ERDC TN-EMRRP-EBA-16
October 2012

Ecosystem Restoration Objectives and Metrics

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OVERVIEW: Managers and practitioners working to restore ecosystems require means to analyze complex trade-offs in a quantifiable, rational, consistent, and transparent manner. Metrics are measurable properties that quantify the degree to which objectives have been achieved. In this way, metrics measure progress toward goals and objectives, raise awareness and understanding, and inform restoration decision making. Quantitative comparisons of alternatives, assessments of trade-offs, and evaluations of investments cannot proceed without metrics. This paper summarizes the scientific principles and best practices for the development and application of metrics with respect to three topics: (1) setting objectives within a decision hierarchy spanning project, regional, and national scales; (2) developing metrics corresponding to objectives; and (3) comparing and combining metrics to facilitate decision making. The proposed principles and practices are then applied to a hypothetical case study regarding restoration of river-floodplain connectivity.

1-OBJECTIVE SETTING: Although the importance of clear, specific goals and objectives may seem obvious, ecosystem restoration and management efforts often develop inarticulate objectives or — worse (Kondolf 1995, Slocombe 1998, Kentula 2000, Tear et al. 2005, Bernhardt et al. 2007) — none at all. Gregory and Keeney (2002) identify three common causes of poor objective setting in environmental management: (1) too little time and effort is spent specifying objectives; (2) getting objectives right is not easy; and (3) the project team takes too narrow a focus. This section reviews types of ecosystem restoration objectives, techniques for developing project-specific objectives, and guidelines for critically evaluating objectives.

Types of objectives. Two common motivations for ecosystem restoration are: (1) the improvement of the environment and accompanying natural resources (i.e., environmental benefits) and (2) the provision of "the benefits people obtain from ecosystems" (i.e., ecosystem goods and services, Heal et al. 2005, MEA 2005, Palmer and Filoso 2009). Although this distinction may appear semantic, ecosystem goods and services are ecosystem structures and functions that are of benefit to or otherwise demanded by humans (Brown et al. 2007). Environmental improvement may be gauged through changes in both ecosystem structure and function. "Ecosystem structure refers to both the composition of the ecosystem (i.e., its various parts) and the physical and biological organization defining how those parts are organized. Ecosystem function describes a process that takes place in an ecosystem as a result of the

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interactions of the plants, animals, and other organisms in the ecosystem with each other or their environment" (Heal et al. 2005). Careful restoration planning is likely to require both structural and functional objectives (Cairns 2000, SWS 2000, Bernhardt and Palmer 2011), and environmental benefits and ecosystem goods and services may both be addressed within the same project. For instance, a riparian restoration project might seek to increase habitat for an imperiled riparian bird and promote floodplain denitrification (structural and functional objectives, respectively) as well as reduce water filtration costs and increase flood attenuation (ecosystem services), which could potentially be antagonistic objectives.

Objectives can be organized into practical categories to help structure thinking and provide a framework for metric comparison (Reichert et al. 2007, Seager et al. 2007). Covich et al. (in preparation) propose five primary categories of ecosystem restoration objectives: hydrogeomorphology, biogeochemistry, biological systems, socioeconomics, and cultural-personal values (Table 1). Each category may be represented by either structural or functional objectives, and all categories may serve ecologically oriented objectives, ecosystem goods and services goals, or both (Table 2).

Table 1. Categories of objectives common to ecosystem restoration.

Objective Category	Description
Hydrogeomorphology	Hydrogeomorphology refers to the physical setting of an aquatic ecosystem and includes physical processes such as hydrologic cycling, local and regional climate, geologic history and process, and watershed land use change as well as the interaction of these processes to create the sediment regime, channel hydraulics, and local geomorphology (SERI 2004, Poole 2010). Hydrologic connectivity may be critical for physical processes such as sediment or large woody debris delivery as well as biological processes such as fish migration or carbon subsidy (Pringle 2003).
Biogeochemistry	Biogeochemistry refers to the "chemical integrity" of a system and addresses the concentration of nutrients, contaminants, and other constituents in an ecosystem as well as their fate and transport (Reichert et al. 2007). Inclusive in these processes are concepts often associated with water and soil quality, nutrient and contaminant cycling and transformation, and biological uptake and storage.
Biological Systems	"Biological integrity" results from the reproduction, survival, and colonization by living components of ecosystems. Biological systems depend on hydrogeomorphic and biogeochemical components of the ecosystem for habitat as well as individual growth and metabolic rates, complex inter- and intra-species interactions (including invasive species), community composition and structure, ecosystem efficiencies (e.g., primary and secondary productivity), biodiversity and biocomplexity, genetic diversity, and evolutionary processes (SERI 2004, Fischenich 2006).
Socioeconomics	Socioeconomic aspects of an ecosystem emphasize their instrumental value to humans through local, regional, and national economic benefit, local development and infrastructure, active use (e.g., recreation), and passive use (e.g., aesthetics). Extensive reviews can be found in Heal et al. (2005), MEA (2005), Brown et al. (2007), and Karieva et al. (2011).
Cultural-Personal Values	Cultural and personal values are the intrinsic values associated with an ecosystem and their direct and indirect influences on ecosystem processes. Cultural interaction includes the demographics and heritage of the residents, non-residents, and special interest groups who may value certain attributes of an ecosystem (e.g., lands sacred to Native Americans or environmental justice of restoration actions). Politico-legal processes directly influence ecosystem function through laws and regulations (e.g., federal environmental policies, county zoning, water rights), land ownership and jurisdiction, and decision-making authority. Personal motivation of planners, local sponsors, and public opinion leaders provide projects with the momentum required for implementation (Fischenich and Payne, in preparation).

Table 2. Examples of interacting objective types and categories.

	Ecologically Oriented Objectives		Ecosystem Goods & Services Objectives	
Objective Category	**Structure**	**Function**	**Structure**	**Function**
Hydro-geomorphology	Maintain peak flows sufficient to induce overbank flooding. Provide suitably balanced distribution of seagrass and marsh habitat.	Abate streambank erosion in the study reach. Promote hydrologic connectivity between the channel and floodplain.	Increase water depth for recreational boating opportunities. Provide 10 million gallons per day of freshwater for municipal use.	Increase storm surge attenuation by vegetated marshes. Promote watershed retention of fine sediment to avoid costly filtration.
Biogeochemistry	Reduce nitrate-nitrogen to avoid toxic algal blooms. Reduce metal ions below toxicity limits for imperiled biota.	Enhance riparian denitrification. Restore magnitude and frequency of the salinity regime.	Reduce drinking water treatment costs. Increase dissolved oxygen to support commercial fishes.	Increase floodplain carbon sequestration. Maintain assimilative capacity of the river.
Biological Systems	Increase habitat for threatened Taxon-X. Increase fish-based index of biotic integrity.	Restore flow regime that promotes annual seed germination. Enhance colonization of migratory fish from downstream habitat.	Increase abundance of pollinating species. Eliminate invasive Eurasian water milfoil.	Enhance productivity of commercially-valuable timber. Increase shellfishery yield.
Socioeconomics	Maintain high bird species richness to promote ecotourism. Increase habitat for recreationally hunted waterfowl.	Promote riparian health for flood attenuation. Maintain sufficient sport fish populations to sustain recreational harvest.	Improve navigability of waters for commercial traffic. Provide adequate access to facilitate recreational use.	Reduce disease by regulating vectors (e.g., mosquitoes). Equitably distribute reservoir services between upstream and downstream user communities.
Cultural-Personal Values	Maintain the ability to view and coexist with rare wildlife or apex predators. Conserve archeological and historic sites.	Provide fair treatment of historically disenfranchised communities. Maintain subsistence fishing opportunities.	Provide an aesthetically pleasing project. Enhance personal pride of residents in the ecosystem.	Enhance breeding of species valuable for wildlife observation. Promote social cohesion.

These categories underscore the role of humans as a part, not apart from, an ecosystem (Christensen et al. 1996, Cairns 2000). Each categorical objective should at least be considered in a qualitative sense because the imbalance of one category could override the benefits of another (Cairns 2000). For instance, the value of a project restoring hydrogeomorphic and biogeochemical systems may be overwhelmed by a socially unacceptable impact on a historically disenfranchised community such as subsistence fishermen. This is not to imply that all categories will be present in all sets of restoration objectives, but simply to encourage consideration of the full suite of restoration effects (both positive and negative).

Planning objectives must clearly define what will be changed, the location where the expected result should occur, and the timing and duration of the effect (Yoe and Orth 1996). That is, objectives have dimensions of space and time, and some projects will require that a single objective be assessed at multiple scales to adequately characterize benefits (or impacts).

The environmental benefits and ecosystem services of restoration are influenced by the spatial composition, configuration, and position of the project. Depending on the process of interest (e.g., breeding habitat v. municipal water provision), landscape composition may be optimal under conditions varying from a large area of a single habitat type (e.g., interior forest breeding habitat for a noise-sensitive bird) to a balanced distribution of multiple habitat types (e.g., waterbirds nesting on islands require adjacent wetlands for foraging). Spatial configuration influences available edge and connectivity for numerous processes (e.g., edge utilization for foraging in coastal marshes, hydrologic connectivity for sediment delivery). Lastly, the location of a project is likely to influence its benefits due to cumulative effects in the surrounding landscape (SWS 2000, Baron et al. 2002, Kondolf et al. 2008, Bernhardt and Palmer 2011).

Temporal dimensions of restoration objectives commonly include long-term sustainability and resilience to disturbance. Sustainability requires that a project meet the short-term needs of the current generation without compromising the long-term needs of future generations (Christensen et al. 1996, Fischenich 2006). Ecosystem resilience is characterized by capacity to: recover from disturbance (e.g., reestablishment of wetland vegetation following a hurricane), resist regime change (e.g., vegetation resisting washout during the hurricane), and avoid disturbance altogether (e.g., bird movement prior to the hurricane, Wang and Blackmore 2009). Ecosystems are, to varying degrees, naturally fluctuating environments; thus, in order to deliver sustainable and resilient benefits, objectives for any restoration project should account for the range of conditions likely to be encountered. Degrees of resilience and related risk of unintended restoration outcomes (e.g., crossing a critical threshold) can change over time after a restoration action, which should be reflected by the monitoring plan (Conyngham and Fischenich in preparation).

Techniques for objective setting. Ecosystem restoration objective setting is a particularly challenging task due to complex interactions between the types and categories of objectives. As such, there is not one single technique for setting objectives, but many sources of guidance from which to draw (Yoe and Orth 1996). A few items of particular note are listed below, and the reader is encouraged to examine referenced materials for additional information. Regardless of the technique(s) applied, restoration teams should, at very least: (1) structure objectives to directly relate to identified problems and opportunities and (2) consider the aforementioned techniques for framing objectives as benefits and/or services, structure and/or function, the five objective categories, and respective spatial and temporal dimensions of each.

- *Structured objective setting*: Numerous authors encourage the use of a stepwise process for objective setting. Gregory and Keeney (2002) offer the following steps for objective setting:
    - Step 1: Write down the concerns you want to address. This step involves brainstorming all of the potential elements that may influence the decision and allows ideas to flow freely among team members.
    - Step 2: Convert the general concerns into specific, succinct objectives. This step requires a project team to synthesize a potentially long list of elements from Step 1 into the verb-object format of objectives (e.g., maximize abundance of threatened taxa X).
    - Step 3: Organize objectives. This is the process of separating the ends (fundamental goals) from the means (milestones to achieving goals). Objectives are often structured hierarchically to explain how means contribute to ends.

  - Step 4: Clarify what is meant by each objective. This step requires the project team to critically examine objectives as well as engage sponsors, agencies, and stakeholders. Gregory and Keeney (2002) note that complete and clear objectives may only result from iterative application of these four steps.

- *Application of existing assessments*: Ongoing assessments of environmental and ecological status are becoming increasingly available through groups such as non-profit entities (e.g., NatureServe), state departments of natural resources, and other federal agencies (e.g., NOAA habitat conservation programs, USGS Gap Analysis). Assessments are excellent sources of existing conditions for ecosystems and taxa and often highlight problem areas for restoration. However, planners should be aware of limitations of these assessments and/or missing segments of information (e.g., a fish inventory is unlikely to address a basal resource of the food web such as algae or riparian litterfall).
- *Use of conceptual models*: "Conceptual models are descriptions of the general functional relationships among essential components of an ecosystem. They tell the story of 'how the system works' and in the case of ecosystem restoration, how restoration actions aim to alter those processes or attributes for the betterment of the system" (Fischenich 2008). Conceptual model development can provide a forum to discuss system function and potential alternatives as well as goals and objectives (Jansson et al. 2005, Niemeijer and de Groot 2008).
- *Referenced-based approaches*: Reference ecosystems may also help project teams identify desirable characteristics of a system and natural ranges of variability, and then incorporate those into objectives (Kentula 2000, SERI 2004, Palmer et al. 2005, Pruitt et al. 2012).

Detailed planning objectives should complement and support higher level objectives, forming a hierarchy of nested objectives to serve larger programmatic goals. Higher level objectives may take the form of strategic or tactical objectives for large regional projects (e.g., the Everglades) or national policy-specified objectives (USACE 2000). Correspondence between large-scale strategic objectives and local planning objectives facilitates the design of metrics that translate across multiple levels of decision making and reporting (Seager et al. 2007). At the regional level, there may be multiple agencies and authorities working on different aspects of a large regional project such as oyster restoration in Chesapeake Bay (Deason et al. 2010). Some groups may even work together to develop a regionally applicable approach to measure environmental benefit such as the hydrogeomorphic method of wetland evaluation (Brinson et al. 1995). The process of developing objectives that are nested within a larger hierarchy is challenging, but necessary. As such, efforts should be made to ensure synchronization with established regional and national objectives and priorities (e.g., USACE restoration policies, the Civil Works campaign plan, the Principles and Standards) while maintaining detail sufficient for on-the-ground project planning and implementation. Seager et al. (2007) demonstrate that categorical objectives (as shown in Table 1) can facilitate the nesting and combination of detailed planning objectives within larger strategic objectives. For instance, combining three disparate hydrogeomorphic objectives (e.g., maintain peak flows, abate streambank erosion, and increase summer water depths for recreation) into a single category can facilitate comparison with another nearby project with slightly different hydrogeomorphic objectives.

Evaluating objectives. A set (i.e., list, group, hierarchy) of objectives should be iteratively developed and critically evaluated by the project development team, cost-share sponsor, partner agencies, stakeholders, and other interested parties (e.g., HQUSACE). The following list provides key points of consideration to address in these discussions.

- Desirable objective sets are complete, clear, nonredundant, concise, specific, flexible, understandable, measurable, attainable, congruent, and acceptable (Yoe and Orth 1996, USACE 2000, Tear et al. 2005, Keeney 2007). Not all objectives will meet all criteria, but the overall objective set should exhibit balance among these.
- Objectives should be separate from metrics and alternatives. For instance, the statement "replant 10 acres of riparian habitat" (i.e., a means to an end) confounds the objective of "restoring riparian habitat" (i.e., the end being sought) with the alternative of planting and the metric of acres.
- Key thresholds for achievement should be explicitly noted in objectives, as appropriate (Conyngham and Fischenich in preparation). For instance, if a waterbird requires a minimum nesting-island size of 20-acres to breed, an objective that states "increase nesting-island size" could result in an 18-acre island that does not meet its needs. Additionally, objectives may also have upper bounds (e.g., the same bird may not utilize an island greater than 300 acres).
- Given the interconnectedness of ecosystem processes, dependency among objectives may be present but difficult to determine. For instance, restoration of the hydrologic and sediment transport regime of a river may also restore nutrient cycling. Disentangling these processes may be impossible or unnecessary, but it should, at very least, be considered when developing a hierarchy of objectives and metrics.
- As discussed, objectives reside in a hierarchy of local, regional, agency, and national scale decision making. Critical evaluation of project objectives relative to higher objectives will help the planning team address project efficacy relative to scope, funding, timing, and other limitations of a particular authority.

2-METRIC DEVELOPMENT: Given innumerable ecosystem functions, goods, and services, it is no surprise that ecosystem restoration projects often have multiple objectives. Metrics are measurable properties that quantify the degree to which objectives have been achieved (Reichert et al. 2007). Depending on the objective set, multiple metrics relating to ecosystem structure, function, goods, and/or services may be and often are required to assess the overall benefits associated with a restoration project.

Types of metrics. Ideally, an appropriate metric (or metric set) would be identified early in project planning and applied throughout the project life cycle (i.e., from reconnaissance to operation). However, planning objectives might change as a project moves from reconnaissance to more detailed levels of analyses to post-construction monitoring and adaptive management. Metrics can evolve accordingly to meet the needs of each step (Figure 1). For instance, alternative formulation may best be informed by detailed ecosystem parameters such as temperature or depth, while multi-project investment decisions may be better informed by a single metric of project performance or success. Even so, monitoring project success may once again be best measured by detailed performance measures of temperature or depth. To address shifting needs throughout a project life cycle, five types of metrics common to restoration projects are presented below:

- *Ecosystem parameters*: At the most detailed level of analysis, planning objectives should be specific, measurable targets that highlight desirable outcomes of a project (e.g., mean July water temperature less than 30^{0}C). Ecosystem parameters measure these objectives with the highest resolution of information. Ecosystem parameters are generally affected by an alternative, and forecast over futures with and without the project.

- *Output metrics*: Although ecosystem parameters provide significant data and information, they tend to be integrated into a single output metric that is then considered during cost-effectiveness and incremental cost analyses. (e.g., combination of physical variables into a habitat suitability index and habitat units).
- *Decision factors*: In addition to project outputs, other decision factors likely influence the selected alternative (e.g., relative degree of uncertainty may be used to select from two alternatives that offer identical mean outputs). Decision factors may include ecological thresholds, outputs yielded by incremental investments, influences of uncertainty, risk tolerances of engaged organizations, capacity to reverse or adaptively manage the decision, acceptability to stakeholders, and myriad other "intangibles" that may or may not be easily quantified.
- *Performance measures*: Project performance must be assessed relative to the planning objectives (Palmer et al. 2005, Conyngham and Fischenich in preparation). Monitoring may require detailed process measurement and/or focus on triggering adaptive management actions that support project performance objectives (Fischenich et al. 2011).
- *Process metrics*: In addition to project goals and objectives, the team or agency may have introspective study objectives associated with how the project is conducted (e.g., to increase public comment opportunities, to engage a diversity of agencies in alternative formulation).

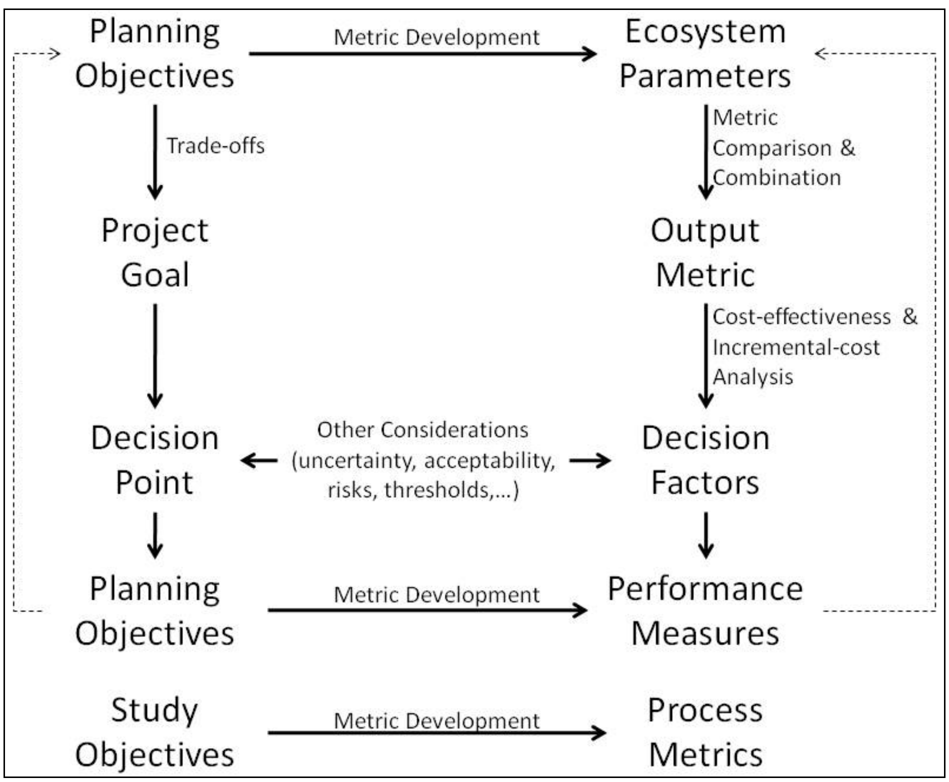

Figure 1. Objectives and associated metric types occurring throughout a project life cycle.

Techniques for metric development and evaluation. Following development of a complete and clear set of objectives, metrics may be identified to evaluate those objectives and inform restoration decision making. McKay et al. (2010) propose a three-step process for developing metrics (Figure 2), which will be reviewed here briefly.

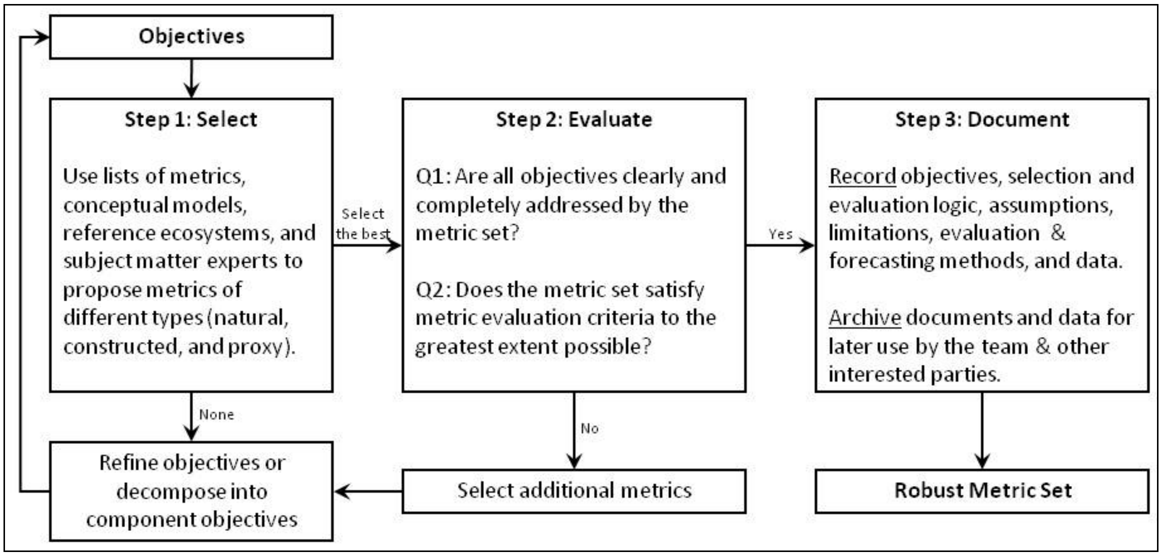

Figure 2. Metric development process (adapted from McKay et al. 2010).

Step 1: Metric Selection. Metric selection must be based on and mapped to specific project objectives. As such, no complete list of universal metrics can exist; however, one need not reinvent the wheel for each project. Existing comprehensive lists of metrics for various ecosystems provide excellent starting points for metric selection (e.g., Thayer et al. 2005). Conceptual models, reference ecosystems, past projects with similar (albeit not necessarily identical) objectives, and subject matter experts are also good sources of appropriate metrics, methods, and available data. At this stage, metric sets should be as comprehensive as possible since metrics will be screened and removed in the evaluation conducted below. However, preference should be given to direct over indirect metrics, as follows (Keeney and Gregory 2005):

- *Natural metric*: A metric that directly measures to what degree an objective is achieved and one that is in general use can be widely recognized and accepted as a standard. This metric type often is a common unit of measure of a given variable, is straightforward, and clearly corresponds to an objective (e.g., water temperature in degrees Celsius is an obvious “natural” metric for the objective “reduce water temperature”).
- *Constructed metric*: A metric that is developed to directly measure an objective when no natural metric exists. Examples include: defined levels (e.g., stakeholder surveys), quality-quantity scales (e.g., habitat suitability index models), and photographic guides (e.g., pictorial guides for selecting marsh connectivity or roughness coefficient). As professional judgment is often required to create a constructed metric, experienced team members and subject matter experts should be engaged to develop a scientifically defensible, well-documented, and appropriate metric.
- *Proxy metric*: A metric that indirectly measures progress toward reaching an objective but is selected because of relative ease or cost of measurement compared to a natural metric is a

type of close substitute for the actual metric (e.g., a collection of indicator species such as benthic macroinvertebrates to represent water quality, geomorphic condition, fish population dynamics, riparian community health, etc.).

Step 2: Metric Evaluation. Once a candidate metric set has been selected, the metric set should be evaluated based on whether it adequately addresses project objectives and meets desirable qualities of metrics. The goal of metric evaluation is to create the most parsimonious metric set possible (i.e., the simplest capable of efficiently measuring objectives). Many criteria have been proposed for evaluating the scientific validity of metrics (e.g., Dale and Beyeler 2001, Orians et al. 2000, Yoe 2002, USEPA 2003, Seager et al. 2007, Niemeijer and de Groot 2008,). Table 3 summarizes these into six fundamental qualities of a "good" metric set (Keeney and Gregory 2005). Each metric need not meet all six evaluation criteria, but the metric set as a whole should address each criterion to the greatest extent practicable. Using these criteria, the restoration team should evaluate the selected metric set, which often results in trading-off one criterion for another. For example, in restoration practice, metric sets often sacrifice comprehensiveness and frequently default to satisfaction of operational criteria.

Table 3. Metric set evaluation criteria (based on Keeney and Gregory 2005).

Criterion	Description
Relevant	Relevant metrics account for specified objectives and priorities of decision makers (e.g., resource significance, project authority) at appropriate spatial and temporal scales and resolution. To maintain scientific validity, a relevant metric is repeatable and verifiable.
Unambiguous	Unambiguous metrics clearly measure consequences of alternatives and are not obscured by direction, magnitude, scale, thresholds, or uncertainty.
Direct	Direct metrics address objectives as clearly as possible. This underscores the importance of measuring what can be controlled by a given action since restoration success can be reliant upon many variables beyond the control of the restoration team.
Operational	Operational metrics are logistically and analytically achievable with available resources and capability. If a metric cannot be assessed, forecasted, or monitored within budget, time, or labor constraints, then it cannot feasibly inform decisions.
Understandable	Understandable metrics clearly communicate decisions to those interested in the analysis.
Comprehensive	Comprehensive metric sets address the suite of objectives and cover the potential range of consequences. In terms of implementation, comprehensiveness is often captured through multiple metrics and well-designed monitoring and forecasting programs.

Step 3: Metric Documentation. The final step in metric development is an obvious, but often overlooked issue – documentation and storage. Metric documentation is critical to help others understand why a metric was used, what objective(s) it addressed, what logic was used to develop the metric, what support exists for use of the metric, what the assumptions and limitations are, how professional judgment is or is not used in the metric, what techniques should be applied to forecast or monitor the metric, and a host of other supporting information. Metric documentation (and data) should be archived and stored in readily available locations (e.g., a website, a District library) for use in future restoration projects.

3-METRIC COMBINATION AND COMPARISON: Project planners use metrics to evaluate, compare, and weigh trade-offs in benefits associated with alternative restoration actions. Broadly defined, a trade-off is giving up one thing to gain another (Yoe 2002). When metrics are similar, trade-off analysis may be straightforward (e.g., comparing economic benefits and costs in terms of present value in dollars). However, when metrics are dissimilar, trade-offs become less clear (e.g., How much does one habitat unit cost? What is the value of that habitat unit relative to some unit of water quality improvement?). In simple decisions with similar or few metrics, comparing the benefits and costs of an alternative may be relatively straightforward; however, as problem complexity increases, more advanced techniques for metric combination may be required to facilitate decision making. This section briefly reviews techniques for metric comparison and combination and provides guidance for selecting a technique.

Techniques for metric comparison. The ability to compare metrics that measure diverse objectives is critical to ecosystem restoration decision making. Techniques facilitating metric comparison and combination have been well studied and may be coarsely divided into four major categories: (1) narrative description, (2) arithmetic combination, (3) multicriteria decision analysis (MCDA), and (4) interdependent combination (Table 4).

These categories are often combined (or nested) to meet the needs of a particular problem. For instance, two habitat suitability indices could be combined with arithmetic averaging and then combined with a third index via geometric averaging, which would assume that the third parameter can act as a limiting factor on the system (nested combination). The overall habitat suitability index generated is then combined with the project extent, in acres, to generate habitat units, which could be compared between two projects because of conversion to a consistent unit.

Evaluating comparison techniques. "Each [metric comparison] method has specific benefits and drawbacks. The different nature of methods means that one cannot a priori determine the superior method for a particular application" (Linkov et al. 2011). Table 4 presents comparison techniques with increasing complexity from top to bottom. Although most projects would benefit from the application of sophisticated metric comparison techniques such as MCDA, the method applied to a particular project should reflect project needs and be commensurate with project complexity and risk of failure. The following evaluation criteria and guiding questions are offered for use in determining the appropriate metric comparison technique:

- *Practicality*: What resources (time, cost, expertise) are available for use in the analysis?
- *Transparency*: What is the public profile of the decision? Are analyses commensurate with the importance of the decision? What are the expected external impacts of the decision?
- *Value*: What is the role of value in the decision? Are some objectives and metrics more important than others from scientific or social perspectives?
- *Analytical Requirements*: Are there multiple metrics? Is there a need for quantitative combination? Can scoring or indexing meet the project needs? Do the metrics have equivalent units? Can metrics be combined linearly (e.g., arithmetic mean, summation)? Are there non-linear effects associated with combination (e.g., geometric mean, thresholds)? Do metrics need to be transformed to a consistent scale for comparison?

- *Uncertainty*: How much uncertainty is there in assessments or forecasts of the metrics? Could this uncertainty alter the decision made? To what degree should methods be able to track uncertainties?
- *Dependency*: Are objectives interdependent? Are these dependencies quantifiable?

Table 4. Overview of techniques for metric comparison and combination.

Technique	Description, Examples, and Select References
Narrative Description	For simple decision problems, metric comparison and trade-off may be straightforward, rapid, and require little or no analysis. However, the more metrics one is comparing, the more challenging trade-offs become. Yoe (2002) suggests that analysts cannot compare beyond 6-7 metrics in parallel. Techniques using qualitative comparison include (Linkov et al. 2009): Listing evidence: This is the simplest application of weight-of-evidence decision making whereby multiple metrics are presented in parallel (e.g., Habitat Units, breeding pairs, and nitrate-nitrogen concentration are listed for each alternative relative to the future without project). Best professional judgment: In this more synthetic version of listing evidence, metrics are integrated using professional judgment and experience, logic, or causal criteria (e.g., An analyst uses prior experiences and knowledge to integrate the lines of evidence to identify the “best” alternative based on their judgment.). Scoring and indexing: Individual lines of evidence are scored or weighted by the analyst and combined quantitatively (e.g., USACE budget ranking criteria for ecosystem restoration projects, USACE 2007).
Arithmetic Combination	A variety of simple arithmetic techniques exist for combining dissimilar metrics. Simple arithmetic: In some cases, metrics may be of the same units and simply from different locations (e.g., nesting pairs from two sides of a river) or benefit streams (e.g., economic benefits of recreation and water supply from the same reservoir), and thus, may be combined through simple summation or averaging. Nested combination: In other cases, simple arithmetic may be nested together to capture a known process (e.g., habitat suitability indices that combine arithmetic and geometric averaging to account for limiting factors). Conversion to consistent units: Dissimilar metrics may be converted into consistent units for direct comparison. For instance, many benefits of ecosystem structure, function, and process may be accounted for in terms of marketizable ecosystem goods and services (Heal et al. 2005, MEA 2005, Brown et al. 2007) or the embodied energy (i.e. emergy) of a given system (Odum 1996). This technique is highly limited by the availability and quality of the conversion factor(s). Transformation to consistent scales. Metrics may also be transformed or normalized to an equivalent scale (e.g., 0 to 1, Yoe 2002). Common examples include habitat suitability indices and inter-alternative comparison (e.g., dividing project benefits of a given alternative by a future without project condition). Various normalization formulae and benchmarks may be applied with varying strengths and weaknesses (See Yoe 2002). In particular, “reference” conditions may provide a relevant, ecologically meaningful scale for normalization (Pruitt et al. 2011).
Multicriteria Decision Analysis	“Multicriteria decision analysis is a set of methods designed to ensure that a synthesis of multiple sources of information is documented and directed toward a stated goal” (Linkov et al. 2011). This technique uses weighted combination of metrics to capture their relative importance in a decision. Although not explicitly weighted, even the simplest arithmetic combination methods are implicitly weighted; that is, all parameters are assumed to have equal weight and import. Although weights are subjective and derived from expert opinion in MCDA, judgments are collected using visible and traceable methods. More thorough reviews of MCDA along with example restoration applications can be found in: Kiker et al. (2005), Suedel et al. (2010), Holzmueller et al. (2011), and Linkov et al. (2011).
Interdependent Combination	Given the interconnectedness of ecosystems, objectives may be intimately related to other objectives (Deason et al. 2010). For instance, increasing oyster abundance and reducing turbidity are tightly coupled due to water filtration by oysters and habitat suitability associated with water clarity. Analysis of dependencies can range in complexity from simple linear dependency of fish passage projects (e.g., Conyngham et al. 2011) to intricate Bayesian belief networks (e.g., Schultz et al. 2011).

4-HYPOTHETICAL CASE STUDY: Muddy River is a hypothetical perennial river with a broad floodplain consisting of cottonwood forests, riparian wetlands, oxbow ponds, and side channels. Over the past several decades, the river and floodplain have undergone significant changes due to urbanization and dam construction. The cumulative effect of these stressors is the disruption of the original hydrologic regime, main stem incision, and reduced river-floodplain interaction, which has reduced wildlife habitat quality and quantity and facilitated encroachment of harmful exotic trees. In partnership with state authorities, USACE is planning an ecosystem restoration project with the goal of restoring the structure and function of the Muddy River floodplain ecosystem.

A multi-agency (federal, state, and local agencies, academia, NGOs, and private consultants), multi-disciplinary (ecologists, geologists, engineers, economists) project delivery team was created to set objectives, develop a conceptual model, identify an approach for assessing environmental benefits, and formulate alternatives to address degradation of Muddy River floodplain. The following sections discuss the team's approach to environmental benefits analysis as it relates to objective setting, metric development, and metric comparison. Based on the project objectives (discussed below, listed in Table 5), four alternatives were identified by the multi-agency team in a series of workshops.

Table 5. Objectives and metrics for Muddy River floodplain restoration.

Objectives	Metrics
HYDROGEOMORPHIC: Reestablish river-floodplain connectivity. 1.1 Increase floodplain inundation frequency and duration for native cottonwood seed germination.	1.1 Acreage of inundation during 1-yr event. 1.2 Acreage of inundation during 2-yr event. 1.3 Duration of inundation during 2-yr event.
BIOGEOCHEMICAL: Increase water quality. 2.1 Promote floodplain denitrification.	2.1 Acreage of wetland inundation during 2-yr event. 2.2 Duration of inundation during 2-yr event.
BIOLOGICAL SYSTEMS: Promote a healthy and resilient biological community. 3.1 Increase floodplain breeding habitat for imperiled Songbird-X to equivalent levels seen in the reference ecosystem. 3.2 Increase side channel refuge habitat for threatened Fish-Y. 3.3 Decrease extent of exotic riparian plants.	3.1 Habitat units (quantity and quality) for Songbird-X as specified in Habitat Evaluation Procedure handbook (i.e., bluebook). 3.2 Habitat units for Fish-Y as specified in Habitat Evaluation Procedure handbook (i.e., bluebook). 3.3 Acreage with more exotic than native trees.
SOCIOECONOMIC: Provide recreational opportunities. 4.1 Expand existing floodplain recreational trails to connect to surrounding neighborhood trail systems.	4.1 Linear feet of paved trails in study area. 4.2 Linear feet of unpaved trails in study area.
CULTURAL-PERSONAL VALUES: Promote interaction of the local community with the ecosystem. 5.1 Create educational opportunities addressing the unique flood-driven floodplain ecosystem. 5.2 Provide subsistence fishing access.	5.1 Number of educational booths, posters, websites, and media outlets (e.g., magazine articles). 5.2 Linear feet of trails from the historically-disenfranchised neighborhood near the study area.
STUDY: Collaboratively develop restoration plans. 6.1 Increase opportunities for effective public engagement 6.2 Increase information exchange with public.	6.1 Number of days between public meetings. 6.2 Number of days between stakeholder meetings. 6.3 Number of outlets for disseminating project updates (i.e., print media, websites, meetings).

- Alt-0: No action (future without project).
- Alt-1: Creation of high-flow channels accessible at 2-yr, 5-yr, and 10-yr return intervals.
- Alt-2: Creation of riparian wetlands and oxbow ponds inundated at 2-yr return intervals.
- Alt-3: Physical removal of exotic riparian trees and replanting of native cottonwoods.

Objective setting. Multiple objective-setting techniques were applied for the Muddy River floodplain restoration. The project team iteratively applied the following four-step objective setting process (Gregory and Keeney 2002). Each successive application engaged a larger audience (i.e., USACE planners; USACE planning, project management, design, and operations teams; combined USACE-State team; resource agencies; pertinent stakeholder groups; and the public). During each iteration, objectives were added and refined, and greater buy-in was obtained. This process resulted in ten objectives (Table 5).

Step 1: Write down the concerns you want to address. This step involves brainstorming all of the potential elements that may influence the decision. It also involves allowing ideas to flow freely among team members. The team examined the structure and function of a reference ecosystem in a neighboring, undeveloped watershed to identify what magnitude of change and range of variability would be appropriate to restore the ecosystem. The team also benefitted from the development of a conceptual model which helped structure thinking about the drivers, stressors, and expected response of the ecosystem. Lastly, the project team drew heavily from existing and ongoing assessments of imperiled taxa and impacted habitat types conducted by state and federal resource agencies (e.g., U.S. Fish and Wildlife Service, State Department of Natural Resources) and non-profit groups (e.g., Audubon Society, The Nature Conservancy).

Step 2: Convert the general concerns into succinct objectives. This step requires a project team to synthesize a potentially long list of elements from Step 1 into the verb-object format of objectives. For instance, degradation of cottonwood forests was identified as a project concern in Step 1. However, this was restated as "Increase floodplain inundation frequency and duration for native cottonwood seed germination" (Obj-1.1) to adequately capture the cottonwood life history element most threatened (i.e., seed germination), as determined by research in the region.

Step 3: Structure objectives. This step focuses on the process of separating ends (fundamental goals) from means (waypoints to achieving goals). Objectives are often structured hierarchically to explain how means contribute to ends. This study structured objectives into the categories of hydrogeomorphology, biogeochemistry, biological systems, socioeconomics, and cultural-personal values to clarify the primary elements of the ecosystem being restored (i.e., the ends). Socioeconomic and cultural-personal values were minimally considered and stated primarily in a qualitative sense to facilitate communication between planning, funding, and stakeholder groups. Lastly, objectives associated with the restoration planning process (i.e., study objectives) were separated from those measuring project benefits.

Step 4: Clarify what is meant by each objective. By iteratively developing objectives with multiple internal and external groups, the objective set became more focused, clear, and complete as the planning progressed.

Metric development. Sufficient description of all objectives and metrics (Table 5) exceeds the scope of this document. However, metric development will be illustrated for floodplain inundation metrics associated with Objective 1.1. Numerous floodplain inundation metrics could be developed, ranging from areal inundation associated with a particular river stage to flow velocity during inundation events required for seed burial in fresh alluvium. Based on knowledge of the system, the project team selected a number of potential metrics for evaluation: maximum acreage of inundation during 1-yr, 2-yr, 10-yr, and 100-yr flood events, duration of inundation during 1-yr, 2-yr, 10-yr, and 100-yr flood events, and frequency of overbank flows of any magnitude. Evaluating these metrics against the specified criteria (relevant, unambiguous, comprehensive, direct, operational, and understandable), the project team narrowed to the three metrics specified in Table 5 because cottonwood seed banks are dislodged at stages near 2-year flood events and banks are overtopped and dropped seeds are transported during 1-year events. Metric selection and evaluation was documented in the project report and utilized peer-reviewed plant biology literature, studies of local hydrology and hydraulics, and review by local experts. In some cases, multiple metrics were used for a single objective (e.g., Objective 1.1), and some metrics address multiple objectives (e.g., metric 1.3 and metric 2.2).

Metric comparison. Multiple metric comparison techniques were applied to the Muddy River restoration to examine the consistency in decision making using multiple methods. Prior to comparison, each ecosystem parameter (metric) from Table 5 was forecast for each alternative and annualized over the 50-year life of the project (Table 6). Socioeconomic and cultural-personal metrics were forecast and presented to stakeholder groups. These metrics were excluded from quantitative exercises of combining ecosystem parameters into an output metric.

Narrative techniques were deemed inappropriate for this project due to: (1) the analytical complexity of trading-off eight hydrogeomorphic, biogeochemical, and biological metrics and (2) the need for transparent methods of identifying the relative importance of individual metrics. To facilitate metric combination, all metrics were transformed (normalized) to a 0 to 1 scale based on their relative difference from the future without project as (Alt-x – Alt-0) / Alt-0 (Note: Because positive effect is associated with decrease, absolute change in metric 3.3 was used.). Two combination techniques were applied to facilitate alternative comparison: (1) arithmetic averaging and (2) weighted, arithmetic averaging. Metric weights were assigned by the interagency team prior to alternatives analysis based on uniform agreement that restoring imperiled taxa is more crucial than cottonwood reproduction or riparian denitrification. Each combination algorithm was applied to the full set of metrics (i.e., un-nested) as well as the average of the categorical outputs (i.e., nested). Table 6 presents the results of this analysis for each alternative and combination algorithm. Un-nested and nested combination resulted in the same relative ranking of alternatives for unweighted arithmetic averaging (i.e., Alt-2, Alt-1, Alt-3, Alt-0). Un-nested and nested combination also resulted in the same relative ranking of alternatives for weighted arithmetic averaging (i.e., Alt-1, Alt-2, Alt-3, Alt-0). However, the rankings differ between unweighted and weighted averaging, demonstrating how assuming equal weight among all objectives (i.e., unweighted arithmetic averaging) could obscure important conclusions. Lastly, metric combination should not obscure important conclusions of the project, and if it does, then alternative algorithms should be considered. As such, individual metrics were examined to ensure aggregation did not conceal subtleties of an alternative (e.g., a zero score for a given metric), and the algorithms were deemed appropriate for this analysis.

Table 6. Metric combination for Muddy River floodplain restoration.

Raw Output Metrics (Units specified in Table 5)

Category	Metric	Alt-0	Alt-1	Alt-2	Alt-3
Hydrogeomorphic	1.1 1.2 1.3	100 150 5	150 200 8	150 200 10	100 150 5
Biogeochemical	2.1 2.2	90 5	100 8	120 10	90 5
Biological Systems	3.1 3.2 3.3	80 30 20	120 60 15	100 40 12	80 30 5
Socioeconomic	4.1 4.2	1,500 1,200	2,000 1,500	1,500 1,200	1,500 1,200
Cultural-Personal	5.1 5.2	5 100	8 500	8 500	8 500

Unweighted Arithmetic Averaging of Normalized Outputs (FWOP-Alt)/FWOP

		Un-Nested				Nested			
Category	Metric	Alt-0	Alt-1	Alt-2	Alt-3	Alt-0	Alt-1	Alt-2	Alt-3
Hydrogeomorphic	1.1 1.2 1.3	0.00 0.00 0.00	0.50 0.33 0.60	0.50 0.33 1.00	0.00 0.00 0.00	0.00	0.48	0.61	0.00
Biogeochemical	2.1 2.2	0.00 0.00	0.11 0.60	0.33 1.00	0.00 0.00	0.00	0.36	0.67	0.00
Biological Systems	3.1 3.2 3.3	0.00 0.00 0.00	0.50 1.00 0.25	0.25 0.33 0.40	0.00 0.00 0.75	0.00	0.58	0.33	0.25
Average Rank		0.00 4	0.49 2	0.52 1	0.09 3	0.00 4	0.47 2	0.54 1	0.08 3

Weighted Arithmetic Averaging of Normalized Outputs

				Un-Nested				Nested			
Category	Metric	Importance	Weight	Alt-0	Alt-1	Alt-2	Alt-3	Alt-0	Alt-1	Alt-2	Alt-3
Hydrogeomorphic	1.1 1.2 1.3	2 2 2	12 12 12	0.000 0.000 0.000	0.060 0.040 0.072	0.060 0.040 0.120	0.000 0.000 0.000	0.000	0.057	0.073	0.000
Biogeochemical	2.1 2.2	3 3	5 5	0.000 0.000	0.006 0.030	0.017 0.050	0.000 0.000	0.000	0.018	0.033	0.000
Biological Systems	3.1 3.2 3.3	1 1 1	18 18 18	0.000 0.000 0.000	0.090 0.180 0.045	0.045 0.060 0.072	0.000 0.000 0.135	0.000	0.105	0.059	0.045
Average Rank				0.000 4	0.065 1	0.058 2	0.017 3	0.000 4	0.060 1	0.055 2	0.015 3

5-CONCLUSIONS: Although it may be an obvious statement, metrics, models, and data do not make decisions, people do. Objectives and metrics contribute to these decisions in two fundamental ways: (1) inform the process and help the team make the right decision and (2) tell the story of the decision and report the benefits of the project. As evident in this document, metrics are merely the quantitative expression of objectives, and the only way to develop good metrics is to first develop good objectives!

This review has provided considerations and guidelines for objective setting, metric development, and metric comparison by addressing each topic from the perspective of two questions: What techniques are available? How does a restoration planner evaluate and choose among techniques?

Development by one party or discipline may skew objectives and metrics to a particular field of study or value system. For instance, given the objective "increase river-floodplain connectivity," a metric may be proposed by a civil engineer as the percentage of time river stage is greater than 4 m, by a biogeochemist as the ratio of river to floodplain nitrate uptake, or by an aquatic ecologist as the acreage of floodplain spawning habitat provided during critical time periods. All of these measures may be valid metrics for achieving specific goals. Each of the topics presented in this technical note requires the bridging of knowledge from multiple fields of study and value systems; thus, a facilitated discussion among experts, professionals, and stakeholders may be required to reach consensus. Lastly, objectives and metrics are not developed in a single step. Consequently, the restoration team should plan to develop, evaluate, collaborate, refine, and iterate.

ADDITIONAL INFORMATION: Research presented in this technical note was developed under the Environmental Benefits Analysis (EBA) Research Program. The USACE Proponent for the EBA Program is Ms. Rennie Sherman and the Technical Director is Dr. Al Cofrancesco. The authors gratefully acknowledge the thoughtful comments and contributions provided by Dr. John Bergstrom, Dr. Alan Covich (University of Georgia), Dr. Melissa Kenney (Johns Hopkins), Mr. Mark Harberg (Omaha District), Mr. Andy Loschiavo (Jacksonville District), Dr. Bruce Pruitt, Mr. Matthew Bates, and Dr. Burton Suedel (ERDC Environmental Laboratory) at two EBA-sponsored workshops on metric development and application. Technical reviews were provided by Mr. Shawn Komlos (Institute for Water Resources), Mr. John Wright (North Atlantic Division, retired), Dr. Alan Covich (University of Georgia), and Mr. Jock Conyngham (ERDC Environmental Laboratory).

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> McKay S. K., I. Linkov, J. C. Fischenich, S. J. Miller, and J. Valverde 2012. *Ecosystem restoration objectives and metrics*. EBA Technical Notes Collection. ERDC TN-EMRRP-EBA-12-16. Vicksburg, MS: U.S. Army Engineer Research and Development Center. *http://cw-environment.usace.army.mil/eba/*

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