Watershed Condition Index

Healthy, functioning watersheds are essential for sustaining fish populations as well as fundamental ecosystem services (Potyondy 2011; NFHB 2010). Watersheds in better ecological condition will be more resilient to invasion by non-native species and the effects of climate change (Potyondy 2011; WMI and TRC 2009). An understanding of the current condition of watersheds is important to informing aquatic conservation and restoration planning decisions by identifying where high quality fish habitat exists and where it may be restored with minimal effort. Additionally, an understanding of watershed condition can identify areas of poor habitat quality where long-term investment needs to take place, perhaps because the presence of a unique or endemic fish species.

Our assessment is based on our review of several other regional and national approaches to evaluating watershed condition. Many of these assessments considered a mix of terrestrial, riparian, and aquatic indicators, and relied on a variety of data sources and expert input (Whittier et al. 2010; NFHB 2010; Potyondy and Geier 2011; Gallo et al. 2005; NMFS ETS Division HC Branch 1996). Informed by this work, particularly the U.S. Forest Service Watershed Condition Classification Technical Guide's 12-indicator framework (Potyondy 2011; Potyondy and Geier 2011), we developed a watershed condition classification framework containing common evaluation metrics from these other approaches, and using readily available spatial datasets having full geographic coverage and at the appropriate scale for all sub-basins within our focal area. We developed a watershed condition classification framework using empirical data instead of relying on qualitative, expert opinion data (or a blend of quantitative and qualitative data) as was done for some of the other approaches we evaluated. We believe a fully quantitative approach provides greater transparency, introduces less bias, and can be more readily and easily updated as new datasets become available for watershed condition evaluation metrics. Initially, we had hoped to incorporate data on geology and other factors to incorporate watershed inherent sensitivity to perturbation in our overall condition assessment. The datasets and accepted methods for incorporating watershed inherent sensitivity were not readily available; however, we remain hopeful that future updates to this component of the tool will incorporate this important aspect. Furthermore, we are aware of some datasets that provide important watershed condition evaluation metrics, particularly for stream channel and fish habitat condition (e.g., data and information provided by U.S. Forest Service, Bureau of Land Management, and Oregon Department of Fish and Wildlife stream surveys); however, we found many of them contain non-standardized data and have limited geographic coverage pertaining to our focal area. Our approach, therefore, evaluates watershed condition at both the 4th field hydrologic unit code (HUC) scale (i.e., sub-basin) and 5th field HUC scale (i.e., a finer geographic scale) using available quantitative data for aquatic and terrestrial measures from datasets with full geographic coverage of our focal area.

Similar to the approach used for evaluating watershed condition on federal lands managed under the Northwest Forest Plan, we framed our understanding of watershed condition in terms of our focal species, as "the ability to provide high-quality fish habitat (Gallo et al. 2005)." We considered indicators of water quality, human development, agriculture, and aquatic invasive species (Table 1). All were considered, to varying degrees, in the other regional and national approaches we reviewed (Table 2). We identified measurable attributes with which to analyze each indicator, all of which were also considered by our reference assessments (Tables 1 and 2).

Table 1. Watershed condition classification framework. Based on Potyondy and Geier (2011, 5–6).

Process categories	Indicators	Attributes
Aquatic Physical	Water quality	303(d)-listed streams
		Point source pollution
Terrestrial Physical	Development	% impervious surface
		Road/stream crossings
		Road density
	Agriculture	Crops
		Pasture
Aquatic Biological	Aquatic invasive species	Evidence of current invasion
		Distance to sources of introduction

Table 2. Watershed condition metrics used in this analysis as considered by other regional and national approaches.

	Water quality	303(d) streams	Point-source pollution	**Invasive Species**	**Development**	Impervious Surfaces	Road/stream crossings	Road density	**Agriculture**	Crops	Pasture
USFS Watershed Condition Classification (Potyondy and Geier 2011)	**x**	x	(x)	**x**	**x**			x			
Intensively Monitored Landscape Classification & Human Disturbance Characteristics (Whittier et al. 2011)					**x**	x		x	**x**	x	x
National Fish Habitat Assessment (National Fish Habitat Board 2010)	**x**		x		**x**			x	**x**	x	x
Northwest Forest Plan (Gallo et al. 2005)					**x**		x	x			
NOAA Fisheries Matrix of Pathways and Indicators (National Marine Fisheries Service Environmental and Technical Services Division Habitat Conservation Branch 1996)	**x**				**x**			x			

Water Quality

To identify areas where water quality is likely to impair freshwater habitat, we analyzed the distribution of 303(d)-listed streams and locations of point-source pollution. Section 303(d) of the 1972 Federal Clean Water Act requires states to identify and report impaired waters to the U.S. Environmental Protection Agency. These waters have been affected by natural processes and human pollution so as to restrict their uses (Miner, Buckhouse, and Borman 1996). We compiled spatial data on the 303(d)-listed streams from each state (Washington State Department of Ecology 2009; Oregon Department of Environmental Quality, Water Quality Division 2008; Idaho Department of Environmental Quality 2004)[1]. Impaired waterways located within federally-designated Wilderness Areas or National Park boundaries were removed from our analysis. Because each state reports this data differently, we calculated the 303(d)-listed stream density per sub-basin for each state's proportion of that sub-basin before combining those values into an area-weighted index ranking the relative density of impaired waterways across our entire focal area.

Additionally, we analyzed point source pollution, using data on the distribution of mines and mineral processing plants, Toxics Release Inventory Program sites, Superfund National Priorities List sites from the Compensation and Liability Information System, National Pollutant Discharge Elimination System Majors sites from the Permit Compliance System (NPDES). These data were produced by the U.S. Geological Survey and the U.S. Environmental Protection Agency, and published spatially as part of the assessment of fish habitat nation-wide for the National Fish Habitat Action Plan (National Fish Habitat Board 2011). The total point source density was calculated for all sub-basins by summarizing the number of occurrences of all point sources for each sub-basin area.

Development

Roads other impervious surfaces can have an array of ecological effects, including the loss and fragmentation of habitat and altered stream hydrology. They decrease the infiltration of precipitation through the soil, where pollutants would normally be filtered and increase run-off, associated pollution, and sedimentation (NFHB 2010). Less directly, roads facilitate human access, leading to changes in land use (e.g., development, logging) and increased recreational use of newly accessible streams and lakes (Heilman et al. 2002; Trombulak and Frissell 2000; Spellerberg 1998).

The effects of human disturbance, particularly from roads, were considered in all five of the approaches we reviewed (Table 2) (Whittier et al. 2010; NFHB 2010; Potyondy and Geier 2011; Gallo et al. 2005; NMFS ETS Division HC Branch 1996). Each included a measurement of road density, and Gallo et al. (2005) considered the density of road-crossings over streams. We included both of these metrics in our analysis, using U.S. Census Bureau Topologically Integrated Geographic Encoding and Referencing (TIGER) system roads data (U.S. Department of Commerce 2010) and National Hydrography Dataset (NHD) stream linework (U.S. EPA and USGS 2005). For each sub-basin we identified the length of roads and number of stream crossings, then calculated the density each.

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[1] For more information on all input datasets, please see the bibliography below, or the data dictionary available at http://aquatic-priorities.apps.ecotrust.org/docs.html

In order to incorporate a measure of human development and land-use change we considered the amount of impervious surface within sub-basins, as in Whittier et al. (2010). We used 30-meter raster data of developed impervious surface from the National Land Cover Database to determine the average percent imperviousness of each sub-basin (Fry et al. 2011).

Agriculture

Agricultural activities can greatly affect fish habitat quality by increasing nutrients and sedimentation, reduced water flow from competing water uses, channelization and impoundment of streams, increased water temperatures. Land use change due to agricultural development can remove wetlands and off-channel habitats, as well as riparian and upland habitat critical for maintaining watershed health (NFHB 2010). Additionally, we included measures of agricultural effects on sub-basin impairment by calculating the proportion of each sub-basin under selected crop or pasture land uses, using the USDA Cropland 30-meter raster data layer (USDA NASS RDD GIB SARS 2011). All crop types were selected for inclusion under the crop analysis, except for most orchard-type crops, which were excluded. Grass and hay pasture types were selected for the pasture lands. For each sub-basin, we then calculated the density of crops and pasture land, separately.

Aquatic Invasive Species

Aquatic invasive species are both a cause and effect of impaired watershed condition. Many aquatic invasive species are tolerant to disturbances and a wide range of environmental conditions, allowing them to colonize degraded habitats where native species can no longer flourish (Davis, Thompson, and Grime 2005). They disturb aquatic ecosystem function in many ways, by altering habitat, water chemistry, water quality, hydrology, and trophic dynamics (U.S.EPA NCEA 2008; Pimentel, Zuniga, and Morrison 2005; Hanson and Sytsma 2001; Meacham 2001).

To account for these effects, we included measures of aquatic invasion from the separate vulnerability to invasion component of the Regional Aquatic Prioritization and Mapping Tool. As part of this component, we identified sub-basin density of non-native species occurrences as evidence of current invasion, as well as average sub-basin distance to common sources of species introduction (for more information on how each measure was calculated, please see the Vulnerability to Invasion document). Because aquatic invasion is an important indicator and consequence of watershed condition, we included these two metrics in the measurement of watershed condition although it is likely that there is some overlap in the conditions that they and other watershed condition metrics measure.

Watershed Condition Index

We combined these attributes – 303(d)-listed stream index, point source pollution density, road density, road/stream crossing density, crop and pasture density, percent imperviousness, evidence of current invasion, and distance to sources of aquatic non-native species introduction – into a final measure of watershed condition. In order to analyze the wide range of attribute values together, we first scaled each attributes sub-basin values from *n* to 100, with 100 representing the most impaired sub-basin for each metric, and *n* the least[2]. We then added these unweighted attribute scores and re-indexed the totals on an n—100 scale to create a comprehensive, standardized, relative ranking of sub-basins by their watershed condition (Figure 1). For more information on how these values are used in regional aquatic priorities tool, please see the "Prioritization Process" PDF available on the "Data and Methods" tab of the Regional Aquatic Prioritization and Mapping Tool website.

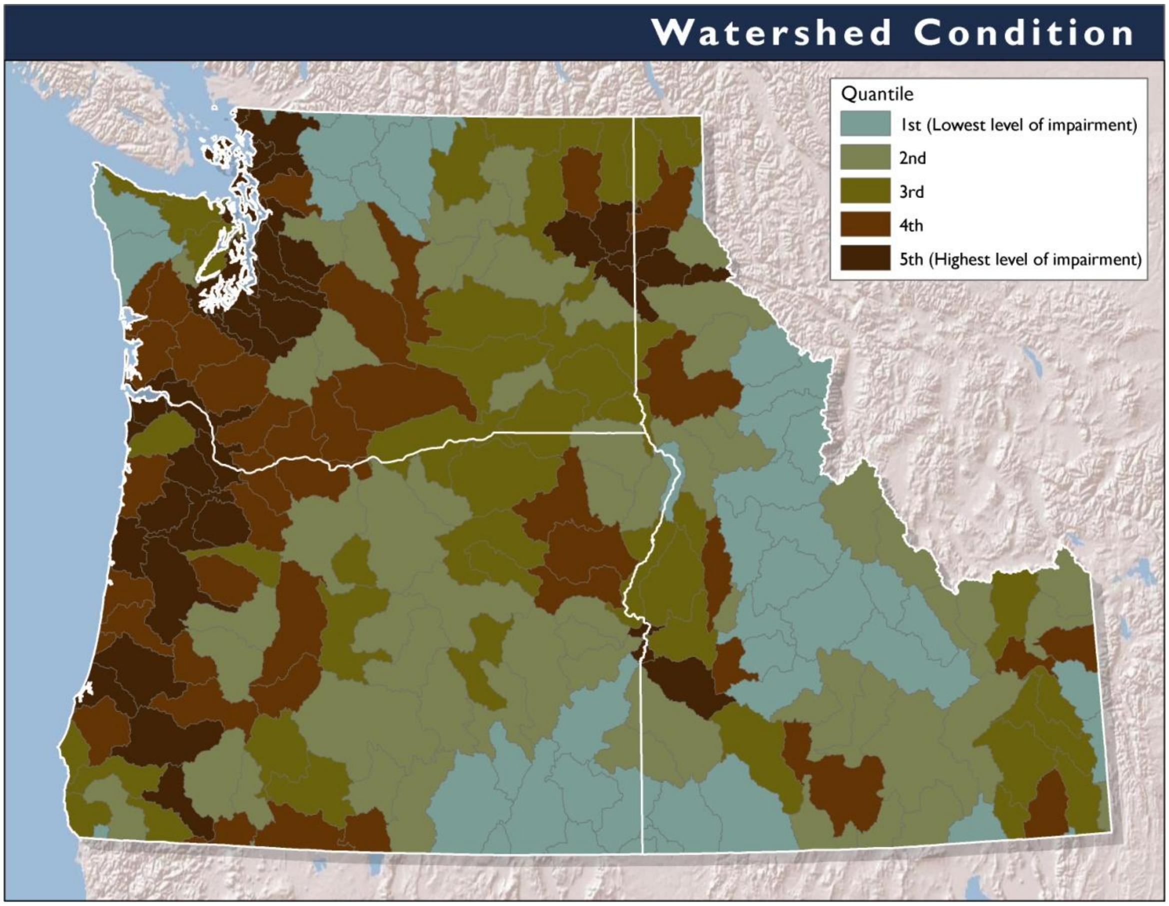

Figure 1. Watershed condition sub-basin index.

[2] For example, if we measured three sub-basins to have point source pollution densities of 48, 31, and 15 points per square mile, we would divide all the values by 0.48 to create an index where the sub-basins were ranked as 100, 65, and 31, respectively. It is important to note that the sub-basin ranked 65 is not necessarily twice as vulnerable as that ranked 31. It is more useful to look at the distribution of condition values both quantitatively and spatially.

Bibliography

Davis, Mark A., Ken Thompson, and J. Philip Grime. 2005. "Invasibility: The Local Mechanism Driving Community Assembly and Species Diversity." *Ecography* 28 (5) (October): 696–704. doi:10.1111/j.2005.0906-7590.04205.x.

Fry, J., G. Xian, S. Jin, J. Dewitz, C. Homer, L. Yang, C. Barnes, N. Herold, and J. Wickham. 2011. *National Land Cover Database 2006 Percent Developed Imperviousness*. Raster digital data. MRLC.gov. http://www.mrlc.gov/nlcd06_data.php.

Gallo, Kirsten, Steven H. Lanigan, Peter Eldred, Sean N. Gordon, and Chris Moyer. 2005. *The Northwest Forest Plan -- the First 10 Years: Preliminary Assessment of the Condition of Watersheds*. General Technical Report. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Hanson, Erik, and Mark Sytsma. 2001. *Oregon Aquatic Nuisance Species Management Plan*. Portland, OR: Portland State University Center for Lakes and Reservoirs. http://www.clr.pdx.edu/publications/files/OR_ANS_Plan.pdf.

Heilman, Gerald E., James R. Strittholt, Nicholas C. Slosser, and Dominick A. Dellasala. 2002. "Forest Fragmentation of the Conterminous United States: Assessing Forest Intactness Through Road Density and Spatial Characteristics." *BioScience* 52 (5): 411. doi:10.1641/0006-3568(2002)052[0411:FFOTCU]2.0.CO;2.

Idaho Department of Environmental Quality. 2004. *2008 Final Integrated Report 305B/303D for Idaho*. Vector digital data. Boise, ID: Idaho Department of Environmental Quality. http://cloud.insideidaho.org/webApps/metadataViewer/default.aspx?path=G%3a%5cdata%5canonymous%5cideq%5cstreams305b2008_id_ideq%5cIDEQ305B_2008_Strms.shp.xml.

Meacham, Pamala. 2001. *Washington State Aquatic Nuisance Species Management Plan*. Olympia, WA: Washington Department of Fish and Wildlife Fish Program.

Miner, R, J. Buckhouse, and M. Borman. 1996. "The Water Quality Limited Stream Segments list: What does it mean?" *Oregon State University Extension Service*. http://extension.oregonstate.edu/catalog/html/em/em8636-e/.

National Fish Habitat Board. 2010. *Through a Fish's Eye: The Status of Fish Habitats in the United States*. Washington, D.C.: Association of Fish and Wildlife Agencies. http://www.habitat.noaa.gov/pdf/fishhabitatreport.pdf.

———. 2011. *National Fish Habitat Action Plan (NFHAP) Catchment Spatial Data for Idaho, Oregon and Washington*. Vector digital data. Michigan: National Biological Information Infrastructure. http://ecosystems.usgs.gov/fishhabitat/.

National Marine Fisheries Service Environmental and Technical Services Division Habitat Conservation Branch. 1996. *Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Watershed Scale*. Portland, OR: National Marine Fisheries Service.

Oregon Department of Environmental Quality, Water Quality Division. 2008. *Water Quality - 2004/2006 Integrated Report Including 303d Streams & Lakes*. Vector digital data. Oregon Department of

Environmental Quality, Water Quality Division. http://www.oregon.gov/DAS/EISPD/GEO/docs/metadata/orlakeswaterquality_0406v2.htm.

Pimentel, David, Rodolfo Zuniga, and Doug Morrison. 2005. “Update on the Environmental and Economic Costs Associated with Alien-invasive Species in the United States.” *Ecological Economics* 52 (3) (February 15): 273–288. doi:10.1016/j.ecolecon.2004.10.002.

Potyondy, John. 2011. *Watershed Condition Framework: A Framework for Assessing and Tracking Changes to Watershed Condition*. USDA Forest Service. http://www.fs.fed.us/publications/watershed/Watershed_Condition_Framework.pdf.

Potyondy, John, and Theodore W. Geier. 2011. *Watershed Condition Classification Technical Guide*. Washington, DC: USDA Forest Service. http://www.fs.fed.us/publications/watershed/watershed_classification_guide.pdf.

Spellerberg, Ian F. 1998. “Ecological Effects of Roads and Traffic: A Literature Review.” *Global Ecology and Biogeography Letters* 7 (5): 317–333. doi:10.2307/2997681.

The Wildlife Management Institute, and The Theodore Roosevelt Conservation Partnership, eds. 2009. *Beyond Season’s End: A Path Forward for Fish and Wildlife in the Era of Climate Change*. Washington, DC: Bipartisan Policy Center. http://www.tu.org/sites/www.tu.org/files/documents/Beyond_Seasons_End.pdf.

Trombulak, Stephen C., and Christopher A. Frissell. 2000. “Review of Ecological Effects of Roads on Terrestrial and Aquatic Communities.” *Conservation Biology* 14 (1) (February): 18–30. doi:10.1046/j.1523-1739.2000.99084.x.

U.S. Department of Agriculture (USDA), National Agricultural Statistics Service (NASS), Research and Development Division (RDD), Geospatial Information Branch (GIB), Spatial Analysis Research Section (SARS). 2011. *USDA National Agricultural Statistics Service 2010 Cropland Data Layer*. Raster digital data. Washington, DC: USDA, NASS Marketing and Information Services Office. http://www.nass.usda.gov/research/Cropland/SARS1a.htm.

U.S. Department of Commerce, U.S. Census Bureau, Geography Division. 2010. *TIGER/Line Shapefile All Roads County-based Shapefiles for Idaho, Oregon and Washington*. Vector digital data. Washington, DC: U.S. Department of Commerce, U.S. Census Bureau, Geography Division. http://www.census.gov/geo/www/tiger/tgrshp2010/tgrshp2010.html.

U.S. Environmental Protection Agency National Center for Environmental Assessment, Immediate Office. 2008. “Effects of Climate Change on Aquatic Invasive Species and Implications for Management and Research (External Review Draft)”. DOCUMENT. *US Environmental Protection Agency*. http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=180043.

U.S. Environmental Protection Agency, and U.S. Geological Survey. 2005. *National Hydrography Dataset Plus - NHDPlus. Regions 16, 17, 18.* Multiple types of spatial digital data. Washington, DC: U.S. Environmental Protection Agency and U.S. Geological Survey. http://www.horizon-systems.com/nhdplus/data.php.

Washington State Department of Ecology. 2009. *2008 Washington Water Quality Assessment, 303(b) Report and 303(d) List*. Vector digital data. Olympia, WA: Washington State Department of Ecology. http://www.ecy.wa.gov/services/gis/data/watqual/303d08.htm.

Whittier, Thomas, Alan T. Herlihy, Chris Jordan, Carol Volk, and Jeannie Sifneos. 2010. *A Landscape Classification to Support Intensively Monitored Watersheds in the Pacific Northwest*. Oregon State University Departments of Fisheries and Wildlife, and Statistics; NOAA Northwest Fisheries Science Center.

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