Water Policy 15 (2013) 850–858

Using watershed function as the leading indicator for water quality

Joan L. Aron[a], Robert K. Hall[b], Michael J. Philbin[c]
and Robin J. Schafer[d]

[a]Corresponding author. Aron Environmental Consulting, 5457 Marsh Hawk Way, Columbia, Maryland 21045, USA
E-mail: joanaron@ymail.com
[b]US Environmental Protection Agency Region IX, WTR2, 75 Hawthorne St, San Francisco, California 94105, USA
[c]US Department of the Interior Bureau of Land Management, Montana/Dakotas State Office, 5001 Southgate Drive, Billings, Montana 59101, USA
[d]US Environmental Protection Agency, Office of Solid Waste and Emergency Response, Center for Program Analysis, 1200 Pennsylvania Ave. NW, Washington, DC 20460, USA

Abstract

Diffuse nonpoint source (NPS) pollutants, such as sediment, nitrogen, phosphorus, and pathogens, have become the primary cause of water quality impairments in the United States of America. Resource management agencies in the USA are expanding the use of tools for the assessment of ecosystem function in water quality programs to control NPS pollution to meet US Clean Water Act objectives. Assessing the ecosystem function of upland and riparian areas provides the context for monitoring data that can improve the targeting of best management practices for NPS pollution, and be a leading (early) indicator for more timely decisions about aquatic habitat and water quality. Assessment of watershed function can be applied to prioritizing resources, developing indicators, monitoring aquatic habitat and water quality, and implementing adaptive management plans to restore degraded ecosystems that are producing NPS pollution. This paper presents three examples of progress in the institutionalization of this approach to water quality programs for sustainable and healthy watersheds that affect federal, state, tribal, and private landowners. Future work should refine the approach by evaluating the benefits, costs, and effectiveness of the use of watershed function in water quality programs.

Keywords: Clean Water Act; Ecosystem function; Indicator; Monitoring; Nonpoint source; Riparian; Sustainability; Upland; Water quality; Watershed

Introduction

The USA is not fully achieving its Clean Water Act (CWA) objective to ‘restore and maintain the chemical, physical and biological integrity of the nation’s waters’ (USEPA, 2012). More than half of US river and

doi: 10.2166/wp.2013.111

stream miles are in poor condition (USEPA, 2013). Initial implementation of the CWA in the 1970s focused on regulating contaminants from factories, sewage plants and other ‘point source’ pollution. As point source emissions were reduced, diffuse ‘nonpoint source’ (NPS) pollutants, such as sediment, nitrogen, phosphorus, and pathogens, came to account for a greater proportion of impairments in US waters than point source pollutants (USEPA, 2009). Resource management agencies in the USA are expanding the use of tools for the assessment of ecosystem function in water quality programs to improve the targeting of best management practices (BMPs) to control NPS pollution. Such improvement relies on the process of assessing ecosystem function to provide the context for the interpretation of data from monitoring biology and water chemistry. The analysis of BMP effectiveness to control NPS pollution has attracted attention from the US regulatory and international water policy communities (e.g. Gasper *et al.*, 2012; Meyer & Thiel, 2012; Ghebremichael *et al.*, 2013; Natural Capital Project, 2013) amid global interest in pollution control and the preservation of the natural environment (Chenoweth, 2012).

A qualitative assessment of ecosystem function can serve as an indicator of current and future ecological conditions (Swanson *et al.*, 2012) that are practical to implement under the CWA. This paper presents progress in the institutionalization of this watershed function approach applied to water quality by resource management agencies in the USA. We trace its evolution from tools employed in the 1990s for resource management (e.g. Evans *et al.*, 2007) and policy initiatives such as the US Environmental Protection Agency (USEPA)’s Healthy Watershed Initiative that emphasize land acquisition and protection agreements (USEPA, 2011) and are exemplified by New York City’s protection of its drinking water supply (New York City Department of Environmental Protection, 2011). The latest development is for programs to incorporate the assessment of ecosystem function, as illustrated by the US Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS)’s National Water Quality Initiative (NRCS, 2013). This evolution represents an expansion of the use of the concept of ecosystem function beyond just an end product of intervention or a target for protection. The concept of ecosystem function now underlies a key measure providing the context for monitoring data used for decisions to support sustainable and healthy watersheds.

Ecosystem function in this context refers to how well the physical processes in upland and riparian areas around streams, lakes, and wetlands are able to assimilate contaminants. Properly functioning ecosystems capture, hold, and slowly release water and NPS pollutants to the benefit and protection of the nation’s waterways (Wyman *et al.*, 2006). In contrast, non-functional ecosystems fail to process surges in flow from upland and upstream inputs, resulting in more soil erosion and extreme flooding (Wyman *et al.*, 2006; Swanson *et al.*, 2012).

An understanding of ecosystem function provides a foundation to determine current conditions and physical processes, establish indicators for monitoring, and develop an adaptive management plan to restore degraded ecosystems producing NPS pollution. Ecosystem function is determined by assessing the physical processes of upland (Pellant *et al.*, 2005) and riparian-wetland areas through consideration of hydrology, vegetation, and soil/landform attributes appropriate for the potential, given the uses (urban, agriculture, logging, grazing, etc.) of an area/reach (Dickard *et al.*, 2013). Once potential is established, other assessment tools can be incorporated. For example, critical source area modeling can contribute by identifying locations with particularly high loads of pollutants (Heathwaite *et al.*, 2005; Qiu, 2009; Trevisan *et al.*, 2010; Doody *et al.*, 2012; Ghebremichael *et al.*, 2013). An assessment of ecosystem function builds on these sources and other information to create a systemic picture of pollutants and their transport within a watershed.

A practical approach to characterizing risk to watershed function, and consequent water quality, is the use of proper functioning condition (PFC) protocols for riparian areas and rangeland health indicators for upland areas (Prichard *et al.*, 1998, 2003; Riparian Coordination Network, 2002; Pellant *et al.*, 2005). These assessments evaluate vegetation, hydrology, soil, and landform, which are altered by land use activities, such as agriculture, forestry, mining, recreation, and urban/suburban development. This active use of ecosystem knowledge links decades of restoration experience with the water quality programs implemented under the CWA. Although the assessment tools are not new, expansion of their use to water quality programs is new and gaining followers (Dickard *et al.*, 2013).

In aquatic environments, not all water pollution is from an external input. Pollution can come from the materials stored in riparian areas and wetlands due to their attributes and processes, or functions (Swanson *et al.*, 2012; Hall *et al.*, 2013; Kozlowski *et al.*, 2013). These aquatic environments represent one kind of NPS pollution. In areas where NPS pollution is the major concern, observations of poor or declining ecosystem function of upland and riparian areas can point to the potential for reduced water quality earlier than traditional measures of degradation in water bodies (Cowley & Burton, 1997; Wyman *et al.*, 2006; Swanson *et al.*, 2012).

A series of PFC assessments conducted in Maggie Creek watershed in the north-east of the US State of Nevada in the years 1994, 2006, and 2011 illustrate how watershed function can be used as the leading (early) indicator for water quality (Kozlowski *et al.*, 2013). These PFC assessments were performed in an area of agriculture and grazing where sediment and nutrients came from the stream systems. In 1994, the US Department of the Interior's Bureau of Land Management (BLM) and local private ranchers worked together to initiate changes in grazing management to improve riparian conditions, aquatic habitat, and water quality. Kozlowski *et al.* (2013) demonstrated that changes in the timing and duration of grazing from 1994 to 2011 resulted in improved stream function leading to reduced sediment and phosphate, stable diurnal dissolved oxygen levels, and improved aquatic habitat. The study also showed that monitoring for water chemistry generated highly variable data, and failed to provide timely information for management of the impairment. In contrast, assessment of multiple indicators of ecosystem function of riparian areas, including features such as vegetation and channel form, produced leading indicators of the improvement, or the degradation, of the stream condition. Changes in water chemistry indicators generally lagged behind changes in ecosystem functions, and monitoring water quality failed to provide early identification of the trends in aquatic habitat. Kozlowski *et al.* (2013) recommend that ambient monitoring programs should focus resources toward measuring multiple indicators of riparian functions (Burton *et al.*, 2011), which are more relevant, faster, less expensive, and can be supported with remote sensing techniques.

A critique of the current standard approach to NPS pollution is laid out below, followed by a discussion of three examples of the institutionalization of the use of PFC and rangeland health indicator methodology in water quality programs. Adopting the watershed function approach from these examples supports the broadening of the policy of managing *for* water quality. That is, assessments of ecosystem function provide the context for monitoring data that could lead to better targeting of BMPs for NPS pollution and more timely information for decisions about aquatic habitat and water quality.

Dilemmas posed by standard practices for nonpoint source pollution

As concerns about NPS pollution have grown, it is useful to rethink the standard practices for water quality management. Many of these practices have been in use since the establishment of the CWA and have worked well in controlling point source pollution. The cornerstone of point source control is the issuance of permits that limit the discharge of pollutants in an attempt to protect water quality, often requiring the use of treatment or dilution separately or in combination. The potential for further water quality gains using this strategy is limited because most US point sources are already regulated. In contrast, NPS pollution is more complex. NPS pollution can have multiple diffuse sources, which frequently do not lend themselves to the constraints of permit targets.

Total Maximum Daily Loads (TMDLs) are a pollutant-by-pollutant target-driven tool intended to restore water quality. TMDLs are used to identify the maximum levels of pollutants that a water body can receive while still supporting its designated uses (e.g. drinking water, aquatic habitat). These plans also include strategies for pollution control and monitoring (USEPA, 2000). While TMDLs were originally developed for US point sources, federal courts have upheld the authority of USEPA and environmental agencies in US state governments to use this tool on waters affected solely by NPS pollution.

The use of TMDLs for NPS pollution is problematic (Hall *et al.*, 2013). TMDLs often focus on water quality measurements and impacts on aquatic communities. However, when dealing with NPS pollution, these observations are typically lagging indicators that result *from* the leading indicators of altered upland and riparian conditions. Thus, it is not surprising that reported progress on controlling NPS pollution using TMDLs has been limited (USEPA, 2008).

Managing for water quality outcomes using lagging indicators often results in reactive decisions, while managing for watershed integrity using leading indicators provides a basis for sustainability (Hubert, 2007). The use of leading indicators for NPS pollution would allow water managers to proactively manage water quality and assist them in addressing the causes of problems, allowing for more complete recoveries.

Difficult, lengthy, and costly techniques are often implemented for the restoration of degraded ecosystems. Focusing on leading indicators could result in earlier intervention and may prevent or reduce NPS pollution (Swanson *et al.*, 2012). For example, if there is too much sediment in a stream, dredging may be used to remove it. This type of remediation focuses on the water quality outcome (lagging indicator). Dredging requires perpetual treatment, disturbs the stream, and is not economically sustainable. A more sustainable approach is to identify and manage the source(s) of the erosion in the watershed (leading indicator). By using this approach, it may be possible to improve water quality by maintaining, moving, or closing roads; altering forest practices; adjusting grazing strategies; relocating recreational facilities; or expanding urban buffer zones. Although dredging might still be necessary, cost savings might be possible by reducing the frequency of treatment. These earlier interventions could prove to be more cost-effective and sustainable than traditional restoration.

Ecosystem function is an important consideration for sustainability in project implementation beyond its use as a leading indicator. For example, engineering practices might simply armor non-functional ecosystems by covering them with rocks and other hard materials to prevent erosion and subsequent sedimentation. Drawbacks of armoring are the loss of desirable ecological function goods and services (e.g. aquatic habitat, natural flood control, water filtration), as well as the costs of building and maintaining structures. Bioengineering techniques, consistent with riparian function, might provide a more sustainable solution while reducing bank erosion.

Assessing watershed function for use in water quality management

Assessing watershed function can become a standard practice for managing NPS pollution under the CWA to identify priorities for long-range planning and better targeting of BMPs. In our three examples of the institutionalization of assessments of ecosystem function under the CWA, PFC assessments (Prichard *et al.*, 1998, 2003) and rangeland health indicators (Pellant *et al.*, 2005) are used to provide qualitative information. Consideration of upland areas is particularly important, as many sources of water pollution can originate outside of riparian areas. However, the condition of riparian areas determines how well any pollution is handled. Where necessary, this qualitative information can be used to focus management's attention on key ecological attributes for more quantitative monitoring (Burton *et al.*, 2011).

Our first example is the US Department of Agriculture NRCS's National Water Quality Initiative, which was announced by NRCS in 2012 and is offering financial and technical assistance to producers (farmers, ranchers, forest landowners, and tribes) in priority watersheds to improve water quality and aquatic habitats in impaired streams (NRCS, 2013). Under this voluntary program, NRCS helps producers implement conservation and management practices through an ecosystem approach to control and trap nutrients. Programs have been initiated across the USA, and a watershed in the US State of Nevada is highlighted here. NRCS, University of Nevada at Reno, Nevada Department of Wildlife, private and tribal ranchers, BLM, and USEPA Region IX (US Pacific Southwest) have completed PFC assessments of the South Fork of the Humboldt River. The qualitative assessments of stream condition noted that riparian vegetation for stream bank protection along the South Fork of the Humboldt River had been significantly reduced as a result of stream incision. The assessments identified and prioritized areas for preservation, and critical source areas for NPS pollution (upland, stream bank instability, incision/nick points, etc.). NRCS has taken the lead in working with ranchers and coordinating with the State of Nevada to develop restoration projects in the areas designated as the highest priority, based on data from the PFC assessments.

Our second example concerns water quality management by Native American tribes in USEPA Region IX. PFC assessment results were introduced in 2006 and are being used to assist with developing and setting adaptive management goals; determining NPS control effectiveness for riparian areas; identifying data quality objectives and monitoring locations; prioritizing restoration; and directing funding opportunities. Function assessments define the current ecosystem condition and its potential to achieve certain criteria, goals or values given the anthropogenic uses and demands on that ecosystem. For example, throughout western USA, anthropogenic activities, such as fire suppression, water control (irrigation and flood control), transportation, and urbanization, have permanently altered natural conditions, resulting in changed hydrological patterns and plant community structure.

Tribal environmental programs use PFC assessments because they connect traditional/cultural environmental knowledge of ecosystems to ecological research. For example, causal impacts of hydrological alterations from historical and current anthropogenic activity have resulted in many stream systems being incised (BLM, 2008; Hall *et al.*, 2013). This loss of function and stream physical form releases sequestered nutrients and sediment, and destroys habitats (Hall *et al.*, 2010a).

Tribal environmental goals are to protect and improve natural resources through habitat evaluation, planning, implementation, education, community outreach and communication, and monitoring (Hall *et al.*, 2010b). The concepts of ecosystem functions and services provide decision makers with the connections between form, function, management, and monitoring, allowing them to better address the underlying causative factors behind ecosystem degradation and loss of cultural value, goods and services (BLM, 2012). Focusing on function, the decision makers of tribal programs have developed sustainable adaptive management plans, established inter-tribal stream teams (Hall *et al.*, 2010b), and, where necessary, targeted USEPA funding for specific restoration projects. This approach allows tribes to be proactive in managing their lands.

Our third example is in the US State of Montana, where BLM and the Montana Department of Environmental Quality (DEQ) established a Memorandum of Understanding (MOU) in 2010 for a proactive framework focused on producing high-quality waters by restoring and maintaining watershed function. The new MOU formalized links between upland and riparian functional assessment results and the process for cooperatively managing and abating NPS pollution from BLM-authorized activities. This MOU is set apart from most other agreements between land managers and state environmental agencies that simply address impaired waters. Under this MOU, the BLM concentrates on upland and riparian function to focus and prioritize its management efforts in addressing the probable causes and sources of pollutants influencing water quality. The DEQ concentrates on assessing the resultant water quality. Both agencies consider that a solution based upon the assessment of watershed function, together with quantitative water quality measures, has the greatest promise of success to achieve sustainability.

An earlier federal/state MOU in 2002 focused on water quality with an emphasis on impaired waters. This led to redundancies as both agencies had a similar focus – water quality. The framework provided by the new MOU in 2010 is expected to maximize each agency's effectiveness and efficiencies by reducing redundancy, allowing each agency to focus on its individual strengths, and by providing a more holistic approach to water quality management. Following the MOU, the agencies entered into a cooperative water quality monitoring agreement, which further clarified agency roles and responsibilities. This agreement shifted more of the BLM's water quality monitoring workload to the DEQ, allowing the BLM to focus more of its attention on watershed function. Both agencies have received clear benefits from the MOU as the BLM is now certain that its program is supported by the state's regulatory agency. The DEQ also has clear commitments from one of the state's largest land management agencies to improve water quality.

A major strength of all three examples is the realization by the agencies involved that managing for water quality requires a team approach. This team approach utilizes the combined strengths of multiple partners to maximize the likelihood of success. Concepts of ecosystem function used in assessments allow these partners to collaborate and manage proactively for the betterment of both water quality and habitat (BLM, 2008, 2012).

Conclusion

Assessing and monitoring riparian and upland areas are critical in understanding how resource management influences the functional state of an ecosystem. Qualitative assessment of ecosystem function provides the context for monitoring data to foster increased and focused efforts on the use of BMPs for NPS pollution. Watershed function can serve as a leading indicator for making decisions about aquatic habitat and water quality.

The examples provided demonstrate progress in the institutionalization of using the assessment of ecosystem function in water quality programs in resource management agencies in the USA to meet CWA objectives. These programs support sustainable and healthy watersheds affecting federal, state, tribal, and private landowners. Future work should refine this approach by evaluating the benefits, costs, and effectiveness of the use of watershed function in water quality programs.

Acknowledgements

The authors would like to thank the efforts of the USEPA Office of Water, the USEPA Office of Research and Development, and the BLM National Riparian Service Team for their critical reviews. The authors also appreciate the assistance of Jami Montgomery in the US Agency for International Development who provided insightful comments at an early stage of the manuscript.

Disclaimer

Although this work was reviewed by the USEPA and approved for publication, the views expressed are those of the individual authors and do not necessarily reflect the views and policies of the USEPA, the US Department of the Interior, or any other organization.

References

BLM (2008). *Water Quality Restoration Plan: Southern Oregon Coastal Basin, Upper Bear Creek Analysis Area*. Available at http://www.blm.gov/or/districts/medford/plans/files/upperbearwqrp.pdf (accessed April 14, 2013).

BLM (2012). *Bear Creek A Continuing Strategy for Accelerating Cooperative Riparian Restoration and Management*. Available at http://www.blm.gov/or/programs/nrst/files/01_bear_creek.pdf (accessed April 14, 2013).

Burton, T. A., Smith, S. J. & Cowley, E. R. (2011). *Riparian Area Management: Multiple Indicator Monitoring (MIM) of Stream Channels and Streamside Vegetation. Technical Reference 1737–23. BLM/OC/ST-10/003 + 1737 + REV.* US Department of the Interior, Bureau of Land Management, National Operations Center, Denver, CO, p. 155.

Chenoweth, J. (2012). Key issues and trends in the water policy literature. *Water Policy 14*, 1047–1059.

Cowley, E. R. & Burton, T. A. (1997). Idaho riparian proper functioning condition (PFC) assessment training material (unpublished data).

Dickard, M., Gonzalez, M., Elmore, W., Leonard, S., Smith, D., Smith, S., Staats, J., Summers, P., Weixelman, D. & Wyman, S. (2013, forthcoming). *Riparian Area Management: Proper Functioning Condition Assessment for Lotic Areas. Technical Reference 1737–15, v. 2*. US Department of the Interior, Bureau of Land Management, National Operations Center, Denver, CO.

Doody, D. G., Archbold, M., Foy, R. H. & Flynn, R. (2012). Approaches to the implementation of the Water Framework Directive: targeting mitigation measures at critical source areas of diffuse phosphorus in Irish catchments. *Journal of Environmental Management 93*, 225–234.

Evans, R. O., Bass, K. L., Burchell, M. R., Hinson, R. D., Johnson, R. & Doxey, M. (2007). Management alternatives to enhance water quality and ecological function of channelized streams and drainage canals. *Journal of Soil and Water Conservation 62*(4), 308–320 (July/August).

Gasper, R. R., Selman, M. & Ruth, M. (2012). Climate co-benefits of water quality trading in the Chesapeake Bay watershed. *Water Policy 14*, 758–765.

Ghebremichael, L. T., Veith, T. L. & Hamlett, J. M. (2013). Integrated watershed- and farm-scale modeling framework for targeting critical source areas while maintaining farm economic viability. *Journal of Environmental Management 114*, 381–394.

Hall, R. K., Guiliano, D., Swanson, S., Philbin, M. J., Lin, J., Aron, J. L., Schafer, R. J. & Heggem, D. T. (2013, submitted). An ecological function and services approach to total maximum daily load (TMDL) prioritization. *Journal of Environmental Monitoring and Assessment*.

Hall, R. K., Swanson, S., Brow, H., Tybo, J., Ogburn, J., Heil, D., Gonzales, J., Flores, J. & Mosley, D. (2010a). Riparian Proper Functioning Condition National Tribal Creeks & Communities Team. 2010 National Tribal Science Forum, June 6–10, Traverse City, MI.

Hall, R. K., Watkins, R. L., Swanson, S., Heggem, D. T., Kozlowski, D., Lin, J. & Hare, L. (2010b). Southwestern Ecosystem Services Program (SwESP) Landscape Assessment of Proper Functioning Condition in the Humboldt River Basin, Nevada. Third Annual Ecosystem Services Research Program (ESRP) Annual Meeting, Abstracts with Programs, October 19–21, Henderson, NV.

Heathwaite, A. L., Quinn, P. F. & Hewett, C. J. M. (2005). Modelling and managing critical source areas of diffuse pollution from agricultural land using flow connectivity simulation. *Journal of Hydrology 304*, 446–461.

Hubert, R. (2007). *Transforming Sustainability: Identifying the Critical Success Factors for Sustainable Cities*. Interim Report on the Sustainable Cities Research Project. Center for Sustainable Environments, Northern Arizona University, Flagstaff, Arizona.

Kozlowski, D., Swanson, S., Hall, R. & Heggem, D. (2013). *Linking Changes in Management and Riparian Physical Functionality to Water Quality and Aquatic Habitat: A Case Study of Maggie Creek, NV, EPA/600/R-13/133*. USEPA Office of Research and Development, Washington, DC.

Meyer, C. & Thiel, A. (2012). Institutional change in water management collaboration: implementing the European Water Framework Directive in the German Odra river basin. *Water Policy 14*, 626–646.

Natural Capital Project (2013). Latin America. Available at http://www.naturalcapitalproject.org/nasca.html (accessed May 26, 2013).

New York City Department of Environmental Protection (2011). Press Release. February 16, 2011, State, city announce landmark agreement to safeguard New York City drinking water. Available at http://www.nyc.gov/html/dep/html/press_releases/11-11pr.shtml (accessed April 14, 2013).

NRCS (2013). National Water Quality Initiative. Available at http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/financial/eqip/?cid=stelprdb1047761 (accessed April 11, 2013).

Pellant, M., Shaver, P., Pyke, D. A. & Herrick, J. E. (2005). *Interpreting Indicators of Rangeland Health, version 4. Technical Reference 1734–6. BLM/WO/ST-00/001 + 1734/REV05*. US Department of the Interior, Bureau of Land Management, National Science and Technology Center, Denver, CO.

Prichard, D., Anderson, J., Correll, C., Fogg, J., Gebhardt, K., Krapf, R., Leonard, S., Mitchell, B. & Staats, J. (1998). *Riparian Area Management: A User Guide to Assessing Proper Functioning Condition and the Supporting Science for Lotic Areas, Technical Reference 1737–15*. US Department of the Interior, Bureau of Land Management, National Applied Resource Sciences Center, Denver, CO.

Prichard, D., Berg, F., Hagenbuck, W., Krapf, R., Leinard, R., Leonard, S., Manning, M., Noble, C. & Staats, J. (2003). *Riparian Area Management: A User Guide to Assessing Proper Functioning Condition and the Supporting Science for Lentic Areas, Technical Reference 1737–16*. US Department of the Interior, Bureau of Land Management, National Applied Resource Sciences Center, Denver, CO.

Qiu, Z. (2009). Assessing critical source areas in watersheds for conservation buffer planning and riparian restoration. *Environmental Management 44*, 968–980.

Riparian Coordination Network (2002). *Creeks and Communities: A Continuing Strategy for Accelerating Cooperative Riparian Restoration and Management*. BLM/WO/GI-02/014 + 6740. US Department of the Interior, Bureau of Land Management, National Science and Technology Center, Denver, CO.

Swanson, S., Hall, R. K., Heggem, D. T., Lin, J., Kozlowski, D. & Gibson, R. J. (2012). Leading or Lagging Indicator for Water Quality Management. Abstracts with Programs, 8th National Monitoring Conference, April 30–May 4, 2012, Portland, Oregon.

Trevisan, D., Dorioz, J. M., Poulenard, J., Quetin, P., Combaret, C. P. & Merot, P. (2010). Mapping of critical source areas for diffuse fecal bacterial pollution in extensively grazed watersheds. *Water Research* 44, 3847–3860.

USEPA (2000). *Revisions to the Water Quality Planning and Management Regulation and Revisions to the National Pollutant Discharge Elimination System Program in Support of Revisions to the Water Quality Planning and Management Regulation: Final Rules, Environmental Protection Agency Part VI*. 40 CFR Part 9 et al. Federal Register, Washington, DC, July 13, 2000.

USEPA (2008). *What are the trends in the extent and condition of fresh surface waters and their effects on human health and the environment?* In EPA's 2008 Report on the Environment, EPA/600/R-07/045F. USEPA National Center for Environmental Assessment, Washington, DC, Section 3.2.

USEPA (2009). *The National Water Quality Inventory: Report to Congress for the 2004 Reporting Cycle, EPA 841-F-08-003*. USEPA Office of Water, Washington, DC.

USEPA (2011). *Healthy Watersheds Initiative: National Framework and Action Plan, EPA 841-R-11-005*. USEPA Office of Water, Washington, DC.

USEPA (2012). The Clean Water Act: Protecting and Restoring our Nation's Waters. Available at http://water.epa.gov/action/cleanwater40/cwa101.cfm (accessed June 16, 2013).

USEPA (2013). *National Rivers and Streams Assessment 2008–2009 A Collaborative Survey Draft, EPA/841/D-13/001*. USEPA Office of Wetlands, Oceans and Watersheds and Office of Research and Development, Washington, DC.

Wyman, S., Bailey, D. W., Borman, M., Cote, S., Eisner, J., Elmore, W., Leinard, B., Leonard, S., Reed, F., Swanson, S., Van Riper, L., Westfall, T., Wiley, R. & Winward, A. (2006). *Riparian Area Management: Grazing Management Processes and Strategies for Riparian-Wetland Areas. Technical Reference 1737–20. BLM/ST/ST-06/002 + 1737*. US Department of the Interior, Bureau of Land Management, National Science and Technology Center, Denver, CO.

Received 25 June 2012; accepted in revised form 9 May 2013. Available online 10 July 2013