection appears to increase the coliform level, apparently because it reduces the levels of predatory protozoa. On the other hand, Ensley (as cited by Socha *et al*)³⁹ found an association between increased cleaning frequency and increased milk production. As other factors, such as exposure to direct sunlight, temperature and increased distance from the feedbunk, are associated with reduced levels of contamination,²⁹ risk reduction is possible. Exposure to environmental sources of water, such as from rainfall on pasture or in an alley being flushed, are much more difficult to eliminate or control.

The most important question that needs to be answered first is whether providing water meeting a certain standard actually provides cattle health, production or food safety benefits. Since it is unknown how much contaminated water contributes to the total pathogen

exposure on a farm, it is presently not possible to determine how much, if any, improvement in animal health would be realized if cleaner water was provided. The Food and Agriculture Organization acknowledges that human food safety hazards can enter the food supply through contaminated feeds and water offered to livestock.¹³ To reduce the level of shiga toxin-producing *E. coli* in the human food supply, the World Health Organization recommends that "potable" water be used for livestock drinking as a control measure.³⁶ In general, the term "potable" in microbiological standards means no detectable fecal coliforms in a 100 mL water sample. Again, these FAO and WHO guidelines are made without quantitative evidence of the actual risks associated with using other than "potable" water. A recent review of the guidelines for re-use of wastewater, such as from dairies, on crops addresses the difficulties of establishing such guidelines.⁸

E. coli measurement is often used as an indicator of water quality. It is not known if the repeated ingestion of significant numbers of *E. coli* has any effects on bovine health or production. On the other hand, the presence of high numbers of *E. coli* is interpreted as an indicator of fecal contamination. If fecal contamination has occurred, the possibility of water contamination by other microorganisms transmitted via the fecal-oral route is increased. Because providing cleaner water to cattle reduces the likelihood of their exposure to deleterious organisms, it stands to reason that doing so is beneficial. Preliminary evidence suggests that cattle performance in cow-calf operations is improved when cleaner water is provided.⁴⁹ Clearly, additional scientific studies are required to determine the livestock health and production risks and benefits associated with the microbiological quality of drinking water offered to cattle.

Risk Communication

The final step of microbiological risk analysis is communication of the risks to the stakeholders, particularly the livestock producers. Without quantitative information on the health and production effects of the risks associated with poor microbiological quality of livestock drinking water or the other water to which livestock are exposed, veterinarians are in an awkward situation when expected to provide advice in the face of livestock water quality concerns. Although readily available from most environmental laboratories, routine microbiological analysis of water is unlikely to provide information on the role of water in the epidemiology of a health or production problem on an individual farm. For the most part, all open water that cattle contact will contain at least some *E. coli*, and occasionally other microorganisms of concern, and often it is not possible to determine if this is the cause of the problem or result of one.

Presently, the most logical approach to take when addressing the possibility of a microbiological water quality problem as the cause of an infectious disease or production problem on a farm is to rule-out as many other possible causes and to institute control measures for all routes of transmission. Since microorganisms are at least occasionally disseminated to cattle via contaminated water, common sense dictates that improving the water quality will decrease the likelihood of this occurring. However, effective methods to maintain high drinking water quality in commercial livestock operations have yet to be identified and the actual benefits from such interventions have yet to be shown.

References

1. Anonymous: Grade "A" Pasteurized Milk Ordinance, 1999 Revision. U.S. Department of Health and Human Services, Public Health Service, Food and Drug Administration, 1999. <<http://vm.cfsan.fda.gov/~acrobat/pmo99-1.pdf>>
2. Anonymous: Water. In Nutrient Requirements of Dairy Cattle, ed 7. Revised, National Academy Press, Washington, DC, 2001, pp 178-183.. <<http://books.nap.edu/books/0309069971/html/178.html>>
3. Anonymous: Outbreak of *Cysticercus bovis* (*Taenia saginata*) in feedlot cattle in Alberta. *J Can Vet Med Ass* 43:227, 2002.
4. Bauder JW, White BA, Inskeep WP: Montana extension initiative focuses on private well quality. *J Soil Water Conserv* 46: 69-74, 1991.
5. Beede DK: Water for Dairy Cattle. In VanHorn HH, Wilcox CJ, (eds.) Large Dairy Herd Management, ed 2, Am Dairy Sci Assoc, Champaign, IL, 1992, pp 260-271.
6. Beede DK and Meyers ZH: Water Nourishment of Dairy Cattle. Proc. 24th Quebec Symp Dairy Nutrition, October 19, 2000, Saint-Hyacinthe, Quebec, CA, pp 1-28.
7. Bitting A: The relation of water supply to animal diseases. *Bull 70 of the Purdue Univ Agric Exp Stn* IX:42-51, 1898.
8. Blumenthal UJ, Mara DD, Peasey A, Ruiz-Palacios G, Stott R: Guidelines for the microbiological quality of treated wastewater used in agriculture: recommendations for revising WHO guidelines. *Bull World Health Organ* 78:1104-16, 2000.
9. Buchanan RL, Smith JL, Long W: Microbial risk assessment: dose-response relations and risk characterization. *Int J Food Microbiol* 58:159-72, 2000.
10. Carson TL: Current knowledge of water quality and safety for livestock. *Vet Clin North Am Food Anim Pract* 16:455-64, 2000.
11. Curtis PW: *Pseudomonas aeruginosa* contamination of a warm water system used for pre-milking udder washing. *Vet Rec* 84:467-477, 1969.
12. Erskine RJ, Unflat JG, Eberhart RJ, Hutchinson LJ, Hicks CR, Spencer SB: *Pseudomonas mastitis*: difficulties in detection and elimination from contaminated wash-water systems. *J Am Vet Med Assoc* 191:811-5, 1987.
13. FAO/WHO, Expert Committee on Food Additives. Animal feeding and food safety. Rome, 1998.
14. Federal Water Protection and Conservation Agency USA. Water Quality Criteria. 1968.
15. Garber LS, Wells S, Schroeder-Tucker L, Ferris K: Factors associated with fecal shedding of verotoxin-producing *Escherichia coli* O157 on dairy farms. *J Food Prot* 62:307-12, 1999.
16. Gay JM, Hunsaker ME: Isolation of multiple *Salmonella* serovars from a dairy two years after a clinical salmonellosis outbreak. *J Am Vet Med Assoc* 203:1314-20, 1993.
17. Goss MJ, Barry DAJ, Rudolph DL: Contamination in Ontario farmstead domestic wells and its association with agriculture: 1. Results from drinking water wells. *J Contam Hydrol* 32:267-293, 1998.

18. Gray SJ, Stickler DJ: Some observations on the faecal carriage of mesophilic *Aeromonas* species in cows and pigs. *Epidemiol Infect* 103:523-37, 1989.
19. Gummow B, Myburgh J, Thompson P, van der Lugt J, Spencer B: Three case studies involving *Leptospira* serovar *pomona* infection in mixed farming units. *S Afr Vet Assoc* 70:29-34, 1999.
20. Hanninen ML, Niskanen M, Korhonen L: Water as a reservoir for *Campylobacter jejuni* infection in cows studied by serotyping and pulsed-field gel electrophoresis (PFGE). *Zentralbl Veterinarmed [B]* 45:37-42, 1998.
21. Hardman PM, Wathes CM, Wray C: Transmission of salmonellae among calves penned individually. *Vet Rec* 129:327-9, 1991.
22. Hudson L, Hankins J, Dattaglia M: Coliforms in a water distribution system: a remedial approach. *J Am Water Works Assoc* 75:564-68, 1983.
23. Jackson SG, Goodbrand RB, Johnson RP, et al: *Escherichia coli* O157:H7 diarrhoea associated with well water and infected cattle on an Ontario farm. *Epidemiol Infect* 120:17-20, 1998.
24. Kabagambe EK, Wells SJ, Garber LP, et al: Risk factors for fecal shedding of *Salmonella* in 91 US dairy herds in 1996. *Prev Vet Med* 43:177-94, 2000.
25. Lammerding AM, Paoli GM: Quantitative risk assessment: an emerging tool for emerging foodborne pathogens. *Emerg Infect Dis* 3:483-487, 1997. <<http://www.cdc.gov/ncidod/EID/vol3no4/adobe/lammer.pdf>>
26. Lammerding AM, Fazil A: Hazard identification and exposure assessment for microbial food safety risk assessment. *Int J Food Microbiol* 58:147-157, 2000.
27. LeChevallier MW, Welch NJ, Smith DB: Full-scale studies of factors related to coliform regrowth in drinking water. *Appl Environ Microbiol* 62:2201-2211, 1996.
28. LeJeune JT, Besser TE, Hancock DD: Cattle water troughs as reservoirs of *Escherichia coli* O157. *Appl Environ Microbiol* 67:3053-3057, 2001.
29. LeJeune, JT, Besser TE, Merrill NL, et al: Livestock drinking water microbiology and the factors influencing the quality of drinking water offered to cattle. *J Dairy Sci* 84:1856-1862, 2001.
30. Linn JG, Hutjens MF, Shaver R, et al: Feeding the Dairy Herd, 34th ed. North Central Regional Extension Publication 346, University of Minnesota, St. Paul, MN, 2002, <<http://www.extension.umn.edu/distribution/livestocksystems/DI0469.html>>
31. Massara F, Paglianiti S, Valentia AV: Quality of drinking water for cattle. Microbiological aspects. *Mondo-del-Latte* 52(6): 440-446, 1998.
32. Malmo J, Robinson B, Morris RS: An outbreak of mastitis due to *Pseudomonas aeruginosa* in a dairy herd. *Aust Vet J* 48:137-139, 1972.
33. Martin JG, Harner JP, Smith JF: Water system design considerations for modern dairies. Proc 5th Western Dairy Management Conference, Las Vegas, NV, April 4-6, 2001, pp 17-25. <<http://www.wdmc.org/2001/WDMC2001p017-26.pdf>>
34. Pommier P, Humbert E: Enquete sur les problemes sanitaires et xotoechniques lies a la qualite de l'eau de boisson en elevage. *Rec Med Vet* 165:367-372, 1989.
35. Rahn K, Renwick SA, Johnson RP, et al: Persistence of *Escherichia coli* O157:H7 in dairy cattle and the dairy farm environment. *Epidemiol Infect* 119:251-259, 1997.
36. Reilly A: Prevention and control of enterohaemorrhagic *Escherichia coli* (EHEC) infections: memorandum from a WHO meeting. WHO Consultation on Prevention and Control of Enterohaemorrhagic *Escherichia coli* (EHEC) Infections. *Bull World Health Organ* 76:245-55, 1998.
37. Shere JA, Bartlett KJ, Kaspar CW: Longitudinal study of *Escherichia coli* O157:H7 dissemination on four dairy farms in Wisconsin. *Appl Environ Microbiol* 64:1390-1399, 1998.
38. Smith, DR, Klopfenstein T, Moxely R, et al: Evaluation of three methods to clean feedlot water tanks. *Bov Pract* 36(1):1-4, 2002.
39. Socha MT, Ensley SM, Tomlinson DJ, Johnson A: Variability of water composition and potential impact on animal performance. Proceedings California Animal Nutrition Conf, May 8-9, 2002, Fresno, CA.
40. Szewzyk U, Szewzyk R, Manz W, Schleifer KH: Microbiological safety of drinking water. *Annu Rev Microbiol* 54:81-127, 2000.
41. Van Horn HH, Bray DR, Nordstedt RA, et al: Water Budgets for Florida Dairy Farms. Circular 1091, Florida Cooperative Extension Service, University of Florida, Gainesville, 1993. <http://edis.ifas.ufl.edu/BODY_DS121>
42. Veling J, Barkema HW, van der Schans J, et al: Herd-level diagnosis for *Salmonella enterica* subsp *enterica* serovar Dublin infection in bovine dairy herds. *Prev Vet Med* 53:31-42, 2002.
43. Waldner DN, Loper ML: Water for Dairy Cattle. Oklahoma Cooperative Extension Publication WF-4275, Oklahoma State University, 2001, <<http://www.ansi.okstate.edu/exten/dairy/wf-4275.html>>
44. Wathes CM, Zaidan WA, Pearson GR, et al: Aerosol infection of calves and mice with *Salmonella typhimurium*. *Vet Rec* 123:590-594, 1988.
45. Wesley IV, Wells SJ, Harmon KM, et al: Fecal shedding of *Campylobacter* and *Arcobacter* spp in dairy cattle. *Appl Environ Microbiol* 66:1994-2000, 2000.
46. White G: Handbook of Chlorination and Alternative Disinfectants, 4th ed, New York, John Wiley & Sons, 1999.
47. WHO (ed): Guidelines for drinking water quality, Vol I - III, 2nd ed. Geneva. WHO, 1993, 1996, 1997. <http://www.who.int/water_sanitation_health/GDWQ/index.html>
48. Wilesmith, JW: Johne's disease: A retrospective study of vaccinated herds in Great Britain. *Br Vet J* 138:321-331, 1982.
49. Willms WD, Kenzie O, Mir Z, et al: Effects of water supplied from old dugouts on the performance of cattle. Rangelands in a sustainable biosphere. Proc Fifth Internat Rangeland Cong, Vol. 1 Salt Lake City, Utah, 1996, pp 606-607.
50. Wray C, Sojka WJ: Reviews of the progress of Dairy Science: bovine salmonellosis. *J Dairy Res* 44, 383-425, 1977.