EPA/600/R-17/138 | October 2017 | www.epa.gov/research

United States Environmental Protection Agency

Using Ecosystem Function in the Clean Water Act

RESEARCH AND DEVELOPMENT

Using Ecosystem Function in the Clean Water Act

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Notice

The information in this document has been funded in part by the United States Environmental Protection Agency under contract number EP-14-Z-000030 to Joan Aron. It has been subjected to the Agency's peer and administrative review and has been approved for publication as a USEPA document.

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Acknowledgments

The authors would like to recognize the good people who helped us with this report: Kevin Broadnax, Tad Harris, Pam Grossmann, May Fong, Maria Gregorio and Howard Kahan. We are also grateful to Robert J. Miltner, Chris O. Yoder, Brian Schumacher and Megan Mehaffey who peer reviewed this report.

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List of Acronyms and Abbreviations

BLM	US Bureau of Land Management
CBF	Chesapeake Bay Foundation
CEC	Commission for Environmental Cooperation
CWA	US Clean Water Act
HAB	Harmful Algal Bloom
IJC	International Joint Commission
LIDAR	Light Detection and Radar
LUMCON	Louisiana Universities Marine Consortium
LVWCC	Las Vegas Wash Coordination Committee
LVWWP	Las Vegas Wash Weed Partnership
MODIS	Moderate Resolution Imaging Spectroradiometer
NOAA	US National Oceanic and Atmospheric Administration
NPS	Nonpoint Source
NPDES	National Pollutant Discharge Elimination System
NRC	US National Research Council
NRCS	US Natural Resources Conservation Service
NRST	US National Riparian Service Team
PFC	Proper Functioning Condition
PNC	Potential Natural Condition
SHCRP	Sustainable and Healthy Communities Research Program
STAC	Scientific and Technical Advisory Committee
TEK	Traditional Ecological Knowledge
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids

List of Acronyms and Abbreviations (cont.)

USACE	US Army Corps of Engineers
USDA	US Department of Agriculture
USDOI	US Department of the Interior
USGAO	US Government Accountability Office
USEPA	US Environmental Protection Agency
WQS	Water Quality Standards

Executive Summary

Clean, fresh water is one of our most precious natural resources. The Clean Water Act was enacted to control pollution. It has been highly successful in controlling pollution at the point of contamination. Yet, there are still areas where vast improvements need to be made. Environmental monitoring for water quality results indicates pollution from nonpoint sources needs to be controlled. Water quality improvements will depend on solutions requiring a different way of thinking. This report gives examples, by way of case studies, showing how monitoring the drivers of ecosystem function physical processes will identify problems and target solutions for water quality and aquatic community improvements. Monitoring the drivers of ecosystem function physical processes can be an integral component of Clean Water Act activities by assisting communities to manage their natural resources to make a difference in the control of nonpoint source pollution.

This report provides a review of research and examples where ecosystem function physical processes are used to support the sustainability of water quality. The aim is to transfer experience from using ecosystem function physical processes for ecosystem restoration and apply it to the control of stressors, particularly nonpoint source (NPS) pollution. The assessment methodology adopted from monitoring restoration projects is well-suited to make a substantial and sustainable contribution to the control of persistent water quality problems. Before turning to a presentation of assessment methodology and examples, we establish the continuing concerns about the quality of US waters, explain how ecosystem function relates to these concerns about water quality, and outline how ecosystem function can be used as a viable tool within the CWA.

Ecosystem function provides a means of managing ecological processes, but what are these processes? The central concept is an ordering of five stream functions so that each stratum depends on the function immediately below it (Harman et al., 2012). The first level is hydrology, which describes how water moves from the watershed to the stream channel. The second level characterizes the movement of water in the channel, on the floodplain and through sediments. The third level is geomorphology for the formation of streambeds from woody material and sediment. The fourth level is physicochemical, including temperature, oxygen and organic matter. The fifth level of biology refers to aquatic (Karr, 1998) and riparian biodiversity (Winward, 2000), whose function depends on all the other physical processes.

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1.0 Introduction

The purpose of this report is to show how the assessment and management of ecosystem function in healthy watersheds can be an integral component of Clean Water Act (CWA) activities. Since the nation has more than four decades of experience in pollution control under the CWA, including a Healthy Watersheds Initiative, a natural question is: *Aren't we already doing this?* The short answer is: *no*.

The CWA establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. The CWA made it unlawful to discharge any pollutant from a point source into navigable waters, unless a permit was obtained through USEPA's National Pollutant Discharge Elimination System (NPDES) permit program controls discharges. (source https://www.epa.gov/laws-regulations/summary-clean-water-act). USEPA programs focused on using permits and chemical centric emphasis has been successful in diminishing point source (PS) stressors but has been lacking in dealing with NPS pollutants (Hall et al., 2014a; Karr and Yoder 2004). This chemical centric process (Karr and Yoder, 2004) ignores ecologically toxic effects of altered flows, excess/depleted sediment supply, groundwater withdrawals, invasive plant and aquatic species, stream channel incision, and release of pollutants long stored in riparian areas (Swanson et al., 2017; Kozlowski et al., 2013). Improved assessment methods have outpaced the pollutant focused administration of the CWA for water quality standards (WQS) and total maximum daily loads (TMDLs) of beneficial uses. Therefore, the objective is to modernize the CWA by incorporating new tools such as measuring the drivers (vegetation, hydrology, soil and landform) of ecosystem function physical processes (Burton et al., 2011; Dickard et al., 2015; Kozlowski et al., 2013; Swanson et al., 2017) to determine essential response indicators and establish plant (Winward 2000) and aquatic biological criteria (Davies and Jackson, 2006; Barbour et al., 2000; Courtemanch 1995; Davis 1995). An ecosystem function approach represents a fundamental (and needed) change in how the core of USEPA water programs have historically implemented the CWA (C. Yoder, pers. comm.; Aron et al., 2013; Hall et al., 2014a; Harman et al., 2012; Hughes et al., 2006; Swanson et al., 2017).

Ecosystem function is notably distinct from other water quality management tools because it provides a means of managing the very ecological physical processes underlying natural, properly functioning watersheds. The science of ecosystem function includes methods leading to early detection of potential water quality problems based on the identification of current ecological condition at risk of losing functions. The use of ecosystem function in water quality control is through targeting ecological physical processes for assessment and remediation. These ecological processes are critical for the sustainability of water quality, which depends on ecosystem resilience. Sustainable ecosystems exhibit resilience, which is the capacity to withstand, respond to and recover rapidly from disturbances (Chaffin et al., 2016; Swanson et al., 2015; Walker et al., 2004; de Groot, 2006; Executive Order No. 13653, 2013). For example, CWA 303(d) total maximum daily loads (TMDLs) focus on quantitative water quality measurements and their

impacts to aquatic communities (Aron et al., 2013). When dealing with NPS pollution, water quality and aquatic indicators are response (lagging) indicators (Swanson et al., 2012; Aron et al., 2013). To address the aquatic impacts from environmental stressors it is important to understand the drivers of riparian and other ecosystem functions, and recognize their role in capture, storage and safe release of water sediment, nutrients, and organic materials. Also, the aquatic and terrestrial ecology and stream form and function needed for locally relevant attributes, processes and resilience. By identifying the condition of a watershed and/or ecoregion to determine whether streams and wetland riparian areas are functioning properly, managers can make the connection between form, function, management and monitoring to address the underlying causative factors behind restoration of biological values and ecosystems.

1.1 Widespread Impairments of Water Quality.

The nation is not fully achieving the CWA objective of restoring and maintaining the integrity of its waters (US Environmental Protection Agency [USEPA], 2012c; Karr and Yoder, 2004). The most recent national assessment of river and stream miles concluded that more than half are in poor condition (USEPA, 2012a; USEPA, 2013a). The early focus of the CWA on pollutants from point sources, such as factories and sewage treatment plants, led to strong regulation of point sources and major reductions in pollution from those sources. In contrast, water quality impairments are now caused more often by diffuse NPS pollutants, such as sediment, nitrogen, phosphorus, and pathogens. A recent national review of the implementation of the CWA found that NPS pollutants caused most of the impairments in water bodies with formal pollution control targets (US Government Accountability Office [USGAO], 2013).

Four examples of large-scale water quality problems illustrate how these impairments affect different parts of the country. A common theme is the need to consider dynamic situations and continue to assess the effectiveness and sustainability of solutions. That is, successful outcomes incorporate both the achievement of water quality criteria and the sustainability of water quality associated with resilient ecosystems.

Mississippi River

Hypoxia is an environmental condition in the water column where living aquatic organisms cannot thrive because of low concentrations of dissolved oxygen (Louisiana Universities Marine Consortium [LUMCON], 2014). The largest hypoxic zone affecting the nation appears every year in late summer where the Mississippi River flows into the northern Gulf of Mexico, principally because of high levels of nitrate causing excessive growth of algae (algal blooms) resulting in oxygen depletion (LUMCON, 2014). Although some hypoxic conditions occur naturally, the Gulf of Mexico hypoxic zone developed since the 1940s because of an increase in nitrates from industrial fertilizers, animal manure, urban areas and wastewater treatment in the Mississippi River basin (Howard, 2014).

A recent study of trends in water quality from 1980 to 2010 in the Mississippi River basin found an increase in nitrate levels in most sampling sites, including the lower sections of the Mississippi River (Murphy et al., 2013). This increase in nitrates occurred despite many conservation efforts, such as reducing agricultural fertilizer use and improving wastewater treatment (Howard, 2014). A contribution to the trend may be a loss of soil microbial activity from the loss of carbon resulting from changes in agricultural practices (Zheng et al., 2017; Wang et al., 2017; van Leeuwen et al., 2017). Other factors may be the replacement of soy production with corn production, which uses more fertilizer (Howard, 2014), and nitrates left in groundwater from decades of pollution (Murphy et al., 2013). A possible solution is an ecosystem function assessment to understand the connection between ecosystem physical processes, natural resources, land management, and sources of nitrates in the Mississippi River basin to guide the formulation of more effective and sustainable policies.

In 2007, the US Army Corps of Engineers (USACE) developed an ecosystem restoration program with the objective "***To conserve, restore, and maintain the ecological structure and function of the Upper Mississippi River System"*** (USACE, 2011). USACE planning emphasized that restoration activities must restore ecosystem physical processes and functions to increase aquatic productivity, and become more resilient to human and natural disturbances (i.e., system-wide sustainable ecosystem). In 2017, there has been over 90 restoration projects complete or in process to restore the river system (USACE, 2017).

Lake Erie

As the smallest and shallowest of the five North American Great Lakes in a watershed of big cities and farmland (Figure 1), Lake Erie is very much affected by human activities (International Joint Commission [IJC], 2014). The problem of excessive nutrients, especially phosphorus, has been recognized as the cause of harmful algal blooms (HABs) in Lake Erie for more than 50 years (IJC, 2014). HABs adversely impact the ecosystem, drinking water supplies, fisheries, recreation, and tourism. Phosphorus from municipal sewage plants was the principal concern in the 1960s and 1970s. Policies to upgrade municipal sewage treatment and reduce phosphorus in detergents resulted in much better water quality as established through standard water quality measures. By the 1980s, the problem appeared to be solved but vulnerabilities remained undetected.

In the early 2000s (Figure 1), the problem of HABs re-emerged (IJC, 2014). The largest HAB recorded in Lake Erie in the IJC report occurred in 2011 and Carroll Township in Ohio shut down its water treatment plant in the summer of 2013 due to high levels of the HAB toxin microcystin (IJC, 2014). Drinking water for Toledo, Ohio was similarly affected in the summer of 2014 (Beauvais, 2015). Although phosphorus remains the principal culprit, NPS pollution rather than municipal sewage discharge (point sources) is cited as the cause of the problem (IJC, 2014). Phosphorus flows into Lake Erie from a variety of sources – agricultural use of fertilizer and manure, urban storm water and combined sewer overflow discharges. Atmospheric deposition

adds to the total load. Assessment of ecosystem function in the stream and wetland riparian areas and uplands is essential in understanding soil dynamics and fate and transport of nutrients. Ecosystem function assessment in addition to the ongoing measures to improve water quality in Lake Erie can prevent us from being caught by surprise in this way.

Figure 1. Moderate Resolution Imaging Spectroradiometer (MODIS) satellite Image of Lake Erie on October 9, 2011. This image shows the algae bloom occurring within Lake Erie. Source: http://ge.ssec.wisc.edu/modis-today/.

Chesapeake Bay

The Chesapeake Bay and many of its tributaries are listed as impaired waters under the CWA because of hypoxia and pollution (Chesapeake Bay Foundation [CBF], 2014a). Agricultural and urban runoff along with wastewater discharges and atmospheric deposition load excessive nitrogen and phosphorus into the Chesapeake Bay, causing algal growth that depletes oxygen needed by other aquatic species (CBF, 2014a). Erosion and construction sites release silt, sand, and clay producing excessive sediment in the water column, blocking sunlight from grasses and smothering oysters and other species at the bottom of the bay (CBF, 2014a). Agricultural conservation practices to prevent soil erosion and reduce runoff of nutrients and sediments in the

Chesapeake Bay watershed have been implemented with success in the Bay (US Department of Agriculture [USDA] Natural Resources Conservation Service [NRCS], 2013).

Unfortunately, existing control measures have failed to address the growing levels of urban and suburban storm water runoff in this region (CBF, 2014b). More than 17 million people live in the Chesapeake Bay watershed where fields and forests are being converted to hardened surfaces at a rate that is roughly equivalent to producing another Washington DC every four years (CBF, 2014b). In addition to nitrogen, phosphorus, and sediment, runoff contains trash, fecal bacteria, oil and other petroleum products, pesticides, herbicides, road salt, copper, lead, zinc and other toxic metals (CBF, 2014b). The impacts include mortality of fish and amphibians, swimming beach closures, restrictions on oyster harvesting, millions of dollars annually for dredging runoff sediment, and higher costs of filtering nitrates and other pollutants from drinking water (CBF, 2014b). The Scientific and Technical Advisory Committee (STAC) for USEPA's Chesapeake Bay Program has criticized the current system of accountability measures that set numeric targets, such as a number of acres of wetlands; these measures cannot be easily altered as conditions change (Blankenship, 2014). The STAC would like to see accountability measures based more directly on observations that the Bay is getting better in supporting its use for drinking, swimming, and fishing (Blankenship, 2014). Managing for ecosystem function can contribute to a flexible system that would allow for measures supporting water quality that can be adjusted as conditions change.

Las Vegas Wash

The Las Vegas Wash drains storm water runoff and highly treated effluent from Las Vegas Valley to Las Vegas Bay, an arm of Lake Mead (USEPA, 2012d). Lake Mead is the largest artificial reservoir in the country, serving as a source of drinking water for millions of people in three states (USEPA, 2012d). Over the past few decades, the Las Vegas Valley has seen rapid population growth and development associated with an increase in impervious surfaces and volume of wastewater. As a result, sediment load in the lower reach of the Las Vegas Wash has at times been in excess of Nevada water quality standards for total suspended solids (TSS) (USEPA, 2012d). Las Vegas community leaders worked with government agencies on a plan to improve water quality in the lower reach by incorporating low dams (weirs) to control erosion, restoring wetlands, and limiting the advance of invasive plant species (Las Vegas Wash Coordination Committee [LVWCC], 2000; USEPA, 2012d). Priorities for invasive plant management include re-introducing native plant communities and other management objectives (LVWCC and Las Vegas Wash Weed Partnership [LVWWP], 2003). Work on the plan continued after the reach was taken off the impaired list in 2004 after being designated two years earlier. By 2006, the implementation of the LVWCC plan had cost $33 million (USEPA, 2012d). As of 2014, the LVWCC plan is still being implemented and the Las Vegas Wash remains off the list of impaired waters.

However, water quality management must/should address both water quality criteria and resilience. Despite the current success in meeting Nevada water quality criteria for TSS, questions

about the resilience of the Las Vegas Wash raise great concern. Las Vegas Valley has a history of large storm events that trigger runoff causing massive erosion and leading to loss of habitat and infrastructure (LVWCC, 2000). Flooding may become more unpredictable as storm events occur against a backdrop of population growth generating more wastewater and development increasing impervious surface area (USEPA, 2012d). Year-round flow from lawn irrigation permits vegetation to grow in and block storm drainage areas. The water management system also relies heavily on an engineered water intake that moves water from the Las Vegas Wash in a tunnel under Las Vegas Lake to Lake Mead. A failure of this structure in a major storm event would be catastrophic and require millions of dollars to repair. Active monitoring of watershed function would help to prevent this type of costly damage and insure water quality for all users.

1.2 Ecosystem Function for Sustainability of Water Quality.

Ecological function concepts and approaches are not new, but are when trying to integrate these concepts into CWA activities. Introducing proper functioning condition (PFC) assessment and managing ecosystems to improve function as part of CWA activities has the potential to reduce stressors, particularly NPS pollution. The objective of introducing PFC and resource management is to provide an ecosystem approach to meet the latest challenges of restoring and maintaining clean water (USEPA, 2011; USEPA, 2010b; USEPA, 2012a).

Sustainability associated with resilient ecosystems is linked to the control of NPS pollution. Properly functioning physical processes in upland and riparian areas around water bodies allow the assimilation of stressors (Swanson et al., 2017). In aquatic environments, not all water pollution is from an external input. Pollution can come from the materials stored in riparian areas and wetlands. Wetlands are used for water quality remediation because of their ability to sequester pollutants by dissipating energy and allowing sediment deposition leading to the creation of aquatic and riparian habitat complexity. Loss of ecological function and physical form unravels the assimilation processes. In most streams, loss of functions causes a significant portion of NPS pollution. This connection can be elucidated by comparing scenarios of erosion and sediment mobilization before and after the loss of functions (Hall et al., 2009; Kozlowski et al., 2013; Kozlowski et al., 2016).

Good water quality supports USEPA's strategic plan to protect public health, watersheds and aquatic resources (USEPA, 2010a). Ecosystem restoration for water quality builds on the scientific study of ecological functions of lotic (running water) (Prichard et al., 1998; Dickard et al., 2015) and lentic (standing water) (Pritchard et al., 1996) riparian areas. For example, in May of 1977, the vegetation along Bear Creek, central Oregon, was mostly absent (Figure 2a). Through restoration efforts (i.e., introduction of stabilizing riparian vegetation) the vegetation was thriving in May of 2007 (Figure 2b). Restoring vegetation allowed the channel to trap sediment and build a new riparian area within the incised channel (Figures 2a and b). Restoration of riparian functions also moderates a stream's temperature extremes by increasing recharge of aquifers, extending base flow discharges into the stream during late summer and early fall (Swanson et al., 2017).

As a result, a comparison of temperatures of water and the surrounding air revealed that Bear Creek habitat became more suitable to support a cold-water fishery. I n August of 1976, water temperature was not much different from air temperature (Figure 3a), but by August of 1998 water temperature considerably cooler than the air temperature (Figures 3b). An associated beneficial effect of restoration was an increase in the amount of water storage in the riparian area from less than half a million gallons per mile in 1976 to nearly four million gallons per mile in 1989 (Elmore, 1998). The experience with Bear Creek reflects how the US Department of the Interior (USDOI) Bureau of Land Management (BLM) changed its management strategy from the exclusion of livestock to maintenance of riparian functions that can support grazing with careful controls on its timing, intensity, and duration (Elmore, 1998; Borman et al., 1999; Swanson et al. 2015).

Ecosystem function approaches support USEPA's initiative for sustainability (NRC, 2011; NRC, 2014b). Ecosystem function research is part of USEPA's research program for sustainable and healthy communities (USEPA, 2012b). Although there has been some progress in many cases of NPS control (USEPA, 2014a), greater advancement requires a systems perspective. Ecosystem function in healthy watersheds can provide sustainable production of high-quality waters. Sustainability in this context refers to a condition of resiliency for linked watersheds, riparian areas, and aquatic and coastal ecosystems. When these ecosystems are resilient, they remain intact and improve their ecosystem functions after a 25-year or 30-year flow event.

Erosion and Sediment Mobilization before Loss of Functions

Experience using ecological function approaches in many watersheds reveals key generalizations about what to expect when the watershed has properly functioning physical processes in upland and riparian areas (Swanson et al., 2015). A functioning watershed keeps water on the land longer with multiple processes whose effects are evident in flow events.

In low to moderate flow events, overland and stream load is primarily finer grained sediment originating from the uplands, which is transported into streambeds and riparian areas (Wang et al., 2015). In larger events, streams mobilize larger substrate and upland soils. Under these conditions, energy is dissipated as the stream accesses its well-vegetated floodplain. Floodplains with abundant vegetation and roughness permit storage of deposited sediment for long durations. The shift from "short duration" and "moderate duration" to "long duration" storage improves water quality by removing sediment from the water column and channel. Hancock et al., 2017, found that appropriate land management practices can have a long-term impact on sediment transport into fluvial ecosystems.

Figure 2a. Bear Creek - Central Oregon, May 1977. Source: National Riparian Service Team [NRST] (2009). Introduction to Riparian Function: Bear Creek Example. BLM USDOI. Slide 33 – Photograph on the left-hand side. Available at http://www.blm.gov/or/programs/nrst/pfcassess.php (accessed April 27, 2014).

Figure 2b. Bear Creek - Central Oregon, May 2007. Source: NRST (2009). Introduction to Riparian Function: Bear Creek Example. BLM USDOI. Slide 33 – Photograph on the right-hand side. Available at http://www.blm.gov/or/programs/nrst/pfcassess.php (accessed April 27, 2014).

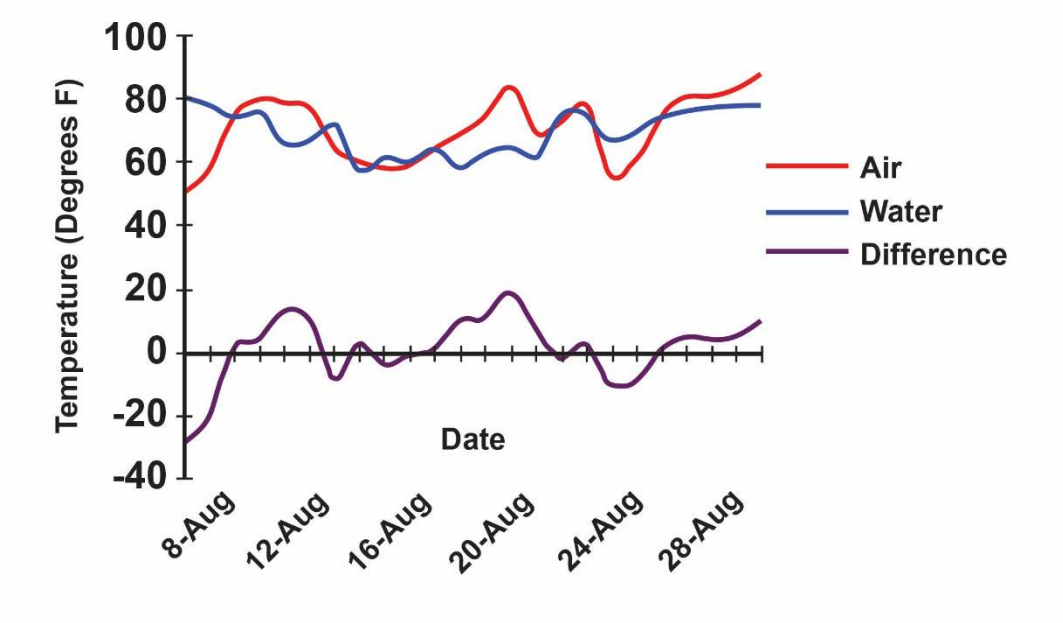

Figure 3a. The difference in air and water temperatures, Bear Creek – Central Oregon, August 1976. Source: NRST (2009). Introduction to Riparian Function: Bear Creek Example. BLM USDOI. Slide 29 – Graph on the left-hand side. Available at http://www.blm.gov/or/programs/nrst/pfcassess.php (accessed April 27, 2014).

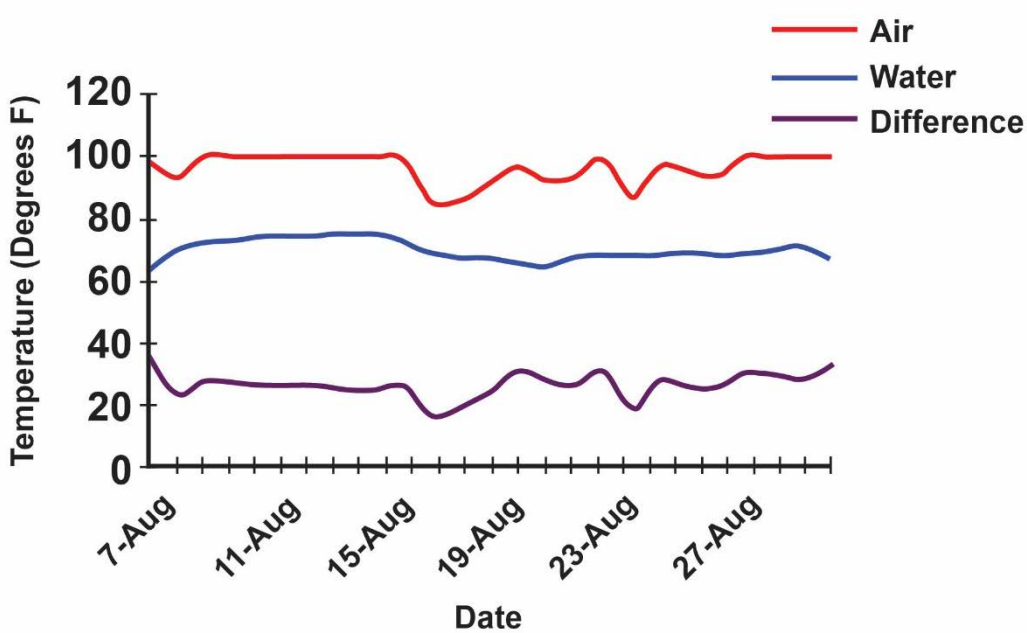

Figure 3b. The difference in air and water temperatures, Bear Creek – Central Oregon, August 1998. Source: NRST (2009). Introduction to Riparian Function: Bear Creek Example. BLM USDOI. Slide 30 – Graph on the left-hand side. Available at http://www.blm.gov/or/programs/nrst/pfcassess.php (accessed April 27, 2014).

Erosion and Sediment Mobilization after Loss of Functions

Watersheds reveal a different pattern after losing properly functioning physical processes in upland and riparian areas. Loss of functions leads to loss of much moderate-term and long-term storage capacity for sediment, leaving these watersheds subject to greater ecological impacts during flow events.

During small flow events, the impacts are similar to those in the Bear Creek scenario before the loss of functions but major differences begin to show up as larger events occur. More un-vegetated bars within the channel become mobilized in moderate events, leading to pool filling and impacts to habitat features, such as destruction of spawning nests for fish (redds). These changes reflect a shift from "moderate duration" storage to "short duration" storage, which affects beneficial uses of the aquatic environment.

Much larger flow events are less frequent but have a greater impact. Under these conditions, the energy is forced upon the banks as the stream is more confined and cannot leave the channel to dissipate energy. Since these banks are not protected by wetland/riparian stabilizers, excessive bank erosion begins (Dickard et al. 2015). The water that does reach the floodplain erodes the floodplain and terraces due to a lack of vegetation and roughness elements. In this case, the stream is not putting sediment into "long duration" storage but rather moving it from the floodplain to the channel and eventually putting it into "short duration" storage (being deposited on the stream bed). During large flow events, the uplands start experiencing erosion through rilling and gullying (formation of channels) although not all sediment reaches a stream (efficiency of delivery is less than 100%) (Wang et al., 2015). In very large events, these problems are intensified. Mass wasting in the uplands can result in extreme sediment production.

1.3 How Ecosystem Function Can Be Used with the Clean Water Act.

Using ecosystem function as a tool for water quality assessment leads to more effective decisions to target best management practices, particularly for NPS pollution. The science of ecosystem function can help with finding early warning signs to protect and devise remediation to restore water quality. An assessment of functional condition in upland and riparian ecosystems considers hydrology, vegetation and soil/landform attributes. This information provides the context for monitoring data used for decisions to support water quality in healthy watersheds.

Riparian vegetation, whose loss typically results in excessive sediment washing into water bodies, provides a focus to illustrate the approach. Stream banks with proper riparian function, which reduces shear stress, facilitate the deposition of sediment. Riparian vegetation provides roughness to slow floodwater and root binding to armor stream banks. An assessment of ecosystem function may note the poor condition of vegetation causing the loss of the riparian function of sediment deposition, which slows and dissipates flood energy and protects stream banks. In this situation, the affected stream might eventually be listed as an impaired water body due to sediment input from sources on the floodplain out of the channel; sediment input from stream banks

(experiencing high shear stress against weakened banks); and excessive water temperature fluctuations due to excessive stream width. Information about the condition of vegetation and other indicators of riparian function can be used to set priority locations for restoring riparian vegetation, a driver for restoring riparian function, with multiple objectives: 1) reduced NPS pollution from sediment and thermal loading; 2) improved assimilation of nutrients; and 3) better quality of riparian and aquatic habitats.

The timing of ecosystem function information is important for practical use. An assessment of ecosystem function in watersheds can provide early (leading) indicators of water quality trends in areas where NPS pollution is, or should be, the major concern (Aron et al., 2013). The loss of functional condition in upland and riparian ecosystems points to a potential for reduced water quality earlier than traditional in-stream measures. If a riparian area does not function properly, it may not retain the same general geometry over time and may be out of balance regarding sediment transport (Kozlowski et al., 2013). If the riparian zone is functioning but stressed or "at risk" because one or more attributes makes it susceptible to degradation, it may be prone to excess channel changes during major disturbances such as flooding or fire (Swanson et al., 2015). Water quality or biological community assessments (USEPA, 2009) cannot predict if an ecosystem is crossing an ecological or geomorphic threshold causing devastating changes to the riparian and aquatic ecosystems (Hall et al., 2014a; Kozlowski et al., 2013). For example, a study in Nevada's Maggie Creek watershed showed that indicators of riparian function, including vegetation and channel form, were more effective than water chemistry indicators in providing early identification of changes in aquatic habitat (Kozlowski et al., 2013). Kozlowski et al. (2013) explain how a focus on riparian functionality led to significant improvements in water quality and habitat for cold-water fish. Kozlowski et al. (2013) found that changes in channel form modified habitats, chemical concentrations, temperatures, and affected various beneficial uses.

The implication is that assessments of ecosystem function can lead to more timely decisions about water quality and associated aquatic habitat. Leading indicators must focus on the drivers of physical functions so they can lead to early interventions to prevent the progression of water quality deterioration. A strategy of waiting to respond to excessive erosion and sediment transport increases the adverse impacts. For example, Hall et al. (2014a), in an assessment of riparian function along the Reese River in central Nevada, demonstrated that water quality monitoring is ineffective for timely recognition of developing ecological problems. Water quality managers can reduce harmful effects caused by NPS pollution by making sure that ecosystem function is on a path of restoration and maintenance. Function assessments can be used to empower resource managers in adaptive management alternatives, prioritize resource allocations, and identify parameters to be monitored (Swanson et al., 2015; Hall et al., 2014a; Kozlowski et al., 2013; Aron et al., 2013; Swanson et al., 2012; Swanson et al., 1996).

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2.0 Assessments

A review of assessment methods would have to cover a broad range of qualitative and quantitative techniques, such as monitoring of improved water quality, the growth of fish populations and greater quality of recreational activities. Such a review is beyond the scope of this report. Instead, the focus is on a single method to provide examples of the use of ecosystem function showing how it could be a component of CWA activities.

Riparian Proper Functioning Condition (PFC) assessment is a qualitative methodology for assessing the physical functionality of riparian and wetland areas. PFC assessment has an extensive history of research and application starting in 1992 and has been adopted by BLM as a local and national standard for riparian-wetland management (Prichard et al., 1993; Prichard et al., 1998; Dickard et al., 2015). PFC assessment has recently generated interest in its use to manage water quality under the CWA (Kozlowski et al., 2013; Swanson et al., 2017). As a qualitative tool, PFC is not appropriate for detailed monitoring of riparian-wetland systems but it is extremely useful in identifying where to monitor and what systems need for a management foundation. PFC assessment provides information about the drivers of trends in water quality, which can reveal early warning signs of deterioration and early indicators of improvement.

The examples in this report use PFC assessment to address attributes and processes required to maintain a functioning riparian ecosystem. Riparian functionality affects base flow, sediments, nutrients, temperature and dissolved oxygen (Wyman et al., 2006; Kozlowski et al., 2013; Kozlowski et al., 2016; Swanson et al., 2015). The PFC assessment checklist covers hydrologic items, vegetation items and geomorphology items, such as sinuosity of the stream, stabilizing riparian vegetation and vertical stability of the stream system (lack of incising), respectively.

PFC ratings, while qualitative, are based on quantitative science (Prichard et al., 1998). If a stream reach is functioning in PFC (Figure 4), it is resilient to disturbances and has adequate vegetation, landform or large woody debris to (Prichard et al., 1996; Prichard et al., 1998):

- dissipate stream energy associated with high water flow, thereby reducing erosion and improving water quality;
- filter sediment, capture bed load (sediment carried immediately above the stream bed), and aid floodplain development;
- improve floodwater retention and groundwater recharge;
- develop root masses that stabilize stream banks against cutting action; and
- develop diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fauna, greater biodiversity, and various uses.

If a stream reach is functional but vulnerable to degradation, it is deemed Functional – At Risk (Figure 4). A stream reach may also be Nonfunctional if it is unable to perform PFC functions (dissipate energy from high flows, etc.).

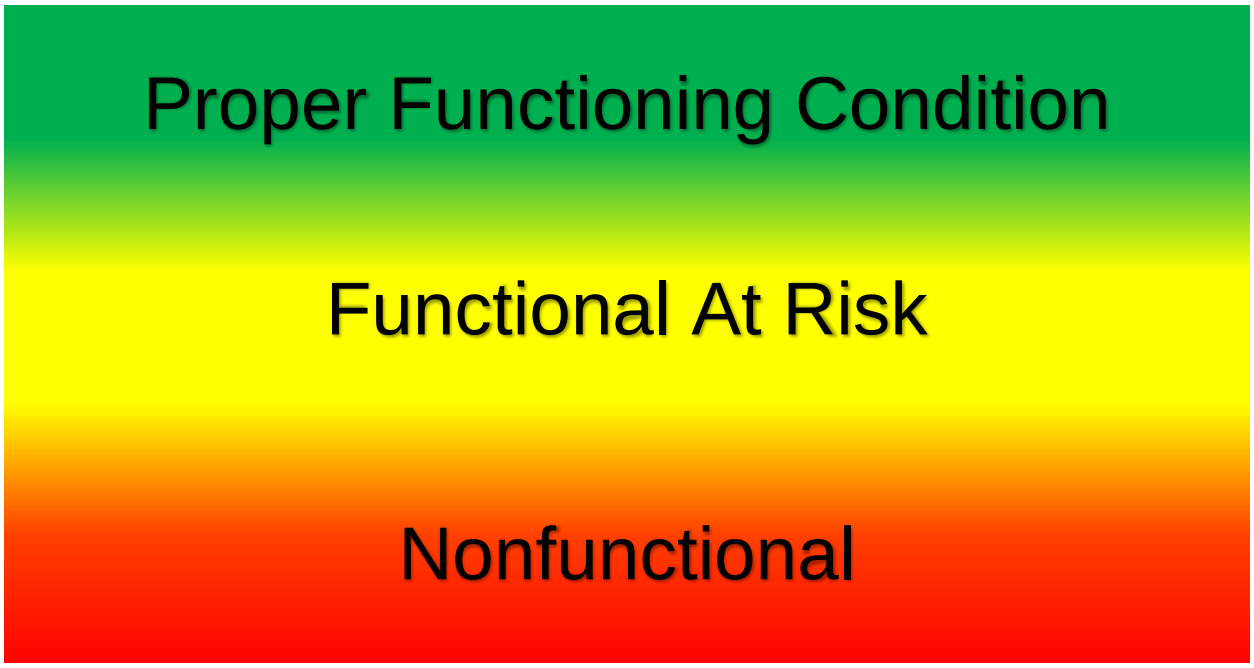

Figure 4. The three functional rating determinations from the Riparian PFC assessement.

The PFC rating of a stream reach must be viewed in the context of its potential natural condition (PNC), which is the highest ecological status a riparian area can achieve in the absence of political, social or economic constraints due to human actions (Prichard et al., 1996; Dickard et al., 2015). An interdisciplinary team can learn about the potential of an area from relict sites in a similar setting, similar areas under differing management, historical records, species lists, soils, knowledge of the watershed and watershed hydrology, plant communities that are in the bioclimatic region that express in similar settings, and observations of the plant community that identify conditions for establishment and continued survival (including geologic setting and soils determining whether or not the site is capable of producing certain types of vegetation). Some possible sources are (Dickard et al., 2015):

- relict species no longer in the study area but living in preserves;
- historic photos revealing historic conditions;
- the presence of animal and plant species noted in current and historical records; and
- cross-sections of soil showing the frequency and duration of flooding.

An area in PFC has reached the point at which the system is physically sustainable and can support multiple desired services, such as water quality, forage, and wildlife habitat. PFC is characterized by a range of conditions whose upper boundary is the natural potential.

Analyzing data in the context of potential is an essential element of the assessment process (Swanson et al., 2017). In an analysis of areas of varying potential, in-stream water quality measures are likely to reflect both differences in potential and the drivers of functionality. For example, a comparison of the natural potential of the Colorado River in the Grand Canyon and high mountain streams reveals different water quality characteristics in terms of sediment and temperature. The Grand Canyon at potential is highly sediment laden and much warmer than currently with cold clear water coming from Lake Powell. In contrast, clear and cold high mountain streams in mountain meadows become very sediment-laden when incised and widening through gully bank erosion.

Data on PFC ratings averaged across many locations without the context of potential are difficult to interpret directly regarding water quality standards. A reach might not support desired beneficial uses of the water body because of limited potential rather than ineffective pollution management. Conversely, streams managed for riparian functionality often far exceed the water quality needed to meet minimum standards or not exceed maximum pollution levels (Figure 3a and 3b; Kozlowski et al., 2016; Swanson et al., 2017). Furthermore, each reach should be understood as a component of a larger watershed system in which the characteristics of one reach may influence the potential of another.

The methodology for PFC could be used to address the problem of natural condition that arises in developing water quality standards. Under the CWA, the general process is to establish designated uses (drinking water, recreation, aquatic life, etc.), criteria to preserve those uses (numeric pollutant concentration or a narrative description) and provisions to protect against further impairments to water quality and aquatic life. In some cases, a surface water body does not meet water quality standards even though it has not been affected by human-caused disturbance and is considered to be in its natural condition (e.g., natural hot springs with distinctive chemical and temperature characteristics). The natural condition provision must include a procedure for calculating or determining a natural condition, which is typically based on using a less disturbed condition of a neighboring or similar watershed as a reference condition (USEPA, 2005). In practice, however, it is difficult to establish a reference condition. The search for a reference water body that is cleaner or less disturbed may result in an area with a different potential, especially if the potential natural condition (PNC) has been altered (e.g., interim land management practice). As defined by Schumm (1977), a watershed can be divided into erosional, transportation and depositional reaches, each of which would have different potential given its natural condition and uses. Therefore, all reaches may have different classification types (Rosgen 1994), different potentials, and, subsequently, biological and chemical differences. A more appropriate approach

would be to use PFC's potential natural condition (PNC) to set water quality standards (Swanson et al., 2017; Swanson et al., 2015; Harman et al., 2012).

Assessment of ecosystem function is also relevant to the identification and protection of healthy watersheds. The components of assessment for healthy watersheds have been classified as landscape condition, habitat, hydrology, fluvial geomorphology, water quality and biological condition (Swanson et al., 2017; Dickard et al., 2015; Kozlowski et al., 2013; Prichard et al., 1998; Karr, 1998). These components are combined into an integrated assessment to inform watershed management (USEPA, 2012a). PFC is listed in this compendium as an assessment for habitat (USEPA, 2012a), but PFC should be compared with approaches for integrated assessment as a combination of hydrology, vegetation, and geomorphology for ecosystem functions and a diversity of ecosystem services, including aquifer recharge, water quality, forage, and habitat.

2.1 Alternative to Total Maximum Daily Loads for Restoring Water Quality.

Under the CWA, total maximum daily loads (TMDLs) of pollutants are estimated as part of a standard approach for pollution control to restore water quality. In principle, TMDLs identify the maximum levels of pollutants that water bodies can receive before the designated uses of the water bodies are compromised (e.g., drinking water or aquatic habitat). A management plan for restoring water quality can use TMDLs by allocating the permitted load among sources of pollutants. The USGAO is critical of the TMDL program, citing its lack of effectiveness in the control of NPS pollution (USGAO, 2013). The US water policy community considers this issue to be of vital importance (e.g., American Water Blog, 2014). Karr and Yoder (2004) believe an integrated view of ecosystem stressors combined with a focus on biological endpoints will improve TMDLs. Swanson et al. (2017) show that focusing on the drivers of ecosystem function is more encompassing and can identify the causes of impairment.

Hall et al. (2014a) demonstrated an alternative approach to NPS pollution control using the restoration of ecosystem function. They investigated water quality impairment in Nevada's Upper Reese River (Figure 5) with the PFC protocol, water quality data, and remotely-sensed imagery. These tools and data permit an analysis of sediment in terms of its sources, transport, distribution, and impact on water quality and aquatic resources. Managers in the Upper Reese River watershed are concerned about water quality and loss of fish habitat in conjunction with increases in sediment and temperature extremes. One benefit of riparian functionality is quality habitat for local populations of Lahontan Cutthroat Trout and Sage Grouse.

TMDL-based management goals for the Upper Reese River and its tributaries are to estimate how much sediment, nutrients, and heat can be delivered into these waters while they remain within the bounds of Nevada's water quality standards. Even if exceeding ecological thresholds is a concern only because of pollution loads, then management focus on the traditional TMDL approach would not have been effective. However, because meeting water quality objectives often depends on integrated riparian management, water quality management should address ecosystem function.

The structure of the Upper Reese River watershed reflects the history of the western expansion of US settlement since the 1880s. Grazing and farming without controls led to the losses of upland and wetland plant populations and the invasion of shrubs into wetland areas. As the river channel became incised, the addition of diversion dams resulted in straightening of the river, concentrating flows through a smaller opening, and accelerating channel erosion. Four sample reaches were selected for PFC assessment to represent different ecological conditions (Figure 5). Two reaches were Nonfunctional and two reaches were Functional – At Risk. Recovery of this watershed and many others depends on floodplain access, dissipation of flood energy, and aquifer recharge to maintain soil water needed for vegetation stabilizing stream banks. In 2007, stakeholders and managers in the Upper Reese River watershed used this PFC assessment (Hall et al., 2014a) to begin planning to reconnect the river to the original floodplain surface with the goal of recovering its ecological goods and services.

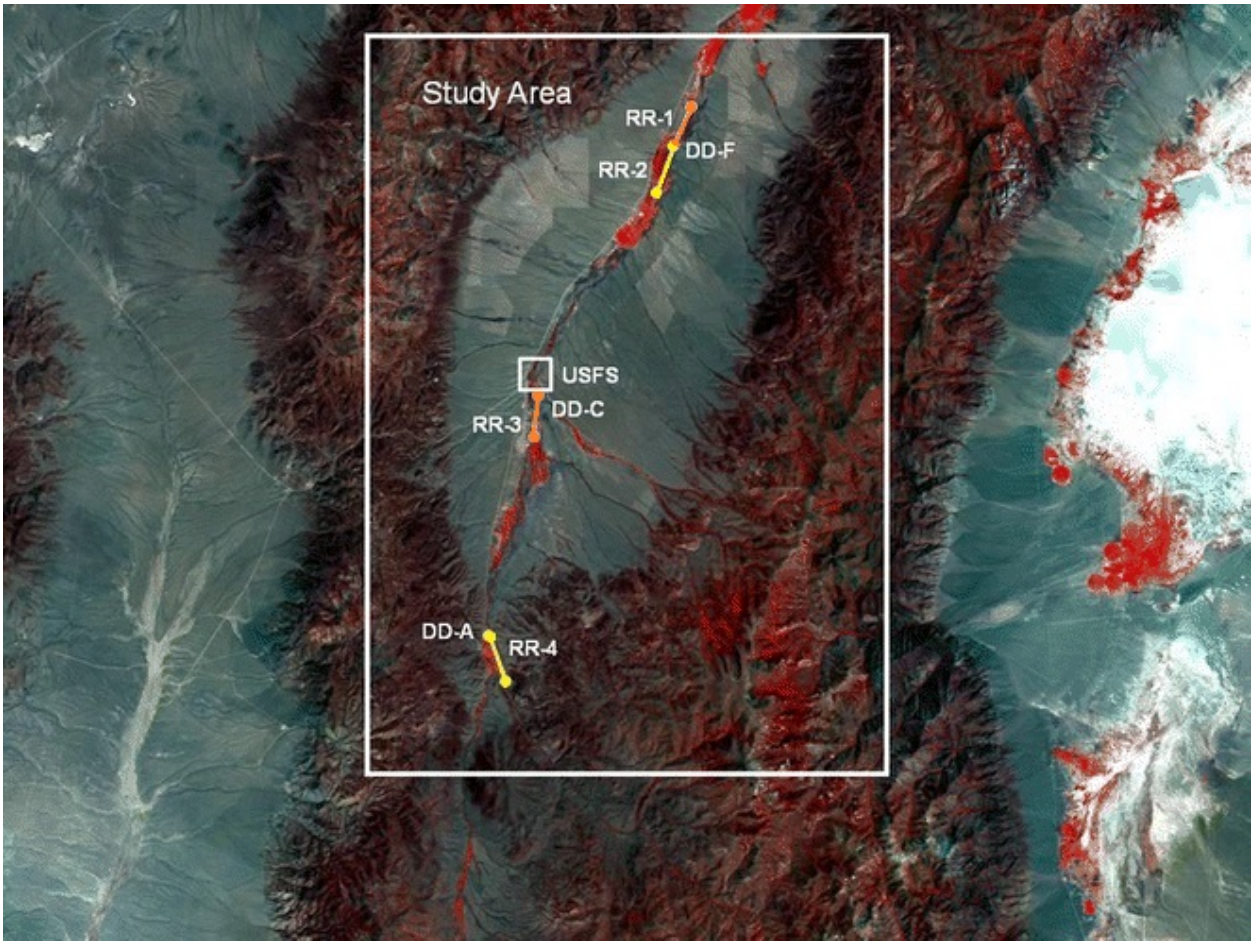

Figure 5. Location map of Upper Reese River Basin assessment reaches (RR-1, RR-2, RR-3 and RR-4). Diversion dams are marked (DD-A, DD-C and DD-F). Center box designates the US Forest Service property. Landsat image is from July 2000. Reaches RR-1 and RR-3 were assessed as Nonfunctional. Reaches RR-2 and RR-4 were assessed as Functional at Risk. Source: Hall et al., 2014a.

2.2 Conserving and Restoring Ecosystem Services.

The PFC protocol is useful for identifying and protecting healthy watersheds with the aim of conserving and restoring ecosystem services. The PFC assessment of the Colquitz River watershed on Vancouver Island in British Columbia (Canada) provides an example (Buchanan et al., 2009) (Figure 6). This watershed in the District of Saanich is affected by encroaching urbanization as well as by some agriculture and industry. The District of Saanich began a program of land acquisition and protection in the 1970s but that was not sufficient to restore Colquitz River to its functional status. The District of Saanich wants to rehabilitate the stream with an interest in restoring salmon runs where possible. The purposes of the PFC assessment were to generate information for setting priorities for different stages of the restoration and to establish a baseline for measuring progress.

Over 18 kilometers of stream channel in 59 reaches were assessed in the summer of 2007 (Buchanan et al., 2009). About 37% were Nonfunctional and 45% were in PFC (Figure 6). The remaining 18% were Functional – At Risk, some with a downward trend, some with an upward trend and some with no apparent trend. The Functional – At Risk category has the highest priority for restoration because functions could be lost or could help with remediation processes. Two of the most critical recommendations were to deal with head cuts (abrupt changes in the profile of the stream channel) from stream incision and remove specific invasive plant species (Buchanan et al., 2009). The incision from headward migration of head cuts suddenly removes existing functions and sets in motion a long process of accelerated bed and bank erosion, sedimentation, and eventual recovery through the gully evolution process (Schumm et al., 1984; Simon and Rinaldi, 2006). General recommendations include integrated watershed management for multiple land-use values and best management practices for storm water to reduce the volume of runoff.

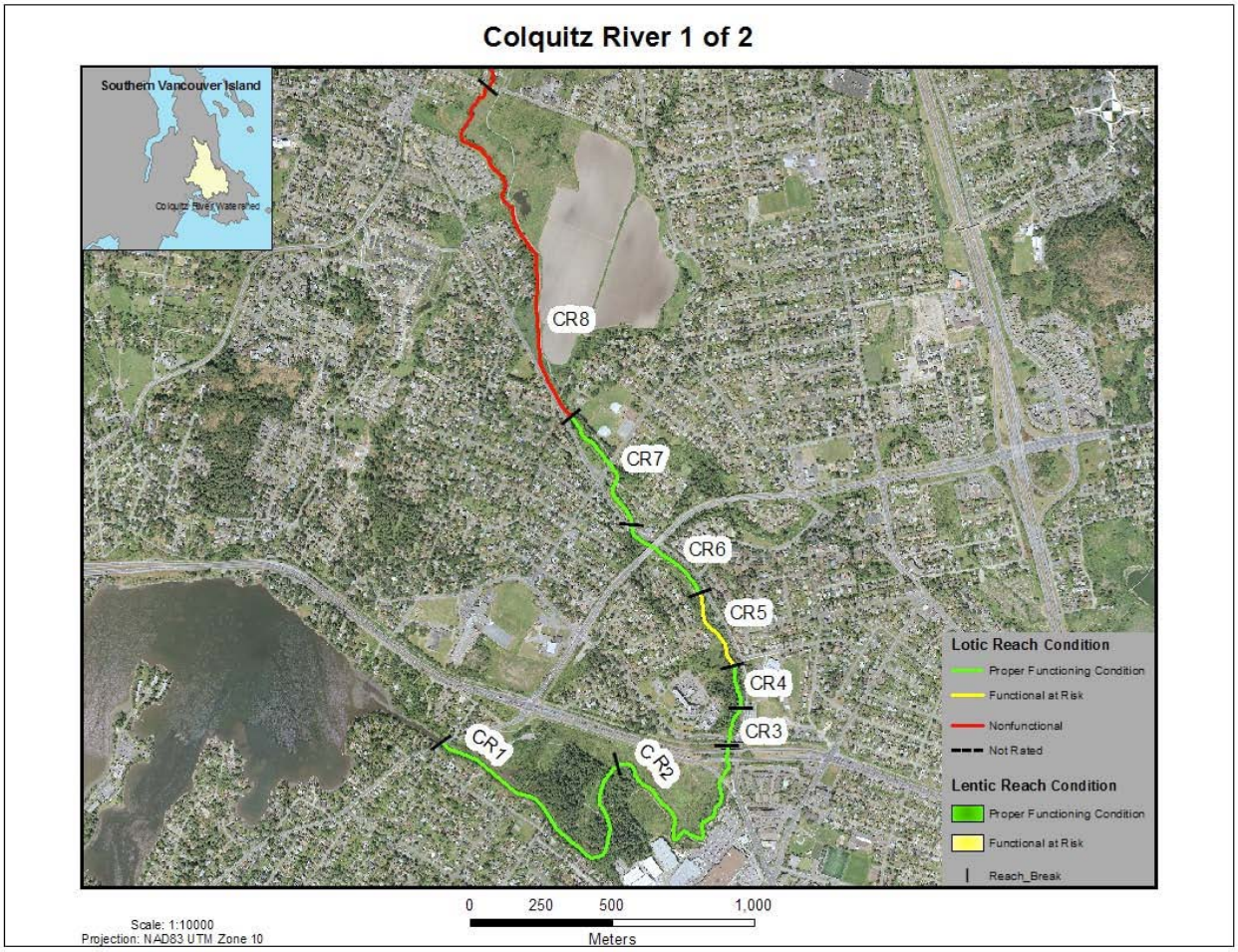

Figure 6. Map showing Colquitz River - Vancouver Island in British Columbia (Canada) with the lower reach breaks used for the PFC assessment. Source: Buchanan et al., 2009.

PFC assessments are also being used by US agencies for water quality management. Financial assistance from the USDA NRCS National Water Quality Initiative supported a riparian function assessment of the South Fork of the Humboldt River in Nevada that identified source areas of NPS pollution and prioritized areas for remediation (Aron et al., 2013). The joint effort was conducted by NRCS, the University of Nevada at Reno, Nevada Department of Wildlife, private and tribal ranchers, BLM, and USEPA Region IX (Pacific Southwest).

A new proposed agreement among Klamath tribes, USDOI, Oregon officials and Upper Klamath irrigators provides solutions for water use that support a stable agricultural economy as well as healthy fisheries and riparian areas (Klamath Basin Task Force, 2014). The use of PFC and riparian restoration played a role in the agreement.

2.3 Protecting the Source.

The general approach for protecting drinking water is one of using multiple barriers. USEPA's manual on assessing source water protection aims at protecting raw sources of drinking water from potential stressors in compliance with the Safe Drinking Water Act and state laws (USEPA, 2006). USEPA supported the development of a handbook on using land conservation to protect drinking water supplies (Trust for Public Land, 2005), elements of which were brought into a subsequent report on healthy watersheds (USEPA, 2012a). Key aspects are building cooperative partnerships, selecting lands to protect and managing those lands. The handbook's recommendations incorporate some concepts of ecosystem function in its section on pollutant mitigation potential by ecosystem (Trust for Public Land, 2005). This section, which was influenced by a national study showing the importance of restoration and protection of riparian zones (NRC, 2002), refers to practices advised by USDA NRCS on the width of buffer strips around riparian zones for maximum removal of pollutants. However, these recommendations do not include the use of ecosystem function assessment as shown in the examples of Section 2.1 and Section 2.

Stewardship of protected watersheds may require a more extensive assessment of ecosystem function to obtain a full picture of threats to the watershed. For example, the width of riparian buffer strips is not an adequate substitute for PFC assessment where most pollution comes from eroding stream banks or where opportunities for riparian function restoration are covered by stream bank revetment (artificial structures placed on top of the soil). Watershed protection can benefit from using the assessment of ecosystem function to identify early warning signs of degradation. Watershed surveillance is important since even small changes in land use can affect the quality of water resources, as shown in a landscape assessment for the New York City water supply (Mehaffey et al., 2001) (New York City Department of Environmental Protection. 2011).

The use of PFC assessment for the Cold Creek, Nevada watershed (Figure 7) illustrates how ecosystem function assessment can help to protect the source of drinking water (Hall et al., 2014b). If the Cold Creek watershed is not functioning properly (Figure 8), it is likely to experience erosion that causes head cuts that move upstream. This process threatens the structure of the spring that feeds the headwaters of Cold Creek. This spring is the ultimate source of drinking water for households in this community, which typically use wells to access groundwater that is connected to the creek and is affected by the condition of the creek.

The PFC assessment of Cold Creek was conducted jointly by US Forest Service, USEPA, BLM and University of Nevada, Reno, scientists to better understand problems and find solutions (Hall et al., 2014b). According to the PFC assessment, feral/wild horse activity and urbanization in the upland and upstream areas were contributing to stream and riparian degradation. Recommendations to deal with this problem involved education of the community, protection of creek banks, improvement of riparian vegetation (managing horses and wildlife and/or re-vegetation), and restoration and maintenance of hydrologic connectivity of streams, meadows, and wetlands.

Figure 7. Satellite Image of the Lotic (Stream) Field Study Site, Cold Creek Nevada, 2014. Source: Hall et al., 2014b.

Restoration of PFC must be coupled, however, with other pollution prevention programs to protect drinking water in the Cold Creek watershed. Wild horses and a variety of wildlife coming into contact with the creek can contaminate it with pathogens. Solutions to prevent or limit contact, such as a watering trough behind a fence that keeps animals away from the riparian area, may contribute to the restoration of the riparian function while they prevent pathogenic contamination. Another potential threat to water quality is leakage from household septic tanks, a traditional point source of pollution. USEPA and tribes have been developing plans for septic remediation, maintenance, and replacement.

Figure 8. Cold Creek Upstream view- Nevada, 2014. This reach of Cold Creek was determined to be nonfunctional using PFC. Source: Hall et al., 2014b.

3.0 Comparison with other Ecosystem Protection and Restoration Approaches

The ability of the environment to sustain human health and well-being is a central concern of USEPA, both in the agency and in its Sustainable and Healthy Communities Research Program (SHCRP) (USEPA, 2010a; USEPA, 2012b). How to protect and restore ecosystems to provide benefits to human communities, such as flood mitigation and water filtration, is a subject of great interest. This interest has led to a whole-hearted adoption of ecosystem services at the agency where a variety of approaches have been taken. The concepts of ecosystem service and ecosystem function serve different purposes in a combined effort for ecosystem protection and restoration.

The concept of ecosystem service is better known, but these two concepts are often informally used as synonyms, obscuring their scientific meanings. Study of the production, use, and benefits of ecosystem services emphasizes how ecosystems contribute to human health and well-being and how environmental markets and policies can encourage resource conservation. Study of ecosystem function emphasizes the ecosystem structures, processes, and biological communities that underlie ecosystem services. In watershed restoration planning, the functional approach of ecosystem function is gaining acceptance over the beneficial use approach of ecosystem service (Fischenich, 2006). A functional approach permits rapid assessment of alternative restoration designs, analyzes ecosystem processes and identifies the risks and causes of environmental degradation. Although a beneficial use approach may be useful in finding public support, it has drawbacks in the design of watershed restoration because beneficial uses, perceptions, and values change over time and political boundaries (Fischenich, 2006). SHCRP has released the new EnviroAtlas (USEPA, 2014b), which helps communities understand the impact of policy decisions on ecosystem services; the tools for assessment and management of ecosystem function help to find solutions for problems identified by the atlas.

In the complex undertaking of ecosystem restoration, the decision on what to restore has a major impact on effectiveness and sustainability. Changes in the restoration approach for the upper Feather River watershed in the Sierra Nevada in northeastern California illustrate the benefits of switching to the new objective of restoring landscape (ecosystem) function from the old objective of stabilizing banks to reduce erosion (Lindquist and Wilcox, 2000; Kondolf, 2011). The Feather River Coordinated Resource Management Group has been restoring channel, meadow and floodplain systems in the Feather River watershed since 1985 because healthy streams, forests, and meadows are important for their region's environment and economy. Big Flat Meadow in this watershed experienced years of intense grazing, logging, and road-building that resulted in a relocated creek and a deep gully. The initial approach to restoration was bank stabilization to treat erosion and sediment supply. In 1994, the management team shifted its approach to landscape (ecosystem) function, which resulted in the elimination of incised channels and the restoration of remnant channels on the historic floodplain. The hydrologic benefits include a longer period of stream flow, moderation of peak flow events, and increased ground water storage. Restored

meadows in this area also contain twice as much total carbon as degraded (unrestored) meadows (Feather River CRM, Plumas Corporation, 2010).

Human impacts on aquatic ecosystems involve hydrologic connectivity and flow regime (Kondolf et al., 2006), both form and function. However, restoration efforts have more often addressed connectivity than flow dynamics, presumably because of the economic importance of water diversions and flood control (Kondolf et al., 2006). This difficulty in restoring flow is tied to the natural variability in river systems. Channels that can migrate provide a setting for greater ecological structure and variation (Kondolf, 2006). Disturbances caused by flooding play an important role in maintaining biological diversity (Hughes et al., 2006).

4.0 Monitoring and Adaptive Management

Ecosystem resilience is the ability to bounce back from a high energy event and is a central concept in the application of ecosystem function assessments and analysis. A functional ecosystem should be able to withstand major (acute) disturbances and rebound from chronic impacts (e.g., grazing, logging) over time. One of the successes of the CWA is in the prevention of ecological and environmental toxic effects (acute, chronic). However, the policies and WQS that contributed to this success have fallen short in addressing habitat and NPS pollution oriented impairments.

Surveillance for the health impacts of water pollution should be coordinated with pollution control activities. Public health agencies have a strong interest in water pollution as a source of contamination for food and drink. Public health and marine agencies should also collaborate since coastal waters are linked to public health in many ways (NRC, 2014a). Land-based pollution can contaminate coastal waters, leading to beach closures with large economic consequences. There is evidence that runoff contains parasites that pose a danger to humans and animals in the marine environment; the *Toxoplasma gondii* cat parasite has been shown to infect marine mammals (Ham and Schaffer, 2014).

Therefore, the importance of managing by observing ecosystems is key because the loss of ecosystem function physical processes can be gradual and longer term. Modifying actions in response to observed changes is not a new idea. Studies of the TMDL process highlight the role of adaptive implementation (NRC, 2001; USGAO, 2013). Adaptive management is considered essential to planning for water resource projects (NRC, 2004). There are many variations in the structure of adaptive management (NRC, 2004) possible through integrated riparian management by using PFC and then monitoring at-risk reaches to adjust management (Wyman et al., 2006; Kozlowski et al., 2013; Dickard et al., 2015; Swanson et al., 2015; Swanson et al., 2017).

Anthropogenic influences may increase the vulnerability of a watershed to disturbances (USEPA, 2012a) and provide an additional impetus for monitoring and adaptive management. Changes in the natural variability of an ecological characteristic may have adverse impacts. Urbanization generally increases the number and size of storm water runoff events. Climate variability can have broad effects through changing temperature and precipitation regimes. Introduced pollutants, such as pesticides, may be harmful to people, animals, and ecosystem functions. Invasive species, which are widely differing kinds of organisms, can disrupt natural communities with far-reaching environmental and economic consequences. Therefore, 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. When functions decline rapidly, most streams can release a significant portion of NPS pollution. For example, sediment is a major pollutant across the United States (USEPA, 2009) and frequently emerges in conjunction with functional decline. Salt Cedar is an invasive tree species that has spread throughout the western U.S. Asian carp, a group of invasive fish species, has disseminated

northward along the Mississippi River and threatens to become established in the Great Lakes. Whatever the challenge, PFC assessment identifies the steps back toward ecosystem functionality.

5.0 Scientific and Technological Developments

Studies of ecosystem function are connected to other scientific and technological developments. The applications of the work can be extended in several ways.

One priority is studies to identify early indicators of changes in ecosystem function in a wider range of settings. Early indicators give decision-makers an opportunity to be more effective in monitoring and developing adaptive management plans. Management and monitoring can focus on what is needed to address issues identified in PFC assessment. Often recovery begins with improvements in riparian vegetation (Wyman et al., 2006; Swanson et al., 2015). It is also important to analyze the relative effectiveness of an ecosystem function approach to protect and restore healthy watersheds in conjunction with other pollution control efforts to limit the sources of pollutants (e.g., reduce fertilizer use) and limit spread of pollutants in waterways (e.g., place buffers around riparian zones and agricultural fields).

The study of ecosystem function for sustainability of water quality fits within a broader study of sustainability tools and approaches at USEPA (NRC, 2014b). USEPA is organizing metrics for sustainability in the Office of Research and Development (USEPA, 2013b). The use of ecosystem function can be expanded with a connection to sustainability metrics. For example, as drought/flood conditions change the potential impacts to sustainable goods and services (i.e., recharging aquifers; transport of essential nutrients; flood damage) is dependent on ecosystem functional physical processes. At proper functioning condition (PFC) an ecosystem is resilience to almost any perturbation.

There are emerging opportunities to use remotely-sensed imagery to speed up PFC assessments and other ecosystem function assessments. As data become more readily available from hyperspectral imagery allowing species of plants to be distinguished and Light Detection and Radar (LIDAR) for detailed topography such as bank height, they can be used for assessment on a larger spatial scale (Hall et al., 2009). Re-analysis of global Earth science datasets for climate and watershed conditions over the past few decades may permit some indicators of watershed health and flooding to be used for risk analysis leading to risk management through remediation of impaired functions (Earth Science Information Partnership, 2014; Federal Big Data Working Group, 2014).

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6.0 Partnerships Needed

Sustainability of water quality requires partnerships between the water quality community and efforts to maintain and restore sustainable natural resources in watersheds, riparian areas, and aquatic and coastal ecosystems. It is crucial to have communication and collaboration not only across agencies at the federal, state, local and tribal levels but also with local landowners and land users. The nature of this work crosses over lines demarcating academic disciplines.

USEPA has articulated the need for integration across CWA programs, all USEPA statutory programs, and the water quality programs of other federal agencies in its long-term vision for assessment, restoration and protection under the CWA Section 303(d) program for impaired waters (USEPA, 2013c). This nonbinding document emphasizes that states have flexibility in using alternatives to TMDLs. Despite common needs and interests, however, mandates for agencies at federal and other levels limit how well agencies can work together. Federal mandates even affect collaboration across different statutory programs at USEPA (CWA, Clean Air Act, Comprehensive Environmental Response, Compensation and Liability Act [Superfund], etc.). It is a great challenge to establish formal cooperation between agencies, especially for the periods of time required for management of ecosystem function and NPS pollution control. BLM and the Montana Department of Environmental Quality provide an example of a successful partnership to produce high-quality waters by focusing on the strengths of their respective agencies. Several items in this partnership address restoring and maintaining watershed function. This partnership was expanded to include cooperative water quality monitoring that meets the needs of both agencies (Aron et al., 2013). McKinney and Harmon (2004) underscore the importance of collaborative leadership in managing natural resources.

Engagement with clean water groups can advance the application of new approaches. The U.S. Water Alliance (formerly Clean Water America Alliance) unifies several activities in the One Water Management Network (U.S. Water Alliance, 2014). Three related associations are the National Association of Clean Water Agencies that heads the Healthy Water Coalition, the Association of Clean Water Administrators that represents the state and interstate water managers and the Association of State Drinking Water Administrators that represents their drinking water counterparts. The IJC is interested in related impacts on the Great Lakes. Another partner is the Urban Waters Learning Network, a peer-to-peer network of people and organizations that share practical on-the-ground experiences to improve urban waterways and revitalize the neighborhoods around them. The network is a partnership between Groundwork USA & River Network, and funding by USEPA. http://www.urbanwaterslearningnetwork.org/.

Land management agencies are important partners. BLM is a leader in applications of riparian function and has been in close collaboration on USEPA projects. The USDA NRCS is critical for dealing with the agricultural sector and has a new structure for its programs under the Regional Conservation Partnerships Program in the 2014 Farm Bill. In addition, the participation

of local landowners and land users is essential.

Land-based sources are the major sources of pollution in the marine environment, affecting aquaculture, marine sanctuaries, fisheries, and desalination. Surveillance of coastal impacts should be coordinated with pollution control activities. The US National Oceanic and Atmospheric Administration (NOAA) is the key marine agency. NOAA has an Office of Aquaculture, an Office of National Marine Sanctuaries, and a Coastal Services Center. The IJC is interested in related impacts on the Great Lakes.

7.0 Conclusion

Watershed assessments of ecosystem functions provides alternative approaches for addressing NPS pollution and planning associated with TMDLs (Houck 1999; Park et al. 2011). Objective is to implement a watershed management plan that will maintain and/or improve ecological resilience. Resilience contributes to a larger picture connecting social, ecological and health concerns in a watershed (Bunch et al. 2014). The US Environmental Protection Agency (USEPA) recently articulated a new long-term vision for assessment, restoration and protection under the Clean Water Act (CWA) Section 303(d) program for impaired waters (USEPA 2013a). This vision does not reflect new regulations or legislation but rather allows USEPA, states and stakeholders greater flexibility in devising strategies to achieve water quality goals using alternative restoration and protection approaches. Such flexibility permits the application of ecosystem knowledge from decades of restoration experience to address the persistent problem of polluted runoff entering water bodies (USEPA 2013b) and the majority of water quality impairments are now caused by diffuse nonpoint source (NPS) pollutants, such as sediment, nitrogen, phosphorus and pathogens, that move across the landscape before being deposited into water bodies (e.g., US General Accountability Office [GAO] 2013).

This work on ecosystem function can be used more widely to help USEPA and the nation manage ecological processes that underlie sustainability of water quality. The aim is to transfer experience from using ecosystem function for ecosystem restoration and apply it to the control of stressors, particularly NPS pollutants. Sustainability associated with resilient ecosystems is linked to the control of NPS pollutants, such as sediment, nitrogen, phosphorus, and pathogens, which are the primary causes of water quality impairments in the United States. This report has shown how the assessment of ecosystem function can be utilized under the CWA in the development of an alternative to the traditional permit and chemical centric TMDL approach for restoring water quality. Examples have shown how assessments for ecosystem function can be used to restore salmon runs in Vancouver Island in British Columbia and to protect a drinking water source threatened by erosion in Cold Creek, Nevada. To be optimally effective, assessment of ecosystem function should be followed by analysis of assessment information to identify priority locations for remediation. The science of ecosystem function is ready for application to necessary investments in water and sanitation infrastructure and it can satisfy the growing demand to couple these projects with conservation of natural resources and integration of natural “green” ecosystems within the built environment.

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9.0 Quality Assurance Summary

A Quality Assurance Project Plan (QAPP) was used for this work entitled, "Ecosystem Service Protection to Improve Tribal Well-Being Proper Functioning Conditions (PFC) Assessing Ecological Function using EMAP, State and Tribal Water Quality and Biological Data, and Satellite and Aerial Imagery using PFC Protocol", approved on December 15, 2015, QA DCN D-SED-EIB-007-QAPP-01. This Report does not include environmental data collected by the USEPA. Laboratory Notebooks were reviewed by the System Exposure Division management and Quality Assurance Manager annually. There were no findings requiring corrective actions. There were no deviations to methods or general or specific limitation on the use of the results.

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