A Quick Guide to a Framework for
ASSESSING OPERATIONAL LOSSES

This *Quick Guide to a Framework for Assessing Operational Losses* is intended as an introduction to designing and implementing a scientifically defensible, repeatable, comprehensive, and process-based assessment of the ecological impacts of hydroelectric projects on river systems and their associated floodplains. The framework, as described here, was used as the basis for the Kootenai River Floodplain Ecosystem Operational Loss Assessment. The framework describes a series of multimetric indices for each order of impact, and then combines those indices into an overall Index of Ecological Integrity (IEI).

A process-based hierarchy is an effective way to represent this succession of impacts, and provides a 'road map' for exploring and assessing the processes linking successive levels of impact. Jorde et al. (2008) proposed a hierarchy for considering operational impacts on floodplain ecosystems, adapted from a framework originally proposed by Petts (1984). This framework is based on Jorde's hierarchy with minor revisions. Figure 1 shows the process-based hierarchy underlying the framework.

The overarching goal of this tool is to assess abiotic and biotic factors (i.e., geomorphologic, hydrologic, hydraulic, aquatic and riparian/floodplain community) to develop a definitive composite measure of ecological integrity, called the **Index of Ecological Integrity** or **IEI**.

Process-based, hierarchical analyses provide a powerful tool for assessing operational impacts of dams on physical processes and consequent ecosystem function because physical drivers and biological responses can be displayed in space and time, with the potential for isolating specific operational impacts. This approach provides an advantage over purely empirical techniques because it allows process-based extrapolation over space and time beyond individual observations (Burke et al. 2009).

PROCESS-BASED HIERARCHY

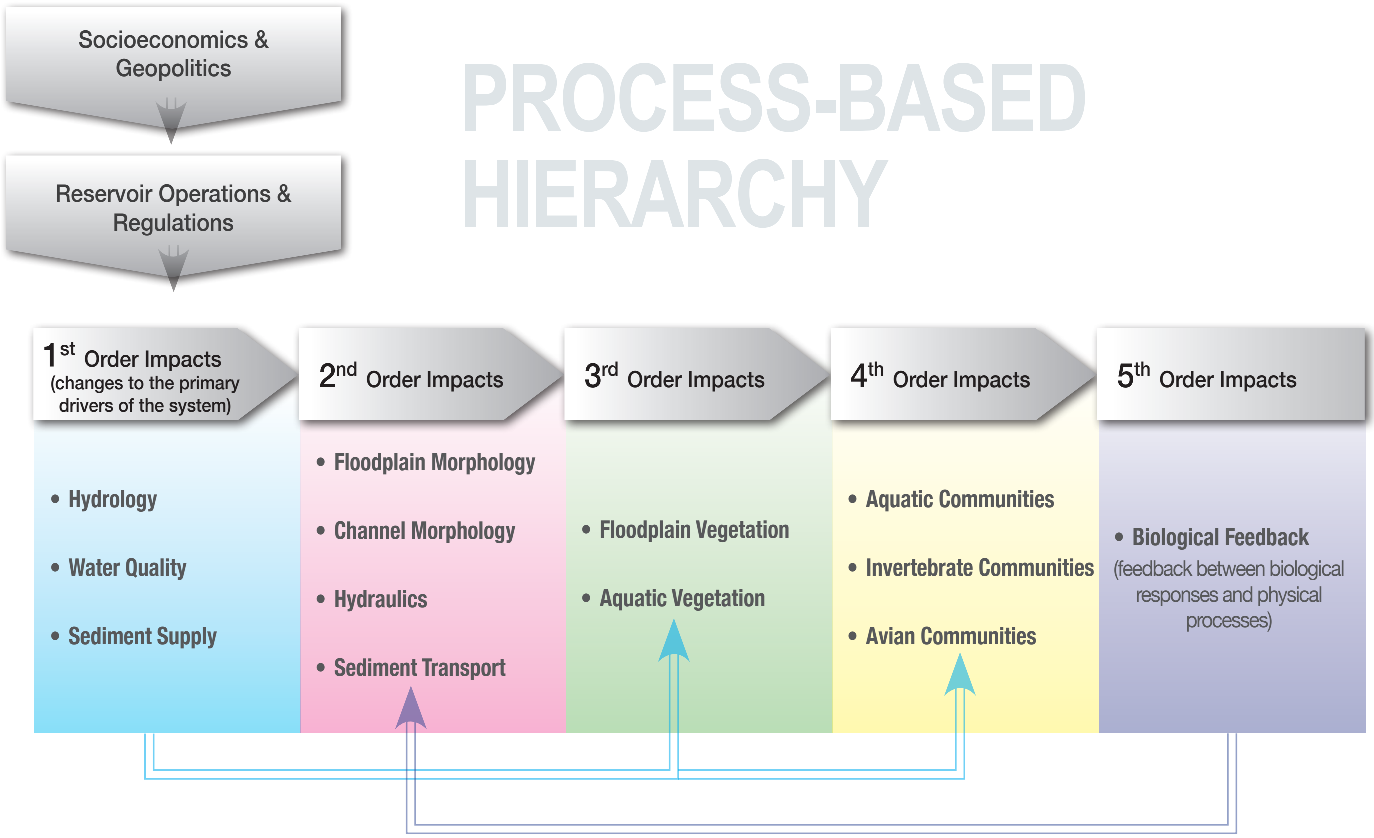


Figure 1. The process-based hierarchy underlying this framework.

Index of Ecological Integrity

The Index of Ecological Integrity (IEI) quantifies the extent of anthropogenic impacts on a river and its associated floodplain. It is a definitive composite measure of ecological integrity and can be defined as a measure of the capability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region" (Karr and Dudley 1981). Its advantages include:

- It provides a system-specific way to rank abiotic and biotic data on a comparable quantitative scale.
- It allows managers to assess direct, indirect, and cumulative effects of management actions on an independent index or a combination of indices at multiple scales.
- It easily adapts to varying audiences — from policy level decision makers that might be interested in the overall score to a scientific audience interested in the details of metric scores and the ecological mechanisms underlying the overall assessment. Land managers and dam operators can also employ this technique to assess and prioritize ecosystem deficiencies and to monitor management actions.
- It can be adapted to each unique river system. If different metrics or additional indices are needed for a specific area (fish, amphibians, big game, etc.), and suitable empirical data were available, a new index could be developed and inserted on a corresponding axis in the IEI radar chart.

The Multimetric Indices

The IEI is calculated by combining a series of **multimetric indices** that measure each order of impact. When rivers can be divided into major geomorphic reaches defined by unique geomorphology, landform, and land use patterns, an IEI score is developed for each reach. The scores allow for comparison of the relative level of impacts between reaches. Figure 2 shows the specific indices used to determine the IEI and their abbreviations. Each index, in turn, is calculated from a group of more specific **metrics**, each carefully selected.

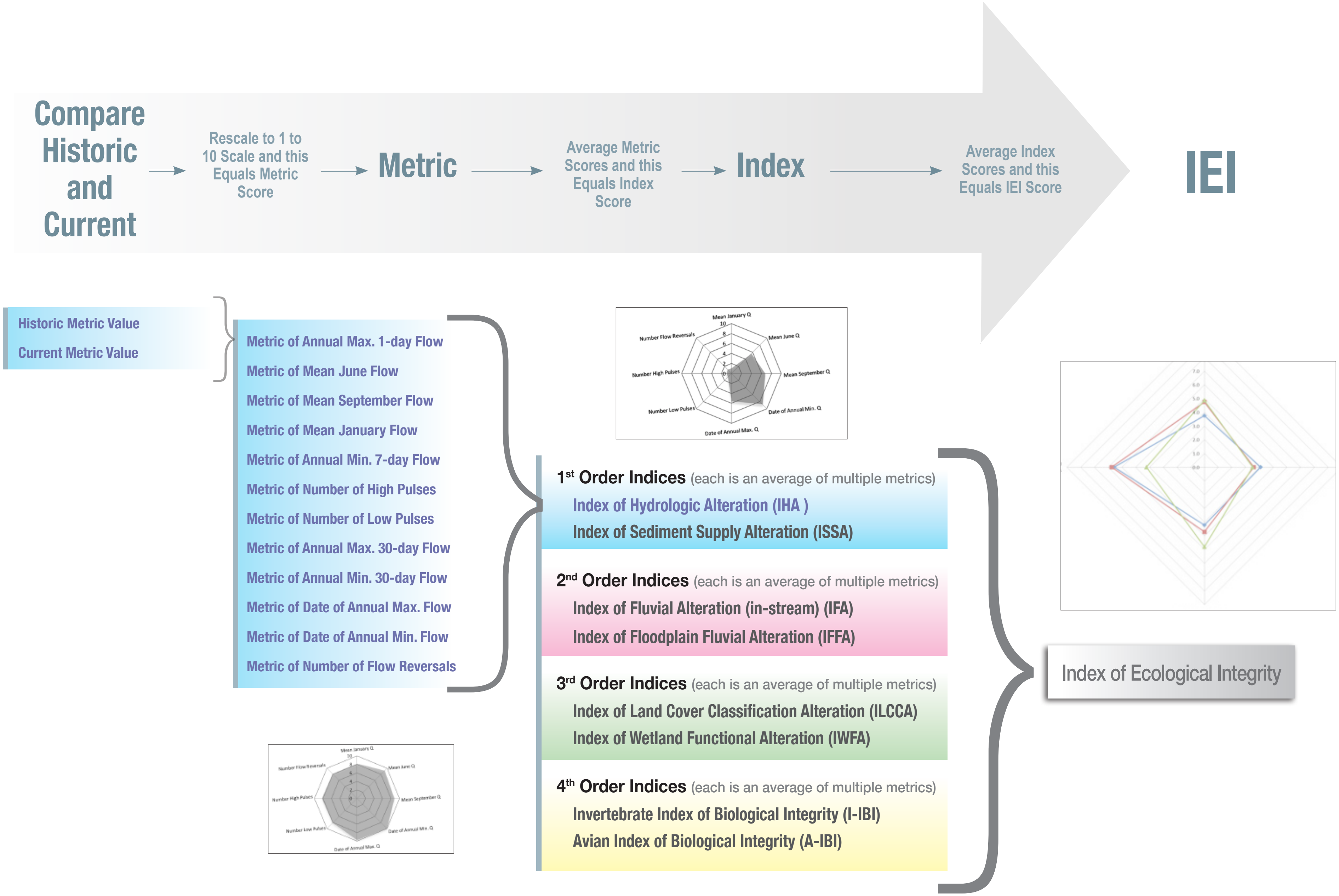


Figure 2. Specific indices used to calculate the Index of Ecological Integrity. Each index is the average of multiple metrics. Insets show examples of radar charts. Note that Riverine Macroinvertebrates and Riverine Fish Index are not included in this Quick Guide.

Research Design and Review Team (RDRT)

The assessment work requires a team of skilled scientists in the fields of hydrology, hydraulics, geomorphology, ornithology, entomology, statistics, riparian and river ecology, among other expertise. This advisory team is known as the Research Design and Review Team (RDRT), and their role is to direct the review, selection, and adaptive management of the research designs used to evaluate the loss of ecological function caused by the operation of a dam.

The Metrics

A list of possible metrics for each index is developed and refined. Then, each metric is calculated in the current and compared to the historic condition[1] and placed on a standardized scale ranging from 1 (drastic change) to 10 (limited change) to quantify the difference. This value is referred to as the metric score. Metric scores are then averaged together to equal the index score. Index scores are then averaged to yield the IEI score.

Radar charts (Figure 2) are used to display and communicate the metric scores, index scores, and IEI scores.

1 *Where historic metric values were not available, a method to assess change was derived and explained under the index where it applied.*

Major Steps

1 Create Research Design & Review Team

2 Define River Reaches

3 Select Indices and Metrics

4 Identify Existing Data Sources and Data Gaps

5 Conduct Field & In-Office Work to Fill Data Gaps

6 Run Models and Calculate Metric & Index Scores

7 Calculate Index of Ecological Integrity

Summary of Indices

1a Index of Hydrologic Alteration (IHA)

1st Order Index

Description

Quantitative index based on statistical analysis of long-term measurements of river discharge at key main-stem gaging stations.

Metrics

The IHA software (Richter 1996) calculates 33 metrics, using a PCA analysis on the historic flow data; 12 metrics explained a majority of the variation of the data. Four metrics were redundant with the others and were dropped, leaving 8 final metrics. The same analysis method was used in the Flathead and resulted in selection of the same 8 metrics.

Number of Low Pulses	Date of Annual Min. Flow
Mean June Flow	Number of Flow Reversals
Mean September Flow	Annual Max. 30-day Flow (optional)
Mean January Flow	Annual Min. 7-day Flow (optional)
Date of Annual Max. Flow	Annual Min. 30-day Flow (optional)
Number of High Pulses	Annual Max. 1-day Flow (optional)

Data and Data Sources

Time series of daily mean discharge obtained from records published by the United States Geological Survey (USGS) and the Water Survey of Canada (WSC). Published data typically available from internet databases (http://waterdata.usgs.gov/nwis; http://www.wsc.ec.gc.ca/hydat/H2O/). For periods lacking data, gage records were extended by graphical correlation and regression methods. The TNC IHA software manual suggests a minimum record length of 15 years to reasonably characterize the attributes and variability of a hydrologic regime. To select our metrics in both the Kootenai and Flathead systems, we conducted a pre-regulation PCA analysis using the 33 variables calculated by the TNC-IHA (Richter et al. 1996) software. The PCA analysis narrowed the metrics to a set of 12, then we refined the set to the final 8 metrics. The 8-metric set was identical between both river systems. Then, we calculated those metrics for each year of record and used a 1000 bootstrap sample (each sample included 16 years of data chosen at random, with replacement) to calculate our final IHA.

Notes

Recommend using an alternate approach to calculating the metrics quantifying the timing of the minimum and maximum flow. For river systems where little flow data exists, or where the primary effects of regulation are short-duration patterns (e.g. intra-daily hydropeaking), alternative hydrologic metrics may be available that are appropriate for use as a basis to calculate alteration.

Cost $45 K*

**This estimate based on a bare-bones approach used to evaluate the transferability to the Flathead Basin*

1b Index of Sediment Supply Alteration (ISSA)

1st Order Index

Description

A rapidly-calculated, order of magnitude, quasi-quantitative characterization of shifts in sediment supply. An 'informative' index that helps explain the manner and the substantial magnitude of alteration in sediment supply.

Metrics

Sediment supply metric (SS*) = the ratio of reduced sediment supply at any point in time to the sediment supply of a reference condition for a given location. GIS-based analysis to estimate a spatially-distributed index of sediment yield (or yield potential) represents an incrementally more complex alternative approach in which the factors considered to control sediment production (lithology, slope, climate and land cover are each described through sub-index values, then combined into a spatially-distributed composite index.

Data and Data Sources

Varies depending on system, history, jurisdictions, agencies, etc.

Notes

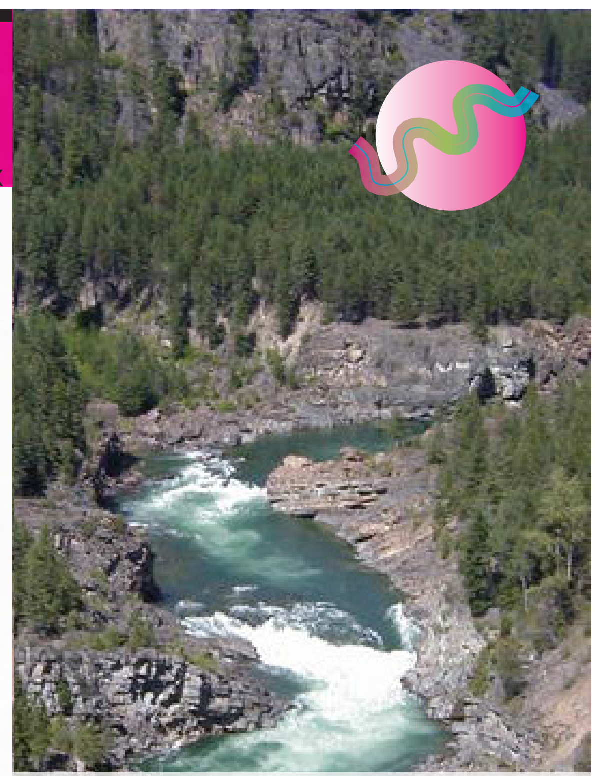
An even simpler approach to the estimate could use relative basin area as a surrogate for sediment supply, instead of the mean annual sediment loads predicted by the Cartier relationship.

Cost $30 K*

* *Based on the original development of the project.*

2a Index of Fluvial Alteration (IFA)

2nd Order Index



Description

A quantitative index based on direct comparisons of flow patterns within the banks of the river for representative years between distinct operational scenarios.

Metrics

- Depth
- Daily Stage Fluctuation
- Velocity
- Shear Stress
- Bed Mobility

Data and Data Sources

The determination of second-order impacts was based on comparison of instream processes between water years representative of a range of climatic conditions (wet, average and dry) within each functional scenario (historic, pre-dam and post-dam). The IFA analysis requires development of a 1-D hydrologic model and cross-section data. Characteristic values for instream processes for each year were generated by simulation of the river flow for the year with hydrodynamic models that solve the St. Venant (1871) equations for unsteady, non-uniform flow.

Notes

An individual hydrodynamic model was developed and calibrated for each of the functional scenarios, which allowed explicit simulation of the spatiotemporal flow characteristics resulting from the conditions representative of each scenario. This approach provides an advantage over other purely empirical techniques because it is possible to obtain information over the time and space between measurement points and events and allows for process-based extrapolation beyond measurement points.

Cost $50 K*

** Based on the original development of the project and assumes access to the ACE models and cross section data produced for the Columbia River Treaty*

2b Index of Fluvial Floodplain Alteration (IFFA)

2nd Order Index

Description

An index that quantifies the changes in hydrology (dam operation) and topography (i.e. levees) to the floodplain by comparing historic versus current water depth, shear stress, flood inundation extent, and duration and frequency of inundation.

Metrics

- Water Depth
- Sheer Stress
- Flood Inundation Extent
- Duration of Inundation
- Frequency of Inundation

Data and Data Sources

Metrics are simulated using six different recurrence interval floods (i.e., 1-, 2-, 5-, 10-, 25-, and 50-year RI floods). Danish Hydraulic Institute (DHI) software packages MIKEFLOOD (2007) and MIKE11GIS (2005) are used to simulate the hydraulic metrics in a spatially-distributed manner over the floodplain. The ACE HecRas model developed for the CRT may be an economic and suitable substitution. This model was used successfully in the Flathead River.

Notes

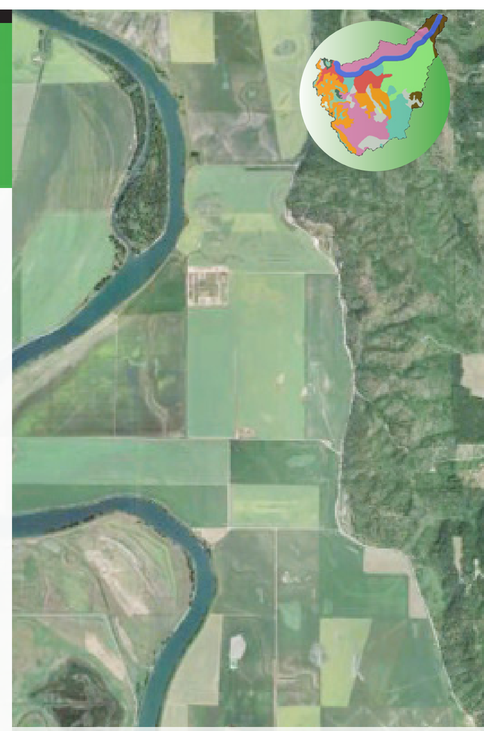
Index alone may not be transferable to other areas to estimate the intensity of human disturbance based on channel flow because reference conditions will be different in other rivers. Reference conditions should be developed at the site where the floodplain IFFA method is applied to analyze the human impacts.

Cost $100 K*

**This estimate based on a bare-bones approach used to evaluate the transferability to the Flathead Basin. Assumes access to the ACE models and cross-section data produced for the Columbia River Treaty.*

3a Index of Land Cover Classification Alteration (ILCCA)

3rd Order Index



Description

Quantified change in vegetation land cover over time.

Metrics

- Streamside Sand/Gravel
- Riparian Conifer Forest
- Riparian Broadleaf Forest
- Wetland
- Riparian Mixed Forest
- Riparian Herbaceous
- Riparian Shrub

Data and Data Sources

National Agricultural Imagery Program (NAIP); Natural-color NAIP imagery for Montana (NRIS; www.nris.mt.gov); 1-meter color infrared (CIR) imagery, analogous to NAIP CIR imagery, acquired in 2004 for the Idaho West subsection, were purchase from Horizons, Inc., a USDA contractor in Sioux Falls, SD; NAIP CIR digital photos; 1934 & 1947 black and white aerial photographs from US Forest Service; USGS 10-meter digital elevation models (DEMS); Ground-based oblique color photographs.

Notes

While this summary describes the use of remote sensing and aerial photos to develop the Land Cover Classification Alteration Index, this method is probably overly expensive and complex for the resolution needed. Aerial photo interpretation alone is probably adequate.

Cost $60 K*

** Based on the original development of the project.*

3b Index of Wetland Function Alteration (IWFA)

3rd Order Index

Description

A measure of changes in wetland quality and function resulting from hydropower operations that uses the Oregon Rapid Wetland Assessment Protocol.

Metrics

- Hydrologic Function
- Water Quality Group
- Nutrient Cycling
- Fish Support Group
- Aquatic Habitat Group
- Terrestrial Habitat Group

Data and Data Sources

Aerial photographs, detailed topographic maps, hydrologic models and NWI and soil maps combined with Oregon Rapid Wetland Assessment Protocol (ORWAP) field visits (FieldF Tab). Wetland boundaries determined using NWI maps, historic and current aerial photographs, LiDAR generated elevations, 1928 topographic maps, NRCS soil maps, and hydraulic model outputs.

Cost $50 K*

** Based on the original development of the project.*

4a Invertebrate Index of Biological Integrity (I-IBI)

4th Order Index

Description

A multi-metric index used to reflect changes in terrestrial invertebrate community complexity due to human disturbance.

Metrics

- Algae_In
- Omni_In
- Canopy_In
- Formicidae
- Coccoidea

These metrics were calculated for the Araneae (spiders), Coleoptera (beetles), Collembola (springtails), Diptera (flies), Hemiptera (bugs), Hymenoptera (ants, bees and wasps) and Orthoptera (grasshoppers, katydids, etc.).

Data and Data Sources

Data collected at randomly selected sites within the 50-year floodplain. Requires a year of site-specific vegetation data, IFFA metrics, and 2-3 years of insect data. The insects were only identified to family.

Notes

The multivariate analyses of the invertebrate data provided an enhanced IBI methodology and produced reasonable IBI scores for the specified invertebrate sites.

Cost $95 K* / $200 K**

**One rotation; **Full three rotations.*
Estimates assume 2 yrs of data collection on 50 sites and collection of the site-specific vegetation data, availability of IFFA metrics.

4b Avian Index of Biological Integrity (A-IBI)

4th Order Index

Description

A multi-metric index used to reflect changes in avian community complexity due to human disturbance.

Metrics

- Richness — Hill's Richness, N_0
- N_2 Hill's Diversity
- N_2/N_1 — Hill's Evenness
- Ave. Key Ecological Functions per Species
- Rel. Abund. Species Dependent on Riparian Veg. for Reproduction
- Rel. Abund. Resident Species
- Rel. Abund. Short Distance Migrants
- Rel. Abund. Species Sensitive to Disturbance

These metrics were calculated for four guild types: Migratory Status, Nesting Status, Trophic Status, Disturbance Tolerance.

Data and Data Sources

Data collected at randomly selected sites within the 50-yr floodplain. Requires a year of site specific vegetation data, IFFA metrics, and 2-3 years of avian data.

Notes

The multivariate analyses of the avian data provided an enhanced IBI methodology and produced reasonable IBI scores for the specified avian sites.

Cost $60 K*

**This estimate based on a bare-bones approach used to evaluate the transferability to the Flathead Basin. Estimate assumes 2 yrs of data collection on 50 sites and collection of the site specific vegetation data,availability of IFFA metrics.*

Literature Cited

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