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Management Practices to Improve Water Quality on Central and Western Rangelands

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ABSTRACT

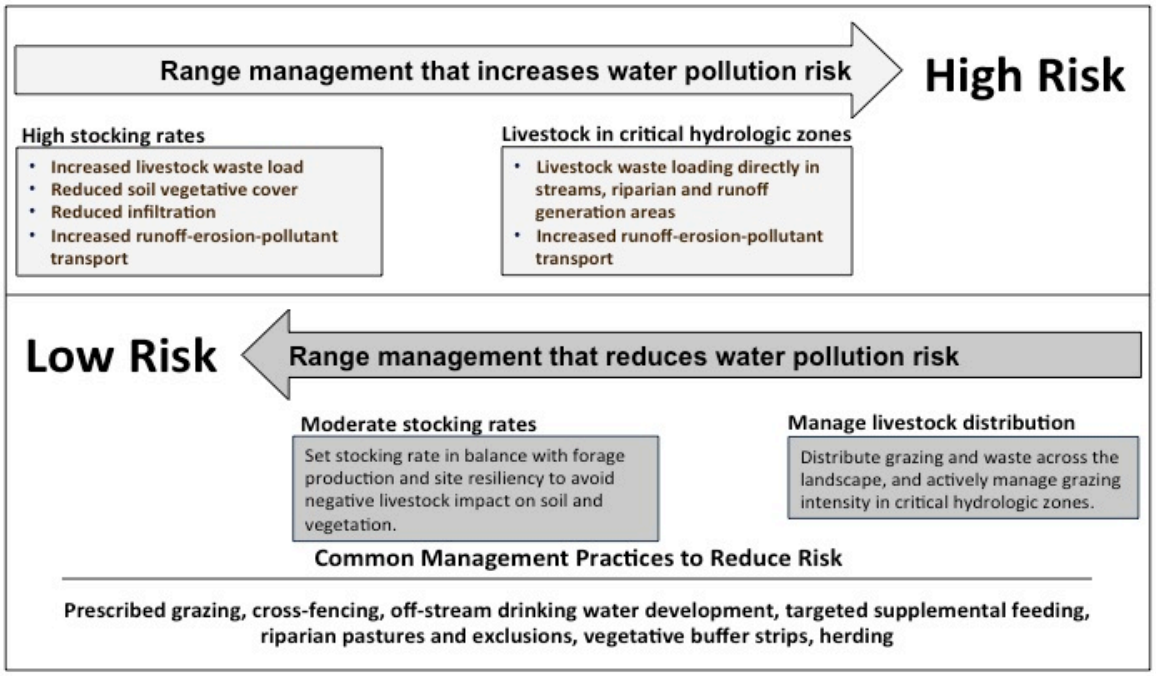
Livestock production on rangelands in the central and western United States can result in pathogen, sediment, and nutrient problems for water. A variety of range management practices can be effective in helping to reduce these problems. Information on the efficacy of these practices is sufficient to form the basis for water quality trading among rangelands, but quantitative models for estimating the cumulative water quality benefits of management for sediment, pathogens, and nutrients do not yet yield credible results.

CONTENT

INTRODUCTION

This supplemental paper focuses on management of rangeland in the central and western regions of the United States, where the major activity is extensive cattle and sheep grazing at low stocking rates (i.e., > 10 acres per animal unit per year) (Valentine 2000). There is little use of fertilizer, irrigation, or imported feedstuffs. Figure 1 conceptualizes the management activities that increase the risk of surface water pollution from rangeland as well as practices to mitigate that risk.

Figure 1. Rangeland Livestock Management Activities That Increase Risk of Surface Water Pollution, and Management Principles and Practices to Mitigate That Risk



RANGE LIVESTOCK PRODUCTION AND WATER QUALITY PARAMETERS OF CONCERN

Rangeland watersheds supply water for human recreation and consumption and irrigation of crops as well as support critical aquatic habitat and dependent species. Concerns have been raised that sediment, pathogen, and nutrient pollution by livestock grazing on rangelands can degrade water quality (Belsky, Matzke, and Uselman 1999; Derlet and Carlson 2006; Myers and Whited 2012). Pollutants of concern include sediment, fecal coliform and *E. coli*, and N and P (Field and Samadpour 2007; Hubbard, Newton, and Hill 2004).

Research confirms that livestock grazing, particularly intensive grazing with high animal densities, can degrade water quality (Hubbard, Newton, and Hill 2004; Agouridis, Workman, Warner, and Jennings 2005; Bilotta, Brazier, and Haygarth 2007; Fleischner 1994; Trimble and Mendel 1995; Belsky, Matzke, and Uselman 1999; George, Jackson, Boyd, and Tate 2011). However, extensive range livestock production does not necessarily degrade water quality (Gary, Johnson, and Ponce 1983; O'Reagain et al. 2005; Lewis, Singer, Dahlgren, and Tate 2006; Adams et al. 2009; Roche, Allen-Diaz, Eastburn, and Tate 2012; Roche et al. 2013; Tiedemann et al. 1987; Holloway, Dahlgren, Hansen, and Casey 1998; Atwill et

al. 2002; Lewis, Tate, Harper, and Price 2001; Ahearn et al. 2005; Meays et al. 2006; Nader, Tate, Atwill, and Drake 1998; Jackson, Allen-Diaz, Oates, and Tate 2006; Lewis, Singer, Dahlgren, and Tate 2006; Knox, Dahlgren, Tate, and Atwill 2008; Roche, Allen-Diaz, Eastburn, and Tate 2012; Roche et al. 2013). Thus, livestock production and water quality goals can be achieved on rangelands by applying sound management principles and practices (Figure 1).

DRIVERS OF RISK TO WATER QUALITY

The primary drivers of water quality degradation by range livestock include excessive livestock numbers relative to site resiliency and livestock's preference to inhabit critical hydrologic zones. These phenomena disproportionately concentrate the negative effects of grazing and waste loads in sensitive areas. Documenting the principles and practices that mitigate pollution risk from range livestock starts with identification of specific rangeland activities and their potential to degrade water quality:

- Excessive grazing can reduce vegetation and increase soil exposure to rain, which degrades soil structure, reduces infiltration, and increases runoff and erosion (Bilotta, Brazier, and Haygarth 2007; Gifford and Hawkins 1978; Blackburn 1984; Gifford 1985).
- Compacting the soil by overgrazing or wet season grazing decreases infiltration and increases runoff and erosion (Greenwood and McKenzie 2001; Bilotta, Brazier, and Haygarth 2007).
- Excessive grazing and waste deposition in streams and near-stream runoff zones increases pollutant transport. Poor livestock management can increase animal time in streams and near-stream runoff zones (Kauffman and Krueger 1985; Armour et al. 1994 Trimble and Mendel 1995; Sheffield et al. 1997; Belsky, Matzke, and Uselman 1999; Tate, Atwill, McDougald, and George 2003; Roche et al. 2013; Stephenson and Street 1978).

Range management practices and strategies that directly and indirectly act to mitigate these drivers will lead to water quality improvements, a conclusion that is well supported by the research literature and in practice by ranchers and range managers.

EFFECTIVENESS OF RANGE MANAGEMENT PRACTICES TO IMPROVE WATER QUALITY

Research Support

Briske (2011b) recently led a comprehensive scientific review of the conservation effectiveness of all range management practices funded through USDA conservation initiative programs (e.g., Environmental Quality Incentive Program, EQIP). In this review, Briske, Derner, Milchunas, and Tate (2011a) and George, Jackson, Boyd, and Tate (2011) conducted a research synthesis to address specific hypotheses about the effectiveness of stocking rate moderation, grazing system selection, and management of timing of grazing and rest from grazing as well as a suite of riparian management practices to improve hydrologic function and water quality. The authors determined that

- Setting moderate stocking rates is essential to minimize erosion runoff;
- Seasonal rotation grazing at moderate stocking rates improves upland soil hydrology compared with intensive rotational grazing systems at higher stocking rates;
- Management of timing and intensity of grazing and rest can improve vegetation, hydrologic function, and water quality;
- Livestock distribution practices, such as drinking water developments, supplemental feed placement, and herding (i.e., using a horse or other means to move livestock into uplands away from surface waters) can reduce livestock residence time and impact in riparian zones;
- Vegetated filter areas can substantially reduce runoff pollutants, but implementation must consider site-specific biophysical factors.

In a recent feasibility assessment for rangeland water quality markets in California's Central Valley, Musengezi et al. (2012) concluded that

- Science supports the effectiveness of range management practices to improve water quality;
- The effectiveness of these practices depends on site-specific conditions;
- California ranchers are interested in providing and marketing ecosystem services such as clean water;
- Documentation of the effectiveness of range management practices is sufficient to form the basis for a rangeland water quality market.

Demonstrated Viability

The research-based review by Musengezi and colleagues identifies a range of management practices available to improve hydrologic functions (in upland and critical hydrologic zones) and water quality (reduction of sediment, nutrients, and microbial pollutants) with appropriate site-specific implementation. A clear indication of the practicality of these practices is their adoption by on-the-ground, for-profit ranch managers. On rangelands in the central and western United States, prescribed (managed) grazing (USDA Practice Code 528) occurs on more than 31 million hectares and is the most extensively implemented conservation incentive practice (Briske 2011b). In a survey of 777 California ranchers who participated in a water quality short course—a survey with a 52% response rate—Larson et al. (2005) found that more than 67% had implemented new water quality management practices. Based on self-assessments of nonpoint source pollution on their ranches, 70% had focused on erosion and sediment control practices and 32% on practices to mitigate riparian and stream degradation. The most widely reported motivations were "to control nonpoint source pollution" (68%), "to support livestock industry water quality initiative" (63%), and "to avoid regulation" (50%).

In a survey of 614 Wyoming ranchers about their natural resources goals and associated management practices—a survey with a 50% response rate—Kachergis et al. (2013) found that water quality was an important secondary goal (ranked 5.0 out of 9). Livestock and forage production were ranked as primary goals (1.8 and 2.0 out of 9, respectively). Management practices considered "key" to achieving these management goals were drinking water development and cross fencing (68% and 35% of respondents, respectively). Livestock exclosures and riparian buffers were not widely considered to be key management practices (6% and 9% of respondents, respectively). However, livestock exclosures and riparian buffers were considered "helpful" practices (28% and 23% of respondents, respectively).

These results indicate that ranchers recognize the effectiveness of these practices and will make use of them within the economic and social context of operating a profitable ranching enterprise. Management practices perceived to be beneficial for livestock production, forage production, and water quality improvement (i.e., moderate stocking rates as well as off-stream drinking water development and cross-fencing to increase flexibility in managing grazing) will be the most readily adopted. Additional research is needed to determine the economic tradeoffs and synergies of managing for both water quality protection and livestock production at the ranch level.

QUANTIFYING BENEFITS OF WATER QUALITY PRACTICES

Managers do not implement management practices in the singular, rather they implement an array of practices based on each manager's prioritization of goals, and their place-based, generational learning about what does or does not work under site-specific conditions. From the management practice toolkit, a manager can develop site-specific pasture or exclosure fencing (fixed or temporary) and livestock drinking water infrastructure that will allow flexibility in the intensity, timing, and location of livestock

grazing across a ranch or management units. The manager can innovate and implement localized grazing strategies that integrate water quality protection with core livestock production and economic goals.

The research literature cannot predict the cumulative water quality improvement from implementing a suite of management practices under spatially and temporally variable site-specific conditions. To date there are no adequate, coupled management-hydrologic-pollutant fate and transport-water quality simulation models for rangeland ecosystems to accurately predict cumulative water quality benefits for sediment, microbes and nutrients. George, Jackson, Boyd, and Tate (2011) conclude that riparian health (and thus water quality) is directly related to the *time invested* in managed grazing to control the season, intensity, and duration of livestock use—indicating that variation in management effort and/or capacity could result in substantial variation in individual practice effectiveness and resulting water quality improvement. Finally, managers regularly *adapt* their management strategies and practice implementation based on observed progress towards goals and in response to variable temporal and spatial conditions—a dynamic process that is difficult to replicate in a controlled research setting, but which likely enhances site-specific practice effectiveness (Briske 2011b).

While there is sufficient information on the effectiveness of rangeland management practices to form the basis for water quality trading, we do not have credible quantitative rangeland models for estimating site-specific cumulative water quality benefits of the diverse management strategies typically applied. Other less specific, practice-based methods may be the only option for quantification at this time.

CONCLUSION

Primary water quality pollutants of concern on rangelands in the central and western United States include sediment and fecal pathogens, and to a substantially lesser extent, N and P. There is strong evidence that commonly used range management practices are effective in improving water quality. There are appreciable cumulative benefits from implementing multiple practices in a comprehensive water quality protection strategy. Practice effectiveness varies based on site-specific factors such as soils, weather, and manager investment of time and effort. Ranchers and rangeland managers are willing to adopt range management practices and develop strategies to improve water quality for multiple reasons– indicating there are potential sellers in a rangeland water quality market based on effective practice implementation. Additional research, and assessment, is needed to determine the ranch enterprise level economic tradeoffs or synergies of managing for water quality protection and livestock production.

REFERENCES

Adams, Michael J., Christopher A. Pearl, Brome McCreary, Stephanie K. Galvan, Stephanie J. Wessell, Wendy H. Wente, Chauncey W. Anderson, and Allison B. Kuehl. 2009. "Short-Term Effect of Cattle Exclosures on Columbia Spotted Frog (Rana luteiventris) Populations and Habitat in Northeastern Oregon." *Journal of Herpetology* 43(1): 132–138.

Agouridis, Carmen T., Stephen R. Workman, Richard C. Warner, and Gregory D. Jennings. 2005. "Livestock Grazing Management Impacts on Stream Water Quality: A Review." *Journal of the American Water Resources Association* 41(2): 591–606.

Ahearn, Dylan S., Richard W. Sheibley, Randy A. Dahlgren, Michael Anderson, Joshua Johnson, and Kenneth W. Tate. 2005. "Land Use and Land Cover Influence on Water Quality in the Last Free-Flowing River Draining the Western Sierra Nevada, California." *Journal of Hydrology* 313(3-4): 234–247.

Armour, Carl, Don Duff, and Wayne Elmore. 1994. "The Effects of Livestock Grazing on Western Riparian and Stream Ecosystem." *Fisheries* 19(9): 9–12.

Atwill, E.R., E. Johnson, D.J. Klingborg, G.M. Veserat, G. Markegard, W.A. Jensen, D.W. Pratt, R.E. Delmas, H.A. George, L.C. Forero, R.L. Philips, S.J. Barry, N.K. McDougald, R.R Gildersleeve, and W.E. Frost. 1999. "Age, Geographic, and Temporal Distribution of Fecal Shedding of *Cryptosporidium parvum* Oocysts in Cow-Calf Herds." *American Journal of Veterinary Research* 60(4): 420–425.

Atwill, Edward R., Lingling Hou, Betsy M. Karle, Thomas Harter, Kenneth W. Tate, and Randy A. Dahlgren. 2002. "Transport of *Cryptosporidium parvum* Oocysts through Vegetated Buffer Strips and Estimated Filtration Efficiency." *Applied and Environmental Microbiology* 68(11): 5517–5527.

Atwill, E.R., B. Hoar, M. das G.C. Pereira, K.W. Tate, F. Rulofson, and G. Nader. 2003. "Improved Quantitative Estimates of Low Environmental Loading and Sporadic Periparturient Shedding of *Cryptosporidium parvum* in Adult Beef Cattle." *Applied and Environmental Microbiology* 68(8): 4604–4610.

Atwill, Edward R., Kenneth W. Tate, Maria Das Gracas Cabral Pereira, James W. Bartolome, and Glenn A. Nader. 2006. "Efficacy of Natural Grass Buffers for Removal of *Cryptosporidium parvum* in Rangeland Runoff." *Journal of Food Protection* 69(1): 177–184.

Barry, S.J., E.R. Atwill, K.W. Tate, T.S. Koopmann, J. Cullor, and T. Huff. 1998. "Developing and Implementing a HACCP-Based Program to Control *Cryptosporidium* and Other Waterborne Pathogens in Alameda Creek Watershed: A Case Study." Paper presented at the annual meeting of the American Water Works Association, Dallas, TX, June 25–28.

Belsky, A.J., A. Matzke, and S. Uselman. 1999. "Survey of Livestock Influences on Stream and Riparian Ecosystems in the Western United States." *Journal of Soil and Water Conservation* 54(1): 419–431.

Bilotta, G.S., R.E. Brazier, and P.M. Haygarth. 2007. "The Impacts of Grazing Animals on the Quality of Soils, Vegetation, and Surface Water in Intensively Managed Grasslands." *Advances in Agronomy* 94: 237–280.

Blackburn, W.H. 1984. "Impacts of Grazing Intensity and Specialized Grazing Systems on Watershed Characteristics and Responses." In *Developing Strategies for Rangeland Management,* edited by B.D.

Gardner and J.H. Brothov, 927–933. Boulder, CO: Natural Resources Council / National Academy of Science, Westview Press.

Briske, David D., Justin D. Derner, Daniel G. Milchunas, and Ken W. Tate.2011a. "An Evidence-Based Assessment of Prescribed Grazing Practices." In *Conservation Benefits of Rangeland Practices: Assessment, Recommendations, and Knowledge Gaps,* edited by David D. Briske, 22–27. Lawrence, KS: Allen Press.

Briske, David D. (ed.) 2011b. *Conservation Benefits of Rangeland Practices: Assessment, Recommendations, and Knowledge Gaps*. U.S. Department of Agriculture, Natural Resources Conservation Service.

Buckhouse, John C., and Gerald F. Gifford. 1976. "Water Quality Implications of Cattle Grazing on a Semiarid Watershed in Southeastern Utah." *Journal of Range Management* 29(2): 109–113.

Derlet, R.W., and J.R. Carlson. 2006. "Coliform Bacteria in Sierra Nevada Wilderness Lakes and Streams: What Is the Impact of Backpackers, Pack Animals, and Cattle?" *Wilderness & Environmental Medicine* 17(1): 15–20.

Field, Katharine G., and Mansour Samadpour. 2007. "Fecal Source Tracking, the Indicator Paradigm, and Managing Water Quality." *Water Research* 41(16): 3517–3538.

Fleischner, Thomas L. 1994. "Ecological Costs of Livestock Grazing in Western North America." *Conservation Biology* 8(3):629–644.

Gary, Howard L., Steven R. Johnson, and Stanley L. Ponce. 1983. "Cattle Grazing Impact on Surface Water Quality in a Colorado Front Range Stream." *Journal of Soil and Water Conservation* 38(2): 124–128.

George, Mel R., Randy D. Jackson, Chad S. Boyd, and Ken W. Tate. 2011. "A Scientific Assessment of the Effectiveness of Riparian Management Practices." In *Conservation Benefits of Rangeland Practices,* edited by David D. Briske, 213–252. Lawrence, KS: Allen Press.

Gifford, G.F., and R.H. Hawkins. 1976. "Grazing Systems and Watershed Management: A Look at the Record." *Journal of Soil and Water Conservation* 31(6):281–283.

Gifford, G.F. 1985. "Cover Allocation in Rangeland Watershed Management: A Review." In *Watershed Management in the Eighties*, edited by E.Bruce Jones and Timothy J. Ward, 23–31. New York, NY: American Society of Civil Engineers.

Greenwood, K.L., and B.M. McKenzie. 2001. "Grazing Effects on Soil Physical Properties and the Consequences for Pastures: A Review." *Australian Journal of Experimental Agriculture* 41(8): 1231–1250.

Holloway, J.M., R.A. Dahlgren, B. Hansen, and W.H. Casey. 1998. "Contribution of Bedrock Nitrogen to High Nitrate Concentrations in Stream Water." *Nature* 395: 785–788.

Hubbard, R.K., G.L. Newton, and G.M. Hill. 2004. "Water Quality and the Grazing Animal." *Journal of Animal Science* 82(E-supplement): E235–E263.

Jackson, Randall D., Barbara Allen-Diaz, Lawrence G. Oates, and Kenneth W. Tate. 2006. "Spring-Water Nitrate Increased by Grazing Removal in a California Oak Savanna." *Ecosystems* 9: 1–15.

Jay, Michael T., Michael Cooley, Diana Carychao, Gerald W. Wiscomb, Richard A. Sweitzer, Leta Crawford-Miksza, Jeff A. Farrar, David K. Lau, Janice O'Connell, Anne Millington, Roderick V. Asmundson, Edward R. Atwill, and Robert E. Mandrell. 2007. "*Escherichia coli* O157:H7 in Feral Swine near Spinach Fields and Cattle, Central California Coast." *Emerging Infectious Diseases* 13(12): 1908–1911.

Kachergis, Emily, Justin D. Derner, Leslie M. Roche, Kenneth W. Tate, Mark Lubell, Rachel Mealor, and Jim Magagna. 2013. "Characterizing Wyoming Ranching Operations: Natural Resource Goals, Management Practices and Information Sources." *Natural Resources* 4(1): 45–54.

Kauffman, J. Boone, and W.C. Krueger. 1984. "Livestock Impacts on Riparian Ecosystems and Streamside Management Implications—A Review." *Journal of Range Management* 37(5): 430–438.

Knox, A. Kate, Randy A. Dahlgren, KennethW. Tate, and Edward R. Atwill. 2008. "Efficacy of Flow-Through Wetlands to Retain Nutrient, Sediment, and Microbial Pollutants." *Journal of Environmental Quality* 37(5): 1837–1846.

Knox, A. Kate, Kenneth W. Tate, Randy A. Dahlgren, and Edward R. Atwill. 2007. "Management Reduces *E. coli* in Irrigated Pasture Runoff." *California Agriculture* 61(4): 159–165.

Larsen, Royce E., J. Ronald Miner, John C. Buckhouse, and James A. Moore. 1994. "Water Quality Benefits of Having Cattle Manure Deposited Away from Streams." *Bioresource Technology* 48(2): 113–118.

Larson, Stephanie, Kelly Smith, David J. Lewis, John M. Harper, and Melvin R. George. 2005. "Evaluation of California's Rangeland Water Quality Education Program." *Rangeland Ecology and Management* 58(5): 514–522.

Lewis, David J., KennethW. Tate, John M. Harper, and Julie Price. 2001. "Survey Identifies Sediment Sources in North Coast rangelands." *California Agriculture* 55(4): 32–38.

Lewis, David J., Michael J. Singer, Randy A. Dahlgren, and KennethW. Tate. 2006. "Nitrate and Sediment Fluxes from a California Rangeland Watershed." *Journal of Environmental Quality* 35(6): 2202–2211.

Li, Xunde, Edward R. Atwill, Lissa A. Dunbar, Ted Jones, Jimmy Hook, and Kenneth W. Tate. 2005. "Seasonal Temperature Fluctuation Induces Rapid Inactivation of *Cryptosporidium parvum*." *Environmental Science and Technology* 39(12): 4484–4489.

Li, Xunde, Edward R. Atwill, Lissa A. Dunbar, and Kenneth W. Tate. 2010. "Effect of Daily Temperature Fluctuation during the Cool Season on the Infectivity of *Cryptosporidium parvum*." *Applied and Environmental Microbiology* 76(4): 989–993.

Meays, Cindy L., Klass Broersma, Rick Nordin, and Asit Mazumder. 2005. "Survival of *Escherichia coli* in Beef Cattle Fecal Pats under Different Levels of Solar Eexposure." *Rangeland Ecology and Management* 58(3): 278–283.

Meays, Cindy L., Klass Broersma, Rick Nordin, Asit Mazumder, and Mansour Samadpour. 2006. "Spatial and Annual Variability in Concentrations and Sources of *Escherichia coli* in Multiple Watersheds." *Environmental Science and Technology* 40(17): 5289–5296.

Muirhead Richard W., Robert P. Collins, and Philip J. Bremer. 2005. "Erosion and Subsequent Transport State of *Escherichia coli* from Cowpats." *Applied Environmental Microbiology* 71(6): 2875–2879.

Musengezi, Jessica, Pelayo Alvarez, Michelle Bacon, Molly Cheatum, and Clayton Ogg. 2012. "The Feasibility of Water Quality Markets for Rangelands in California's Central Valley." Conservation Economics White Paper. Conservation Economics and Finance Program. Washington, DC: Defenders of Wildlife.

Myers, Lindsey, and Brenda Whited. 2012. "The Impact of Cattle Grazing in High Elevation Sierra Nevada Mountain Meadows over Widely Variable Annual Climatic Conditions." *Journal of Environmental Protection* 3(8A): 823–837.

Nader, Glenn A., Kenneth W. Tate, Robert Atwill, and James Bushnell. 1998. "Water Quality Effects of Rangeland Beef Cattle Excrement." *Rangelands* 20(5): 19–25.

O'Reagain, P.J., J. Brodie, G. Fraser, J.J. Bushell, C.H. Holloway, J.W. Faithful, and D. Haynes. 2005. "Nutrient Loss and Water Quality under Extensive Grazing in the Upper Burdekin River Catchment, North Queensland." *Marine Pollution Bulletin* 51(1-4): 37–50.

Roche, Leslie M., Lea Kroemschroder, Edward R. Atwill, Randy A. Dahlgren, and Kenneth W. Tate. 2013. "Water Quality Conditions Associated with Cattle Grazing and Recreation on National Forest Lands." *PLoS ONE* 8(6): e68127. doi:10.1371/journal.pone.0068127.

Roche, Lelie M., Barbara Allen-Diaz, Danny J. Eastburn, and Kenneth W. Tate. 2012. "Cattle Grazing and Yosemite Toad (*Bufo canorus* Camp) Breeding Habitat in Sierra Nevada Meadows." *Rangeland Ecology and Management* 65(1): 56–65.

Sheffield, R.E., S. Mostaghimi, D.H. Vaughan, E.R. Collins Jr., and V.G. Allen. 1997. "Off-stream Water Sources for Grazing Cattle as a Stream Bank Stabilization and Water Quality BMP." *Transactions of the ASAE* 40(3): 595–604.

Stephenson, G.R., and L.V. Street. 1978. "Bacterial Variations in Streams from a Southwest Idaho Rangeland Watershed." *Journal of Environmental Quality* 7(1): 150–157.

Tate, Kenneth W., Edward R. Atwill, Melvin R. George, Neil K. McDougald, and Royce E. Larsen. 2000. "*Cryptosporidium parvum* Transport from Cattle Fecal Deposits on California Rangeland Watersheds." *Journal of Range Management* 53(3): 295–299.

Tate, Kenneth W., Edward R. Atwill, Neil K. McDougald, and Melvin R. George. 2003. "Spatial and Temporal Patterns of Cattle Feces Deposition on Rangeland." *Journal of Range Management* 56(3): 432–438.

Tate, Kenneth W., Maria Das Gracas C. Pereira, and Edward R. Atwill. 2004a. "Efficacy of Vegetated Buffer Strips for Retaining *Cryptosporidium parvum*." *Journal of Environmental Quality* 33(6): 2243–2251.

Tate, Kenneth W., Dennis D. Dudley, Neil K. McDougald, and Melvin R. George. 2004b. “Effects of Canopy and Grazing on Soil Bulk Density on Annual Rangeland.” *Journal of Range Management* 57(4): 411–417.

Tate, Kenneth W., Edward R. Atwill, James W. Bartolome, and Glenn A. Nader. 2006. “Significant *E. coli* Attenuation by Vegetative Buffers on Annual Grasslands.” *Journal of Environmental Quality* 35(3): 795–805.

Tiedemann, A.R., D.A. Higgins, T.M. Quigley, H.R. Sanderson, and D.B. Marx. 1987. “Responses of Fecal-Coliform in Streamwater to Four Grazing Strategies.” *Journal of Range Management* 40(4): 322–329.

Trimble, Stanley W., and Alexandra Mendel. 1995. “The Cow as a Geomorphic Agent: A Critical Review.” *Geomorphology* 13(1-4): 233–253.

Valentine, John F. 2000. *Grazing Management*. Academic Press.