*This document is part of a collection of [Ecological Integrity Assessments] addressing 67 of Washington's 99 [Ecological Systems]. These documents were prepared by the Washington Natural Heritage Program with funding provided by the Washington Department of Fish and Wildlife.*

# Ecological Integrity Assessment: North Pacific Lowland Riparian Forest and Shrubland

## Ecological Summary

This riparian ecological system occurs throughout the Pacific Northwest and in Washington is most abundant throughout low elevations west of the Cascades and is also found along the eastern base of the Cascades south of Lake Chelan. These forests and tall shrublands are linear in character, occurring on low-elevation, alluvial floodplains that are confined by valleys and inlets or lower terraces of rivers and streams. Riparian forests are the most structurally and floristically diverse type of vegetation in the Pacific coastal region (Naiman and Bilby 1998). This system is found below the *Abies amabilis* forest zone. This ecological system is spatially heterogeneous with a multitude of vegetation patches occurring within the riparian zone (Naiman and Bilby 1998). Complex geomorphic and biotic components and processes maintain the long-term integrity of this system (Gregory et al. (1991). Riverine flooding and the succession that occurs after major flooding events are the major natural processes that drive this system. The system does **not** develop under stagnant hydrological regimes (i.e. is not a swamp). Frequent flooding erodes existing streambanks, deposits sediment and nutrient on existing communities, and creates new substrates for primary succession. Beaver activity is an important driver of hydrological change and subsequent development of a diversity of habitat patches. The contribution of large woody debris (LWD) from riparian or adjacent upland trees is important to maintaining the hydrological and sediment regimes. LWD has a significant impact on the evolution of channel morphology and also contributes to the spatial distribution and diversity of habitat patches within this system (Naiman and Bilby 1998). Annual flooding is a key ecological processes which results in a diversity of patch types such as woodlands, shrublands, wet meadows, and marshes. These various plant communities are adapted to specific flooding regimes or seral stages. Very early successional stages can be sparsely vegetated or dominated by herbaceous vegetation. Willows such as *Salix sitchensis* may also dominate early- to mid-seral types. Dominant species of mid- to late-seral patches are typically deciduous trees (i.e., *Populus balsamifera* ssp. *trichocarpa* and *Alnus rubra*) but conifers can be dominant as well. Conifers such as *Abies grandis, Pseudotsuga menziesii, Picea sitchensis,* and *Thuja plicata* tend to increase with succession in the absence of major disturbance. Conifer-dominated plant communities are now very rare and not well described are important. Major broadleaf dominant species are *Acer macrophyllum, Alnus rubra, Populus balsamifera ssp. trichocarpa, Salix sitchensis, Salix lucida* ssp. *lasiandra, Cornus sericea,* and *Fraxinus latifolia*.

*Stressors*

The stressors described below are those primarily associated with the loss of extent and degradation of the ecological integrity of existing occurrences. The stressors are the cause of the system shifting away from its natural range of variability. In other words, type, intensity, and duration of these stressors is what moves a system's ecological integrity rank away from the expected, natural condition (e.g. A rank) toward degraded integrity ranks (i.e. B, C, or D).

Historic and contemporary use practices have impacted hydrologic, geomorphic, and biotic structure and function of riparian areas in Washington. Human land uses both within the riparian area as well as in adjacent and upland areas have fragmented many riparian reaches which has reduced connectivity between riparian patches and riparian and upland areas. Adjacent and upstream land uses also have the potential to contribute excess nutrients into riparian areas. Reservoirs, water diversions, ditches, roads, and human land uses in the contributing watershed can have a substantial impact on the hydrologic and sediment regimes. Alterations to both processes can affect the establishment of new and maintenance of existing riparian vegetation. Management effects on woody riparian vegetation can be obvious, e.g., removal of vegetation by dam construction, roads, logging, or they can be subtle, e.g., removing beavers from a watershed, removing large woody debris, or construction of a weir dam for fish habitat. Logging activities tend to reduce the amounts of large woody debris in streams and remove future sources of that debris. Timber harvest can also alter hydrology, most often resulting in post-harvest increases in peak flows. Mass wasting and related disturbances (stream sedimentation, debris torrents) in steep topography increase in frequency with road building and timber harvest. Roads and other water diversion/retention structures change watershed hydrology with wide-ranging and diverse effects, including major vegetation changes. The most significant of these are the major flood controlling dams, which have greatly altered the frequency and intensity of bottomland flooding. Increases in nutrients and pollutants are other common anthropogenic impacts *Phalaris arundinacea* is an abundant non-native species in low-elevation, disturbed settings dominated by shrubs or deciduous trees. Many other exotic species also occur. This system has also decreased in extent due to agricultural development, roads, dams and other flood-control activities.

*Conceptual Ecological Model*

The general relationships among the key ecological attributes associated with this system are presented in Figure 1.

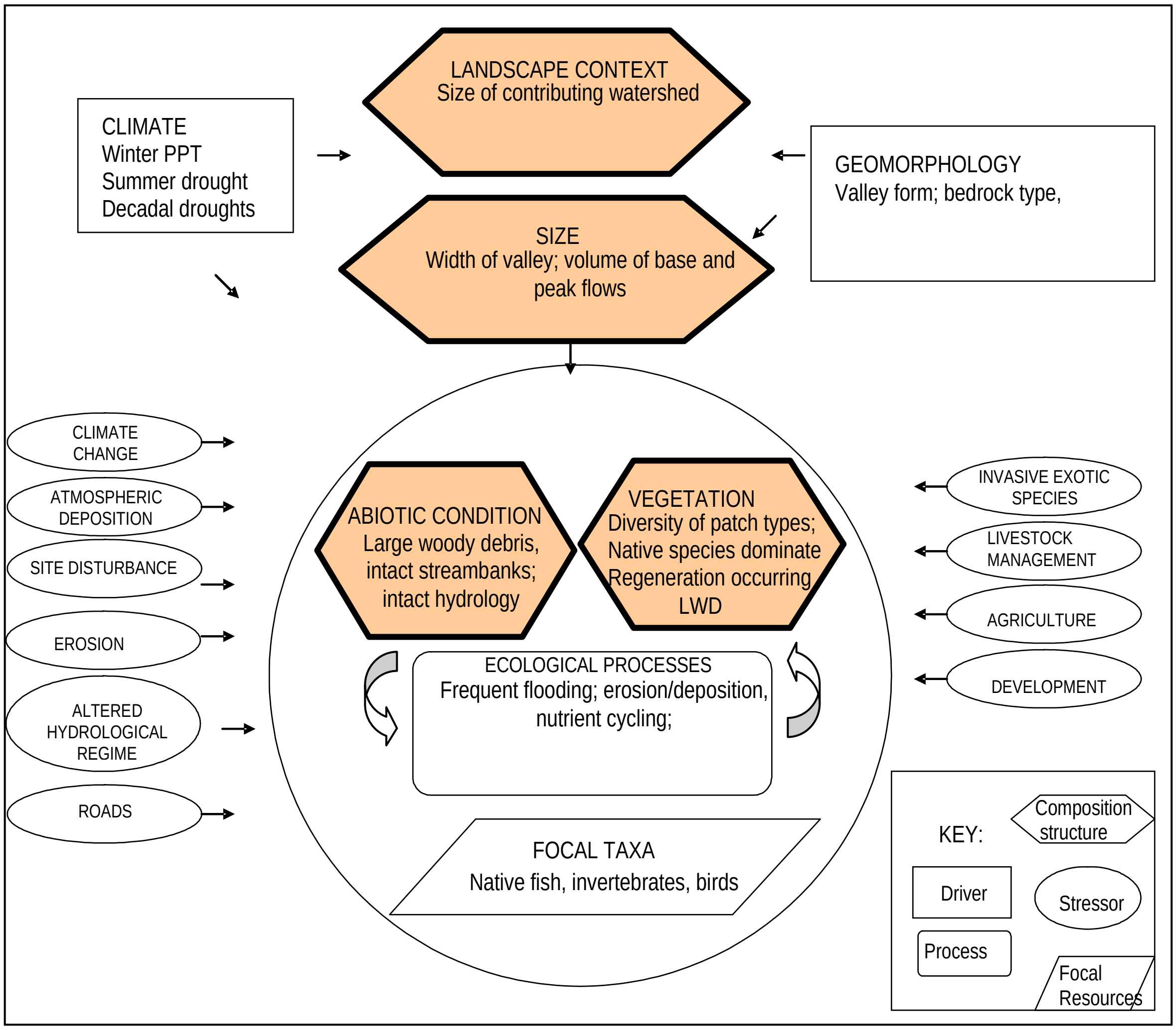


Figure 1. Conceptual Ecological Model for the North Pacific Lowland Riparian Forest and Shrubland.

## Ecological Integrity Assessments

The assessment of ecological integrity can be done at three levels of intensity depending on the purpose and design of the data collection effort. The three-level approach is intended to provide increasing accuracy of ecological integrity assessment, recognizing that not all conservation and management decisions need equal levels of accuracy. The three-level approach also allows users to choose their assessment based in part on the level of classification that is available or targeted. If classification is limited to the level of forests vs. wetlands vs. grasslands, the use of remote sensing metrics may be sufficient. If very specific, fine-scale forest, wetland, and grassland types are the classification target then one has the flexibility to decide to use any of the three levels, depending on the need of the assessment. In other words, there is no presumption that a fine-level of classification requires a fine-level of ecological integrity assessment.

Because the purpose is the same for all three levels of assessment (to measure the status of ecological integrity of a site) it is important that the Level 1 assessment use the same kinds of metrics and major attributes as used at Levels 2 and 3. Level 1 assessments rely almost entirely on Geographic Information Systems (GIS) and remote sensing data to obtain information about landscape integrity and the distribution and abundance of ecological types in the landscape or watershed. Level 2 assessments use relatively rapid field-based metrics that are a combination of qualitative and narrative-based rating with quantitative or semi-quantitative ratings. Field observations are required for many metrics, and observations will typically require professional expertise and judgment. Level 3 assessments require more rigorous, intensive field-based methods and metrics that provide higher-resolution information on the integrity of occurrences. Level 3 EIAs often use quantitative, plot-based protocols coupled with a sampling design to provide data for detailed metrics.

Although the three levels can be integrated into a monitoring framework, each level is developed as a stand-alone method for assessing ecological integrity. **When conducting an ecological integrity assessment, one need only complete a single level that is appropriate to the study at hand.** Typically only one level may be needed, desirable, or cost effective. But for this reason it is very important that each level provide a comparable approach to assessing integrity, else the ratings and ranks will not achieve comparable information if multiple levels are used.

**Level 1 EIA**

A generalized Level 1 EIA is provided in Rocchio and Crawford (2009). Please refer to that document for the list of metrics applicable to this ecological system.

**Level 2 EIA**
The following table displays the metrics chosen to measure most of the key ecological attributes in the conceptual ecological model above. The EIA is used to assess the ecological condition of an assessment area, which may be the same as the element occurrence or a subset of that occurrence based on abrupt changes in condition or on artificial boundaries such as management areas. **Unless otherwise noted, metric ratings apply to both Level 2 and Level 3 EIAs. The difference between the two is that a Level 3 EIA will use more intensive and precise methods to determine metric ratings.** To calculate ranks, each metric is ranked in the field according the ranking categories listed below. Then, the rank and point total for each metric is entered into the EIA Scorecard and multiplied by the weight factor associated with each metric resulting in a metric 'score'. Metric scores within a key ecological attribute are then summed to arrive at a score (or rank). These are then tallied in the same way to arrive at an overall ecological integrity score.

Table 1. North Pacific Lowland Riparian Forest and Shrubland Level 2 EIA.

| Metric | Justification | Rank | | | |
|---|---|---|---|---|---|
| | | **A (5 pts.)** | **B (4 pts.)** | **C (3 pts.)** | **D (1 pts.)** |
| **Rank Factor: LANDSCAPE CONTEXT** | | | | | |
| **Key Ecological Attribute: *Buffer*** | | | | | |
| **Buffer Length** | The buffer can be important to biotic and abiotic aspects of the wetland. Buffer Width Slope Multiplier 5-14% -->1.3; 15-40%-->1.4; >40%-->1.5 | Buffer is > 75 – 100% of occurrence perimeter. | Buffer is 50 – 74% of occurrence perimeter. | Buffer is 25 – 49% of occurrence perimeter | Buffer is < 25% of occurrence perimeter. |
| **Buffer Width** | | Average buffer width of occurrence is > 200 m, adjusted for slope. | Average buffer width is 100 – 199 m, after adjusting for slope. | Average buffer width is 50 – 99 m, after adjusting for slope. | Average buffer width is < 49 m, after adjusting for slope. |
| **Buffer Condition** | | Abundant (>95%) cover native vegetation, little or no (<5%) cover of non-native plants, intact soils, AND little or no trash or refuse. | Substantial (75–95%) cover of native vegetation, low (5–25%) cover of non-native plants, intact or moderately disrupted soils; minor intensity of human visitation or recreation. | Moderate (25–50%) cover of non-native plants, moderate or extensive soil disruption; moderate intensity of human visitation or recreation. | Dominant (>50%) cover of non-native plants, barren ground, highly compacted or otherwise disrupted soils, moderate or greater intensity of human visitation or recreation, no buffer at all. |
| **Key Ecological Attribute: *Landscape Structure*** | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Watershed Connectivity** | The types of land cover/uses in the contributing watershed has a significant affect on ecological processes (May 2002) | Landscape of contributing watershed primarily natural land cover; no connectivity barriers and no regional flood control dams upstream; <5% of contributing watershed urban or agricultural land cover types; few to no recent (<20 years) clearcut (<10% of the landscape) | 5-20% of contributing watershed urban or agricultural land cover types; connectivity mostly retained; heavily managed forest landscape with many tree plantations (<50% of watershed in recent clearcuts) | 20-50% of contributing watershed urban or agricultural land cover types; limited connectivity; heavily managed forest landscape with many tree plantations (<50% of watershed in recent clearcuts) | >50% of contributing watershed urban or agricultural land cover types; limited connectivity largely disrupted; one or more regional flood control dams upstream. |
| **Landscape Fire Regime Condition** | In mixed severity fire landscapes, fire effects can be out of Natural Range of Variability (Dwire and Kauffman 2003). | FRCC 1 No departure from historic fire regime. | | FRCC 2 Slight-moderate departure from historic fire regime. | FRCC 3 Severe departure from historic fire regime. Fire suppression is evident; Fuel laddering is severe and throughout much of stand. |
| **Landscape Condition Model Index** | The intensity and types of land uses in the surrounding landscape can affect ecological integrity. | Landscape Condition Model Index >= 0.8 | | Landscape Condition Model Index 0.79 – 0.65 | Landscape Condition Model Index < 0.65 |
| **Rank Factor: CONDITION** | | | | | |
| **Key Ecological Attribute: *Vegetation Composition*** | | | | | |
| **Relative Cover Native Understory Plant Species** | Native species dominate this system; non-natives increase with human impacts. | Cover of native plants 95-100%. | Cover of native plants 80-95%. | Cover of native plants 50 to 79%. | Cover of native plants <50%. |
| **Absolute Cover of Invasive Species** | Invasive species can inflict a wide range of ecological impacts. Early detection is critical. *Phalaris arundinacea*, are examples. | None present. | Invasive species present, but sporadic (<3% cover). | Invasive species prevalent (3–10% absolute cover). | Invasive species abundant (>10% absolute cover). |
| **Relative Cover of Native Increasers** | Some stressors such as grazing can shift or homogenize native composition toward species tolerant of stressors. | Absent or incidental | <10% cover | 10-20% cover | >20% cover |

| | | | | | |
|---|---|---|---|---|---|
| **Species Composition** Note: Once developed, the Floristic Quality Assessment index could be used here instead. | The overall composition of native species can shift when exposed to stressors. | Species diversity/abundance at or near reference standard conditions. Native species sensitive to anthropogenic degradation are present, functional groups indicative of anthropogenic disturbance (ruderal or "weedy" species) are absent to minor, and full range of diagnostic / indicator species are present. | Species diversity/abundance close to reference standard condition. Some native species reflective of past anthropogenic degradation present. Some indicator/ diagnostic species may be absent. | Species diversity/abundance is different from reference standard condition in, but still largely composed of native species characteristic of the type. This may include ruderal ("weedy") species. Many indicator/diagnostic species may be absent. | Vegetation severely altered from reference standard. Expected strata are absent or dominated by ruderal ("weedy") species, or comprised of planted stands of non-characteristic species, or unnaturally dominated by a single species. Most or all indicator/diagnostic species are absent. |

## Key Ecological Attribute: *Vegetation Structure*

| | | | | | |
|---|---|---|---|---|---|
| **Canopy structure** | Intact riparian areas should have a diversity of tree age classes. | Average tree cover generally > 25%; mixed age. Mature cottonwood and/or conifers present; Trees are of sufficient size to provide future LWD to stream or floodplain. | | Somewhat homogeneous in density and age, AND canopy cover >90% OR <25% | Canopy extremely homogeneous, sparse, or absent (<10% cover). |
| **Regeneration of Woody Species** | Regeneration of woody species is expected in riparian areas with intact hydrology | Saplings/seedlings of native woody species (cottonwood/willow) present in expected amount; Obvious regeneration. | Saplings/seedlings of native woody species (cottonwood/willow) present but less than expected; Some seedling/saplings present. | Saplings/seedlings of native woody species (cottonwood/willow) present but in low abundance; Little regeneration by native species. | No reproduction of native woody species |
| **Large Woody Debris** | Large woody debris (LWD) in the stream channel is very important for channel formation, fish habitat, habitat heterogeneity, and sediment/ hydrological processes (NMFS 1996, Fox 2001). Bank-full Width: 0-6 m | # of LWD pieces/100m (piece = >10cm diameter and > 2 m in length) >38 pieces | | 26-38 | <26 |
| | >6-30 m | >63 pieces | | 29-63 | <29 |
| | >30-100 m | >208 pieces | | 57-208 | <57 |
| **Patch Diversity and Connectivity** | When hydrological processes are intact, a diversity of seral patch and habitat types are present within this system. The patches are well connected without interruption from anthropogenic land cover/use. | Heterogeneous mix of well connected patch types. Mature conifer, mature deciduous (cottonwood, alder, or maple)/conifer mixed, or mature cottonwood (alder) patches present along with early seral stands of trees, wetland shrub and emergent vegetation patches. | Expected patch diversity present but connectivity between patches is becoming fragmented. OR less diversity than expected, especially of mature stands of trees. | Patch diversity is low and becoming homogeneous; few if any mature stands of trees present. Many patches isolated due to fragmentation within the riparian system. | Mostly dominated by one patch type. No mature conifer or deciduous tree patches present. Patch is isolated due to fragmentation within the riparian system. |

## Key Ecological Attribute: *Hydrology*

| | | | | | |
|---|---|---|---|---|---|
| **Water Source** | Anthropogenic sources of water can have detrimental effects on the hydrological regime | Source is natural or naturally lacks water in the growing season. No indication of direct artificial water sources | Source is mostly natural, but site directly receives occasional or small amounts of inflow from anthropogenic sources | Source is primarily urban runoff, direct irrigation, pumped water, artificially impounded water, or other artificial hydrology | Water flow has been substantially diminished by human activity |
| **Channel Stability** | Alteration in hydrology or sediment loads or some onsite stressors can degrade channel stability | Natural channel; no evidence of severe aggradation or degradation; | Most of the channel has some aggradation or degradation, none of which is severe | Evidence of severe aggradation or degradation of most of the channel | Concrete, or artificially hardened, channels through most of the site |
| **Streambank Stability** | Stable streambanks are indicative of intact hydrological and sediment regimes (Henshaw and Booth 2000). | Stable<br><br>Perennial vegetation ot waterline; no raw or undercut banks (some erosion on outside of banks normal); no recently exposed roots; no recent tree falls | Slightly Stable<br><br>Perennial vegetation to waterline in most places; minor erosion and/or bank undercutting; recently exposed tree roots rare but present | Moderately Unstable<br><br>Perennial vegetation to waterline sparse (mainly scoured or removed by lateral erosion); bank held in place by hard points (trees, boulders) and eroded back elsewhere; extensive erosion and bank undercutting; recently exposed tree roots and fine root hairs common | Completely Unstable<br><br>No perennial vegetation to waterline; banks only held by hard points; severe erosion of both banks; recently exposed tree roots common; tree falls and/or severely undercut trees common |
| **Hydrological Connectivity (Riverine)** | Floodwater should have access to the floodplain. Stressors resulting in entrenchment affect hydrological connectivity | **LEVEL 2:** Completely connected to floodplain (backwater sloughs and channels) | Minimally disconnected from floodplain by dikes, tide gates, elevated culverts, etc | Moderately disconnected from floodplain by dikes, tide gates, elevated culverts, etc. | Extensively disconnected from floodplain by dikes, tide gates, elevated culverts, etc. |
| | | **LEVEL 3:** Unconfined: Entrenchment ratio > 4.0; Confined: Entrenchment ratio > 1.4 | Unconfined: Entrenchment ratio 1.4 – 2.2; Confined: Entrenchment ratio 1.0 – 1.4 | Unconfined: Entrenchment ratio < 1.4; Confined: Entrenchment ratio < 1.0 | |
| **Key Ecological Attribute: *Physicochemical*** | | | | | |
| **Soil Surface Condition** | Soil disturbance can result in erosion thereby negatively affecting many ecological processes | Bare soil areas are limited to naturally caused disturbances such as flood deposition or game trails | Some bare soil due to human causes but the extent and impact is minimal. The depth of disturbance is limited to only a few inches and does not show evidence of ponding or channeling water. | Bare soil areas due to human causes are common. There may be pugging due to livestock resulting in several inches of soil disturbance. ORVs or other machinery may have left some shallow ruts. | Bare soil areas substantially & contribute to altered hydrology or other long-lasting impacts. Deep ruts from ORVs or machinery may be present, or livestock pugging and/or trails are widespread. Water will be channeled or ponded. |

| | | | | | |
|---|---|---|---|---|---|
| **Water Quality** | Excess nutrients, sediments, or other pollutant have an adverse affect on natural water quality | No evidence of degraded water quality. Water is clear; no strong green tint or sheen. | Some negative water quality indicators are present, but limited to small and localized areas. Water may have a minimal greenish tint or cloudiness, or sheen. | Negative indicators or wetland species that respond to high nutrient levels are common. Water may have a moderate greenish tint, sheen or other turbidity with common algae. | Widespread evidence of negative indicators. Algae mats may be extensive. Water may have a strong greenish tint, sheen or turbidity. Bottom difficult to see during due to surface algal mats and other vegetation blocking light to the bottom. |
| **Rank Factor: SIZE** | | | | | |
| **Key Ecological Attribute: *Size*** | | | | | |
| **Relative Size** | Indicates the proportion lost due to stressors. | Site is at or minimally reduced from natural extent (>95% remains) | Occurrence is only modestly reduced from its original natural extent (80-95% remains) | Occurrence is substantially reduced from its original natural extent (50-80% remains) | Occurrence is severely reduced from its original natural extent (<50% remains) |
| **Absolute Size** | Absolute size may be important for buffering impacts originating in the surrounding landscape | Streams with limited floodplain development, primarily braided channels, or extremely sinuous stable channels (Rosgen A, B, D, E, or F types)<br><br>> 5.0 linear miles (8 km) | 3.0 to 5.0 linear miles (5-8 km) | 1.0 to 3.0 miles linear miles (1.5 to 5 km) | < 1.0 linear miles (1.5 km) |
| | | Meandering streams with well-developed floodplains and wide channels (mostly Rosgen C type)<br><br>>25 meander wavelengths or 50 point bars | 10-25 meander wavelengths or 20-50 point bars | 4-10 meander wavelengths or 8-20 point bars | <4 meander wavelengths or <8 point bars |

**Level 3 EIA**
Level 3 metrics would include more quantitative measures of the metrics listed above. In addition, the following metrics should be considered in a Level 3 EIA:

- Benthic invertebrate Index of Biotic Integrity (BIBI; Kleindl 1995; Morley 200; WADOE 2003); see Morley (2000); May (2002); or WADOE (2003) for rating the BIBI scores. Statewide data are maintained by WADOE: http://www.ecy.wa.gov/apps/watersheds/streambio/regions/state.asp?symtype=1
- Index of Hydrological Alteration (Richter et al. 1997)
- Specific water quality measures (e.g., the temperature, dissolved oxygen, pH, conductivity, turbidity of stream water
- Specific nutrient levels of riparian vegetation (e.g., carbon to nitrogen (C:N) ratio in the aboveground biomass of plants)
- Pool Quality Index (May (2002))
- Riffle Quality Index (May (2002))

**Triggers or Management Assessment Points**
Ecological triggers or conditions under which management activities need to be reassessed are shown in the table below. Since the Ecological Integrity rankings are based on hypothesized thresholds, they are used to indicate where triggers might occur. Specific details about how these triggers translate for each metric can be found by referencing the values or descriptions for the appropriate rank provided in the Table above.

Table 2. Triggers for Level 2 & 3 EIA

| Key Ecological Attribute or Metric | Trigger | Action |
|---|---|---|
| Any metric (except Connectivity) | ▪ C rank<br>▪ Shift from A to B rank<br>▪ negative trend within the B rating (Level 3) | Level 2 triggers: conduct Level 3 assessment; make appropriate short-term management changes to ensure no further degradation<br><br>Level 3 triggers: make appropriate management adjustments to ensure no additional degradation occurs. Continue monitoring using Level 3. |
| Any Key Ecological Attribute | ▪ any metric has a C rank<br>▪ > ½ of all metrics are ranked B<br>▪ negative trend within the B rating (Level 3) | Level 2 triggers: conduct Level 3 assessment; make appropriate short-term management changes to ensure no further degradation<br><br>Level 3 triggers: make appropriate management adjustments to ensure no additional degradation occurs. Continue monitoring using Level 3. |

**Protocol for Integrating Metric Ranks**

If desired, the user may wish to integrate the ratings of the individual metrics and produce an overall score for the three rank factor categories: (1) Landscape Context; (2) Condition; and (3) Size. These rank factor rankings can then be combined into an Overall Ecological Integrity Rank. This enables one to report scores or ranks from the various hierarchical scales of the assessment depending on which best meets the user's objectives. Please see Table 5 in Rocchio and Crawford (2009) for specifics about the protocol for integrating or 'rolling-up' metric ratings.

*Supporting documents for the EIAs can be found at:*
*http://www1.dnr.wa.gov/nhp/refdesk/communities/eia.html*

*Documentation about Ecological Systems can be found at:*
*http://www1.dnr.wa.gov/nhp/refdesk/communities/ecol_systems.html*

**References**

Chappell, C. 2000. Riparian Forests and Shrublands Appendix 11 Willamette Valley – Puget Trough – Georgia Basin Ecoregion Terrestrial Ecological System EO Specs and EO Rank Specs. *In* Floberg, J., M. Goering, G. Wilhere, C. MacDonald, C. Chappell, C. Rumsey, Z. Ferdana, A. Holt, P. Skidmore, T. Horsman, E. Alverson, C. Tanner, M. Bryer, P. Iachetti, A. Harcombe, B. McDonald, T. Cook, M. Summers, D. Rolph. 2004. Willamette Valley-Puget Trough-Georgia Basin Ecoregional Assessment, Volume One: Report. Prepared by The Nature Conservancy with support from the Nature Conservancy of Canada, Washington Department of Fish and Wildlife, Washington Department of Natural Resources (Natural Heritage and Nearshore Habitat programs), Oregon State Natural Heritage Information Center and the British Columbia Conservation Data Centre.

Chappell, C.B. and J. Kagan. 2001. Westside Riparian-Wetlands. *In* Johnson, D.H. and T.A. O'Neil. 2001. Wildlife-Habitat Relationships in Oregon and Washington. Oregon State University Press, Corvallis, OR.

Collins, J.N., E. Stein, and M. Sutula. 2008. California rapid assessment method (CRAM) for wetlands. Version 5.0.2. San Francisco Estuary Institute. San Francisco, California. Available online at: http://www.cramwetlands.org/

Dwire, K.A. and J.B. Kauffman. 2003. Fire and riparian ecosystems in landscapes of the western USA. Forest Ecology and Management 178 : 61–74

Fox, M.J. 2001. A New Look at the Quantities and Volumes of Instream Wood in Forested Basins within Washington State. M.S. Thesis. College of Forest Resources, University of Washington. Seattle, WA. Online: http://water.washington.edu/Theses/fox.html

FRCC. 2008. Interagency Fire Regime Condition Class (FRCC) Guidebook Version 1.3.0. www.landfire.gov.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An Ecosystem Perspective of Riparian Zones. BioScience 41(8): 540-551.

Henshaw, P.C. and Booth, D.B., 2000. Natural Restabilization of Stream Channels in Urban Watersheds. Journal of the American Water Resources Association, 36(6): 1219-1236.

Kleindl, W.J. 1995. A benthic index of biotic integrity for Puget Sound lowland streams, Washington, USA. M.S. Thesis, University of Washington, Seattle, WA.

May, C.W. 2002. Measures of Ecological Integrity for Salmonid Streams on Department of Defense Facilities in the Pacific Northwest: Current Watershed Conditions and Management Recommendations. Technical Report APL-UWTR0104. Applied Physics Laboratory, University of Washington, Seattle, WA. Online: http://www.serdp.org/Research/upload/CS-1154-FR-01.pdf

Morley, S.A. 2000. Effects of Urbanization on Biological Integrity of Puget Sound Lowland Streams: Restoration with a Biological Focus. M.S. thesis, University of Washington, Seattle, WA.

Naiman, R.J. and R.E. Bilby. 1998. River Ecology and Management: Lessons from the Pacific Coastal Ecoregion. Springer-Verlag. New York, NY.

National Marine Fisheries Service (NMFS). 1996. Coastal Salmon Conservation: Working Guidance for Comprehensive Salmon Restoration Initiatives on the Pacific Coast. National Marine Fisheries Service, National Oceanic and Atmospheric Administration. Northwest Region, Seattle, WA.

NatureServe Explorer. 2007. Descriptions of Ecological Systems for the State of Washington. Data current as of October 06, 2007. NatureServe, Arlington, VA. [http://www.natureserve.org/explorer/index.htm]

Richter, B.D., J.V. Baumgartner, J. Powell, and D.P. Braun. 1997. A Method for Assessing Hydrologic Alteration within Ecosystems. Conservation Biology 10: 1163-1174.

Rocchio, F.J. and R.C. Crawford. (2009) Monitoring Desired Ecological Conditions on Washington State Wildlife Areas Using an Ecological Integrity Assessment Framework. Washington Natural Heritage Program, Washington Department of Natural Resources, Olympia, WA.

Rocchio, J. 2006. Rocky Mountain Lower Montane Riparian Woodland and Shrubland Ecological Integrity Assessment. Report Prepared for NatureServe, Arlington, VA. Colorado Natural Heritage Program, Colorado State University. Fort Collins, CO. Online: http://www.cnhp.colostate.edu/download/documents/2005/ecological_integrity/Rocky%2

0Mountain%20Lower%20Montane%20Riparian%20Woodland%20and%20Shrubland_EIA_Dec09_05.pdf

Washington Department of Ecology (WADOE). 2003. Multi-metric Index Development for Biological Monitoring in Washington State Streams. Publication 03-03-035. Washington Department of Ecology, Olympia, WA. Online: http://www.ecy.wa.gov/pubs/0303035.pdf

Authorship: Joe Rocchio, Washington Natural Heritage Program
February 18,2011