United States
Environmental Protection
Agency

ENVIRONMENTAL RESEARCH BRIEF

Green Island and the Hyporheic Zone: Why Restoration Matters

Laura A. Hockenbury[1], Barton R. Faulkner[2], Kenneth J. Forshay[2], J. Renée Brooks[3]

Abstract:

Large river floodplains present diverse benefits to communities, yet management strategies often fail to consider the broad suite of ecosystem services they provide. The U.S. Environmental Protection Agency (EPA) is evaluating the benefits associated with restoring large river floodplains, with emphasis on the benefits of levee setbacks and revetment removals. This effort will provide scientific support for community-based environmental decision making within our study area on the McKenzie River, a tributary to the Willamette River in Oregon, and support emerging restoration efforts along the Yakima River in Yakima, Washington, and across the nation. The EPA is working with the McKenzie River Trust, the City of Yakima, and the Washington Department of Transportation to bring a more holistic approach to enhance sustainability, with consideration of the ecosystem services offered by dynamic river systems. Restoring hydrologic connectivity in floodplains can enhance the overall ecological condition of riparian systems. We have examined groundwater flow patterns, denitrification rates, and water isotopic signatures for identifying water sources at Green Island, a 1,100 acre restoration effort located at the

[1] *U.S. Environmental Protection Agency, Region 10, Seattle, WA 98101, United States*

[2] *U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Ada, OK 74820, United States*

[3] *U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, Corvallis, OR 97333 United States*

confluence of the McKenzie and Willamette Rivers in order to identify specific benefits of increased hydrologic connectivity. The Yakima River, which winds through a highly productive agricultural valley, has been identified as having high potential for successful restoration and increased floodplain connectivity. The EPA is undergoing research to assess groundwater flow and denitrification rates occurring within the Yakima River floodplain. With these two case studies, the EPA will present a scientific review of the issues and benefits associated with restoring large river floodplains through levee setback and the influence of hydrologic connectivity.

Introduction

The Willamette River is the 13th largest river in the conterminous U.S. and produces more runoff per unit of land area than any of the larger rivers (Hulse et al., 2002). Dams and other human modifications of the river network have contributed to the decline of native fish populations, in particular salmon (Rathert et al., 1999). Green Island is at the confluence of the McKenzie River and Willamette River north of Eugene, Oregon (McKenzie River Trust, 2013). The Green Island section along the Willamette is unique in that it closely resembles natural stream conditions and natural riparian forest development in the central valley. At 1,100 acres, Green Island is the largest protected property managed by the McKenzie River Trust and presents one of the best remaining opportunities within the Willamette Valley for preserving and restoring a dynamic and ecologically diverse river system. Since 2007, more than 5,600 feet of levees have been removed from the Island, over 100,000 native trees and shrubs have been planted on the property, and 475 acres have been converted from agriculture fields to floodplain forest (McKenzie River Trust, 2013). In July-August of 2008, the EPA installed 50 shallow (~30 feet deep) groundwater monitoring wells on the Green Island site in locations ranging from young to old riparian systems, to agricultural areas of the island still protected by levees.

The goal of installing groundwater monitoring wells was to examine the sustainability and efficacy of the extensive restoration efforts occurring on Green Island. The McKenzie River Trust's goal for Green Island is to create a robust ecosystem composed of a rich mosaic of historic floodplain habitat types, through cooperative partnerships dedicated to innovative, flexible and adaptive management (McKenzie River Trust, 2013). Through a combination of field and lab studies measuring biogeochemistry, we are evaluating effects of floodplain restoration on nitrogen retention, ***hydraulic connectivity***, and water quality, as well as quantifying the benefits of ecosystem services created by best management practices (BMP's). There are few to no evaluations of the suite of ecosystem services or effects of best management practices on nitrogen in literature (Forshay and Dodson, 2011). Our Willamette Ecosystem Services Project at Green Island will help identify floodplain habitats and processes that enhance denitrification; assess biogeochemical benefits of restoring floodplains; develop sustainable practices to retain nitrogen; and estimate the nitrogen-removing ecosystem services provided by floodplains in large river corridors of the Pacific Northwest.

Our Research

At Green Island, the EPA has focused on three components of water quality: identifying source water, modeling near channel (hyporheic) connectivity, and assessing rates and drivers of nitrogen processing. This combination details an overall story of where the water is coming from, where it is going, how it changes in the floodplain, and the potential benefits provided. Here, we review each approach and the current results.

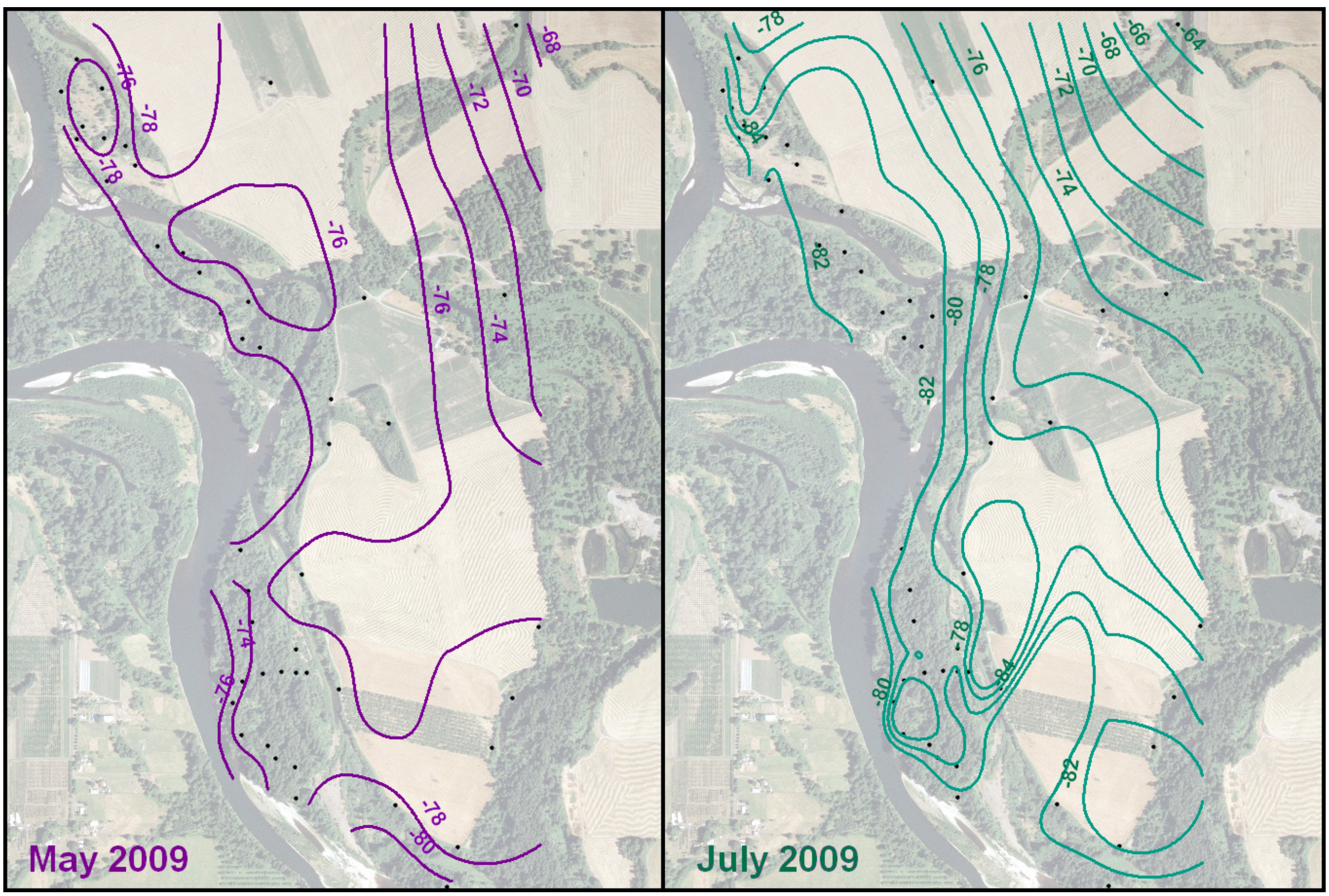
Source water

By looking at variation in stable isotope composition of river water, we can determine the source water for the Willamette and McKenzie Rivers. Due to the rainout effect or ***Rayleigh fractionation***, as weather systems move inland, heavier water isotopes, expressed as relative concentration of deuterium (δ^2H) in water, will preferentially form water droplets and become precipitation (Brooks et. al, 2012). By the time the system reaches higher elevations and mountain ranges, the remaining precipitation occurs as much lighter water isotopes. Thus, we are able to track the mean elevation of the source water based on the isotopic signature.

Source water for the Willamette has a distinct seasonal pattern in regards to elevation. There are three major hydrologic zones in the Willamette separated by elevation: valley floor (<200 m), low mountains of the Western Cascades (200-1200 m), and the snow zone (>1200 m). River isotope values are lowest/lighter during the dry summer months and highest/heavier during February to March. During the dry summer, source water is primarily from a higher elevation, principally snow melt. During the wet season, source water is also influenced by valley floor or low mountain precipitation. While the snow zone only accounts for 12% of the land area and receives 15% of the overall precipitation, it makes up 60-80% of the Willamette flow during the summer. These findings highlight the vulnerability of flow in the Willamette to the influence of a warming climate on snowpack (Brooks et al., 2012). The elevation difference between source water for the river and local precipitation means that we can use water isotopes to detect the proportion of river water versus local precipitation contributions to the groundwater on Green Island.

Groundwater

But where does this water go? How does it interact with the surrounding floodplain? Green Island is a river system with a greater amount of naturally influenced landscape as compared to rivers with river bank ***armoring***. Because of this, Green Island hydrology is considered to be well connected—i.e., the river and the floodplain have a greater rate of interaction. Well connected floodplains may offer significant benefits to river water quality. Specifically, the ***hyporheic*** zone may play a substantial role in denitrification enhancement, water temperature buffering, and riverbank filtration (Faulkner et al., 2012). The hyporheic zone is defined broadly as the zone of exchange between surface water (i.e.



Isoscapes for hyporheic zone δ^2H ratios for May and for July 2009 the river) and subsurface flow (i.e., groundwater) (Faulkner et al., 2012). In these zones, water flows under and adjacent to river channels where streamwater and groundwater meet. Hyporheic zones are ecotones and create a rich ecological interface.

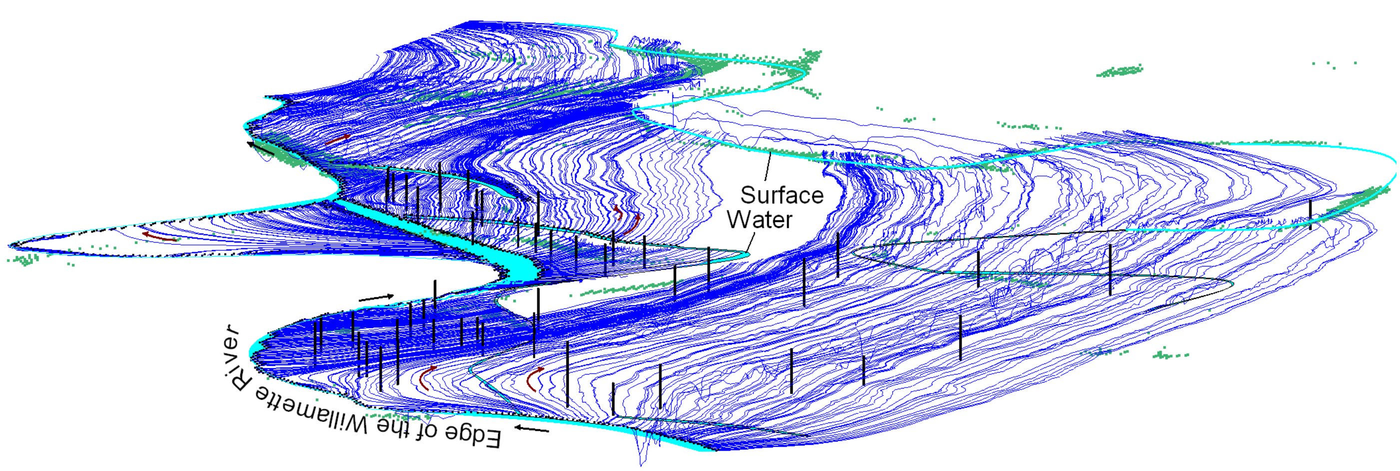
We found that in May, 2009 at the tail end of the wet season, δ^2H is higher and relatively well-mixed due to increase hyporheic flow, while in July it was lighter, with the isolines bunched, indicating greater heterogeneity and influence from surrounding lower valley groundwater areas.

If we could see hyporheic flow in the floodplain landscape. This image shows the subsurface pathlines from a groundwater flow model based on hydraulic measurements in wells. Flow originates at the black cells along the Willamette River's edge as well as the edges of its tributaries and alcoves, and then moves laterally into and beneath the riverbanks. The green cells show areas where hyporheic water and other groundwater emerge in connected cutoffs and alcoves for the naturally meandering river system.

Our model indicates that during the dry season, hyporheic flow along the Willamette River moves primarily parallel to the main river channel (Faulkner et al., 2012). During the wet season, water moves laterally away from the river through the hyporheic zone, with deeper infiltration into the underlying aquifer of groundwater. This groundwater-surface water interaction indicates connectivity and river dynamism, traits associated with increased ecological functional hyporheic zones. Since the levees were removed at Green Island, this reach of the river can be a cross-connecting more complex network of channels with greater interaction of surface water with hyporheic zones through subsurface pathlines. These results, along with our stable isotope results, imply that in the warm summer months, hyporheic flow plays an important role in regulating the near-river groundwater environment. It allows us to lay out a framework for evaluating the potential water quality benefits, such as nitrogen reduction due to denitrification and water cooling due to heat dissipation along these subsurface pathlines. Although not discussed further here, this latter component of our research is also important and ongoing, since many river ecosystems in the Pacific Northwest are sensitive to temperature increase, which may be mitigated by hyporheic flows (Faulkner et al., 2012).

Ecosystems and Denitrification

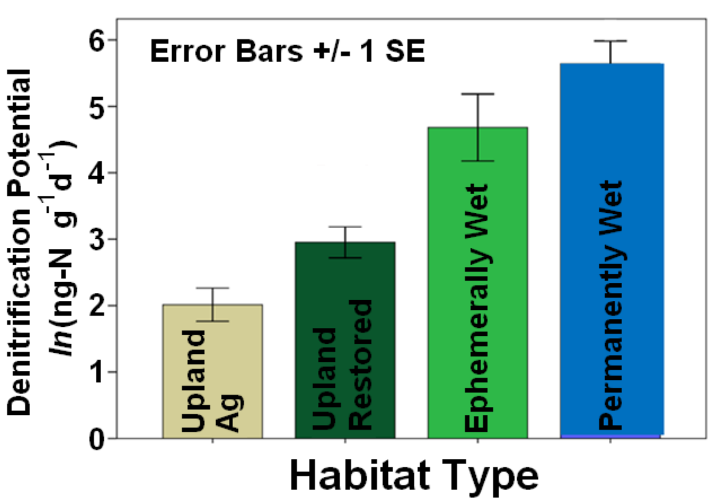
The main focus of our research is on the potential benefits provided by the hyporheic zone, with a specific lens on the hyporheic zone's potential to be a nitrate sink. Nitrate is a naturally occurring oxide of nitrogen, an essential component of all living things, a primary source of nitrogen for plants, and a pollutant (Steward, 2012). When concentrations of nitrogen get too high in a system, it can lead to adverse consequences for ecosystems and human health. High levels of nitrate can result in eutrophication, lower quality drinking water, toxic algal blooms, fish kills, and a variety of other negative effects (Fewtrell, 2004). Health risks to humans include



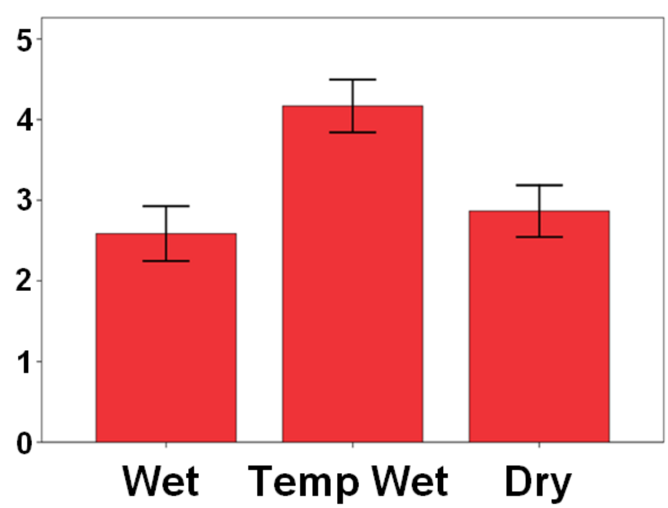
blue baby syndrome (methaemoglobinemia), where nitrate interferes with the ability of blood to carry oxygen to vital tissues in infants six months old or younger. Drinking water that is treated chemically to remove algae (e.g, from algal blooms present in the source water) may contain elevated levels of disinfection by-products which have been linked to increased cancer and reproductive health risks as well as liver, kidney and central nervous system problems (Hans and Scott, 2010). Sources of high levels of nitrogen include fertilizers, septic systems, wastewater treatment seepage, animal wastes, industrial wastes, and food processing (Fenn et al., 1998).

At Green Island, we presume that nitrogen primarily enters the system from agricultural sources. Since agricultural application of nitrogen fertilizer is a common practice, the solution to nitrogen pollution requires a multi-part, all-inclusive approach that can help reduce nitrogen pollution. For example, in addition to managing fertilizer use, there is evidence that nitrogen management should focus on restoration of streams, because greater stream surface area-to-volume of water ratios (i.e. increasing the size and connectivity of the floodplain) favors nitrate uptake (Forshay and Dodson, 2011).

Microbial communities consume and transform nutrients by processes such as denitrification. In particular, these processes are enhanced by the cycling of surface water and groundwater. This cycling provides the medium for dissolved components (oxygen, nutrients, and pollutants) to make direct contact with carbon sources, microbial communities, and both oxidative and high reducing biogeochemical conditions (Hester and Gooseff, 2010). We have observed that low elevation and hydrologic connection increases potential for microbial processes and biogeochemical reactions. In addition, the increased residence time of water and solutes in the porous media of the hyporheic zone increases the potential for microbial processes and biogeochemical reactions to occur relative to the water moving in the stream channel above (Hancock et al., 2005; Baker et al., 2000). Thus, when greater river connectivity is developed, for example through restoration of side channels or removal of levees and armoring, it allows for larger floodplains and consequently larger hyporheic zone surface area, in turn creating greater fish and microbial habitat, nutrient cycling and nitrate removal. Coupled with denitrification benefits, the hyporheic zone supports stream ecosystem functions for biota—such as providing a refuge zone from high flows for aquatic life, providing a habitat away from predators, and housing organisms responsible for biogeochemical cycling (Fischer et al., 2005).This floodplain hyporheic ecotone is often overlooked



Surface denitrification rates in different habitats of floodplain.



Surface denitrification rates below different habitats of floodplain.

in restoration strategies, yet has potential to be a cornerstone of holistic ecosystem restoration in floodplain areas where nitrate concentrations pose problems.

Take-home story about Green Island

Our research shows that the floodplain at Green Island is well-connected with the river, showing distinct flow path changes based on seasonal variation. Within this well functioning ecotone proximal to the floodplain, there is

- more microbial habitat
- increasing the potential for denitrification

The hyporheic zone is beneficial for the entire ecosystem, providing

- increased habitat
- enhanced nutrient cycling
- pollutant buffering, and
- temperature regulation.

The hyporheic zone's ability to produce cold water refuges during warm water times of the year is particularly important, as this directly enhances habitat for aquatic life, in particular increasing salmon habitat (Weston, 1998). Given this wide range of ecosystem services ranging from improved physical, chemical, and thermal conditions along the river, which translate to improved habitat, greater nutrient cycling, measureable pollutant buffering, and significant temperature regulation, it is beneficial to restore and maintain the Green Island hyporheic zone.

Larger Scope: EPA intentions

Green Island

Because we examined the connectivity and potential for nutrient processing, our research at Green Island sets the stage for highlighting the capabilities of a restored, more naturally functioning floodplain. This can be applied at similar locations on the Willamette River. The main intention of river restoration is to reestablish the ecological integrity of a river as judged by the ability of the river to self-sustain ecological functions, species and processes (Whol et al., 2005). Restoration efforts focus on recreating "natural" rates of specific ecological, biogeophysical, and chemophysical processes, as well as potentially replacing damaged or missing biotic elements. The core biogeochemical processes of rivers depend upon connectivity and geomorphic setting: water, sediment, organic matter, nutrients and chemicals move from uplands, through tributaries, and across and under floodplains before interacting with the main channel (Whol et al., 2005). Broadening restoration practices to include near-channel processes creates an ecosystem-wide effect, because the hyporheic zone is the critical ecotone linking stream water and groundwater flow. Restoration efforts over time may become a new type of farming of the benthos, microbial films, and hyporheic microscopic communities, with stewards managing the land and supporting self-sufficient sustainable resources resulting in clean water, salmon and wildlife populations, esthetic pleasure—on a timescale surpassing generations.

Our research develops the scientific underpinnings of restoration efforts, by measuring benefits beyond those normally associated with healthy, dynamic river ecosystems. The research that we are conducting at Green Island is part of a broader project examining large river floodplains in the Pacific Northwest and the ecosystem services that they, and restoration projects in them, can provide. The EPA is attempting to create a framework for an ecological understanding of restoration outcomes. The expansive goal of this research is to create a more holistic approach to regulation that includes industry, land trusts, and local community involvement to protect the nation's water quality. A comparison site is based along the Yakima River, located in a highly agricultural valley in south-eastern Washington.

Yakima Basin, Washington

Built over the course of the last century, large protective levees near the Yakima River disconnect the floodplain from the main river channel and contribute to loss of salmon spawning and rearing habitat. The Gap-to-Gap reach of the Yakima (from the Selah gap to Union Gap) was identified as having the most potential for successful restoration

as well as beneficial, community wide ecosystem services (Stanford et al., 2002; Hilldale and Godaire, 2010). While Green Island is an active, developed restoration project, the Yakima River is still confined— particularly in the Gap-to-Gap reach, but a local consortium has received funding to set levees back and re-establish floodplains. Work performed in this project will establish baseline measures of floodplain indicators on ecosystem services "pre-restoration", or prior to levee breach. Monitoring sites will be established along and through levee setback locations, incorporating existing monitoring wells established by local municipalities and government agencies as well. In conclusion, Green Island acts an example of the potential benefits of restoring the Yakima River and other locations on the Willamette River. The ultimate goal is to create support for river restoration practices as a whole, so the EPA can bring a more holistic approach to regulation.

Literature Cited

Baker, M.A.; Dahm, C.N.; Valett, H.M. (2000). "Anoxia, anaerobic metabolism and biogeochemistry of the stream-water—groundwater interface. (In) Jones, J.B. Jr., and Mulholland, P.J. (Eds.), *Surface-Subsurface Interactions in Stream Ecosystems.* Pages 259—283. Elsevier, Inc.

Brooks, J.R.; Wigington, P. J. Jr.; Phillips, D. L.; Comeleo, R.; Coulombe, R. (2012). "Willamette River Basin surface water isoscape ($\delta^{18}O$ and $\delta^{2}H$): temporal changes of source water within the river." *Ecosphere* 3(5):39. http://dx.doi.org/10.1890/ES11-00338.1

Faulkner, B. R.; Brooks, J. R. ; Forshay, K. J.; Cline, S. P. (2012). "Hyporheic Flow Patterns in relation to large river floodplain attributes." *Journal of Hydrology,* 448-449: 161-173.

Fenn, M.E.; Poth, M.A.; Aber, J.D.; Baron, J.S.; Bormann, B.T.; Johnson, D.W.; Lemly, A.D.; McNulty, S.G.; Ryan, D.F.; and Stottlemyer R.

(1998). "Nitrogen excess in North American ecosystems: predisposing factors, ecosystem responses, and management strategies." *Ecological Applications* 8:706-733. http://dx.doi.org/10.1890/1051-0761(1998)008[0706:NEINAE]2.0.CO;2

Fewtrell, L. 2004. "Drinking-Water Nitrate, Methemoglobinemia, and Global Burden of Disease: A Discussion." *Environmental Health Perspectives.* 112, 14.

Fischer, H.; Kloep, F.; Wilzcek, S.; Pusch, M.T. (2005). "A river's liver—microbial processes within the hyporheic zone of a large lowland river." *Biogeochemistry* 16:349-371.

Forshay, K. J. and Dodson, S. I. (2011). "Macrophyte presence is an indicator of enhanced denitrification and nitrificiation in sediments of a temperate restored agricultural stream." *Hydrobiologia*, 668:21-34.

Hancock, P.J.; Boulton, A.J.; and Humphreys, W.F. (2005). "Aquifers and hyporheic zones: Towards an ecological understanding of groundwater." *Hydrogeology Journal* 13(1), 98-111.

Hans, P.W.; Scott, J.T. (2010). "Throwing Fuel on the Fire: Synergistic Effects of Excessive Nitrogen Inputs and Global Warming on Harmful Algal Blooms." *Environmental Science and Technology.* 44, 77556-7758.

Hester, E. T. and Gooseff, M. N. (2010). "Moving Beyond the Banks: Hyporheic Restoration is Fundamental to Restoring Ecological Services and Functions of Streams." *Environmental Science and Technology,* 44:1521-1525.

Hilldale, R. and Godaire, J. (2010). "Yakima River Geomorphology and Sediment Transport Study: Gap to Gap Reach, Yakima, WA, Technical Report No. SRH-2010-09". US Department of the Interior Bureau of Reclamation.

Hulse, D.; Gregory, S.; Baker, J. (2002). Willamette River Basin Atlas: Trajectories of Environmental and Ecological Change. Oregon State University Press.

McKenzie River Trust. "Green Island" http://www.McKenzieriver.org/protected-lands/ownder-properties/green-island/ . Accessed 2013.

Rathert, D., D. White, J. Sifneos, and R. M. Hughes. (1999). Environmental correlates of species richness in Oregon freshwater fishes *Journal of Biogeography* 26:257-73.

Stanford, J.A.; Snyder, E.B.; Lorang, M. N.: Whited, D. C.; Matson, P. L.; and Chaffin, J. L. (2002). " The Reaches Project: Ecological and Geomorphic Studies Supporting Normative Flows in the Yakima River Basin, Washington." US Department of the Interior, Bureau of Reclamation.

Steward, S. (2012). Fact Sheet: Nitrate in Drinking Water. *State of Oregon Department of Environmental Quality.*

Weston, R.F. (1998). Final Report: Groundwater/Surface Water Interactions, Conceptual Models and Assessment Endpoints. USEPA Work Assignment No. 3-353. July 1998.

Whol, E; Angermeier, P.L., Bledsoe, B., Kondolf, M.; MacDonnell, L; Merritt, D.M.; Palmer, M.A.; Poff, N.L; and Tarboton, D. (2005). "River Restoration." *Water Resources Research,* 41, W10301.

Acknowledgements

The authors thank the Board of the McKenzie River Trust and Chris Vogel and Joe Moll of the McKenzie River Trust, Ryan Anderson of the City of Yakima, and Jason Smith of the Washington Department of Transportation for providing access and logistic support for the use of the properties described in this report. We thank Bruce Duncan, David Hulse, Dixon Landers for their input and review comments. Martha Williams (SRA International, Inc.) assisted with final editing and formatting for publication.

Glossary

Armoring- A natural or artificial process where an erosion-resistant layer of relatively large particles is established on the surface of the streambed through the removal of finer particles by stream flow. A properly armored streambed generally resists movement of the bed material at discharges up to approximately "three fourths" bank-full depth.

Biogeochemistry- involves the study of chemical, physical, geological, and biological processes and reactions that govern the composition of the natural environment.

Chemicophysical- of or relating to physics and chemistry,

Confluence- the junction of two rivers.

Ecotone- a transitional zone in which one ecosystem gives way to its neighbor; typically this will be a zone in which elements of both ecosystems are identifiable.

Ecological Entities- A general term that may refer to a species, a group of species, an ecosystem function or characteristic, or a specific habitat. An ecological entity is one component of an assessment endpoint.

Ecosystem Services- humankind benefits from a multitude of resources and processes that are supplied by natural ecosystems; those components of nature that are directly valued by people, or combined with other factors to produce valued goods and services.

Eutrophication- excess richness of nutrients which causes a dense growth of plant life and death of animal life from lack of oxygen.

Hydraulic connectivity- essentially a measure of permeability of a given body of rock with respect to water; a measure of how fast fresh water can move among surface and ground water.

Hydrologic- addresses water occurrence, distribution, movement and balances in an ecosystem.

Hyporheic- Denoting an area or ecosystem beneath the bed of a river or stream that is saturated with water and that supports invertebrate fauna which play a role in the larger ecosystem.

Reach- a continuous extent of water, often a stretch of river between two bends.

Riparian- region of land near the banks of a river.

Piezometer- a small-diameter well specially constructed to measure the head at a specific depth within an aquifer.

Subsurface pathlines- direction of flow of water beneath the ground surface during the course of time.

United States
Environmental Protection
Agency

Please make all necessary changes on the below label, detach or copy, and return to the address in the upper left-hand corner.

If you do not wish to receive these reports CHECK HERE: ☐ detach, or copy this cover, and return to the address in the upper left-hand corner.

PRESORTED STANDARD
POSTAGE & FEES PAID
EPA
PERMIT No. G-35

National Risk Management
Research Laboratory
Cincinnati, OH 45268

Official Business
Penalty for Private Use
$300

EPA/600/F-13/340
August 2014