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Reference Concepts in Ecosystem Restoration and Environmental Benefits Analysis (EBA): Principles and Practices

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OVERVIEW: Though reference condition concepts are not explicitly required for use by U.S. Army Corps of Engineers (USACE) Civil Works Ecosystem Restoration practitioners, these concepts are often applied during ecosystem restoration project planning. Describing restoration objectives in a scientifically founded yet easily understandable way remains a challenge to the ecosystem restoration community. The application of reference concepts helps restoration practitioners overcome these challenges. A basic understanding of ecosystem structure and function through study and characterization of reference condition can influence how planning teams formulate planning objectives and alternatives, benchmark future ecological conditions, evaluate performance and sustainability, and seek to justify investments. Site-based reference characteristics, functions, and landscape position are critical considerations when evaluating plan alternatives in a systems context. Likewise, coherent approaches to developing references can serve as assets to planners investigating opportunities for ecosystem restoration investments at project, watershed, and system scales.

The field of study for reference ecosystems is vast, with a recent emphasis on standardizing definitions, interpretation, and methods to create a more rigorous and pragmatic framework for ecosystem restoration practitioners (Stoddard et al. 2006, Dufour and Piegay 2009). A scientifically valid lexicon and standardization of techniques for applying reference conditions during investigations and planning of ecosystem restoration actions can help to ensure that these concepts are applied properly to ecosystem restoration (Stoddard et al. 2006). Ecosystem restoration history and state of the science are broadly established and reference concepts are widely used. However, the current system of approaches has not been standardized for all aquatic ecosystems, leaving gaps within and between science and practice relevant to ecosystem restoration activities conducted by USACE. Based on the breadth and variety of techniques and practices that influence Corps ecosystem restoration planning activities, it is proposed that the ecosystem restoration community would benefit from:

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- A common understanding of the relationships between characteristics of reference systems and attributes of ecosystems such as “naturalness,” “function,” and “resilience/self-regulation,” inclusive of a common lexicon.

- Guidelines and methods for identifying, selecting, defining, and applying reference approaches to the characterization, evaluation, and comparison of ecosystem restoration project baseline conditions and planning alternatives.

- A thorough scientific framework for considering the potential role(s) of reference condition during Environmental Benefits Analysis (EBA).

This technical note provides a background and summary of the scientific foundation for applying reference condition concepts to ecosystem restoration, project planning, and EBA. Information is presented on the state of reference approach practices and the how the most practical of identified practices might be applied to ecosystem restoration efforts. The authors discuss gaps that seem to exist between the state of the science and the practice associated with how reference approaches are used in the pursuit of ecosystem restoration. A strategy is proposed to better couple the science with the practice by describing a set of functional reference condition types, defining applicable reference approaches and criteria, and introducing the potential for use of reference condition as a foundation for EBA. Ecosystem restoration topics that can be streamlined and improved through this strategy include a) which reference approach to use, b) what type of reference target(s) to use, c) which parameters to measure, d) how to compare and prioritize dissimilar projects at the program scale, e) how to reconcile less-than-perfect datasets, and f) how to incorporate reference condition comparisons into the practice of restoring ecosystems. This technical note provides the scientific foundation necessary to address these topics; further detail and additional specific application guidelines for reference concepts in EBA are provided in Pruitt et al. (2012).

BACKGROUND: Ecosystem references have been used to set ecosystem restoration or mitigation priorities, develop ecosystem restoration designs, support ecological monitoring programs, evaluate sustainability, and set and assess restoration success criteria (Steyer et al. 2006, Busch and Trexler 2003, Angradi 2006, Roni 2005, Harris 1999, Moore et al. 1999, Stephenson 1999, Society for Ecological Restoration International (SERI) 2004, Asbjornsen et al. 2005, Dodds et al. 2006, Christensen et al. 1996, Short et al. 2000, Hobbs 2003). The practice of restoring ecosystems requires planning teams to characterize degradation that has occurred or will occur and change that is expected to result from proposed restoration measures, with associated benefits of those changes. This is most readily achievable when a benchmark – a characterization of state, trend, or range of conditions representative of the ecosystem of interest – has been established. A benchmark can be used to help practitioners understand what changes in system characteristics might be necessary to achieve a target or otherwise desired future condition. This can be particularly helpful in communicating which attributes of a naturalistic, functioning, and self-regulating system are being reestablished via restoration of significant ecosystem function, structure, and dynamic processes that have been degraded (USACE 1999a, 1999b, 2000). In this context, “degraded” refers to an altered ecosystem condition that is not naturalistic, functioning, or self-regulating.

A first step in characterizing the reference ecosystem “condition” is classifying the system (i.e., land cover classes, aquatic classes, etc.). Because this is so fundamental, classification may be taken for granted and its importance undervalued, but it can contribute greatly to the identification of federal interest and potential demand/role for federal involvement. In ecological terms, classification is the systematic arrangement of plants, animals, landforms, etc., in groups or categories according to established criteria, common properties, intrinsic characteristics, relative abundance, distribution, and/or associations. Classifying current, past, and potential conditions supports development of conceptual models, development of planning objectives and selection of metrics, and provides critical insight necessary to support selection of a reference approach (discussed below).

At the most basic level, ecosystem classification is important to project planning because it:

1. Facilitates communication of ecosystem characteristics, structures/functions, and possible environmental benefits.
2. Helps characterize intra-class (within) and inter-class (between) variability. The intent is to decrease intra-class variability and increase inter-class variability.
3. Helps differentiate between ecosystems by requiring thorough development of a more resolved level of understanding.
4. Facilitates recognition of similarities.
5. Aids in identifying applicable and appropriate metrics to be assessed.
6. Helps to develop appropriate and specific planning/design restoration goals (as a function of ecosystem class).

With specific respect to reference conditions, classification is important because it:

1. Expedites identification of the appropriate reference condition.
2. Facilitates discussions of baseline or background conditions.
3. Facilitates extrapolation of reference conditions and associated metrics, and the formulation of regional indices.
4. Improves capacity to perform statistical analysis, ordination, and stratification by narrowing selection of reference ecosystem metrics.
5. Aids in identifying natural variability and thresholds within an ecosystem.

REFERENCE CONCEPTS AND TERMINOLOGY: Although they may not use the same specific terms, all restoration practitioners adopt and utilize reference concepts in their work. At its most inclusive, an ecosystem “reference” represents some target, benchmark, standard, model, or template from which or to which ecosystem biological integrity, structure, function, condition, or relative health are compared (Smith et al. 1995, Brinson and Rheinhardt 1996, U.S. Bureau of Land Management (USBLM) 1995, Costanza et al. 1992, Boulton 1999, Jensen et al. 2000, Davis and Simon 1995, Barbour et al. 1999, Karr and Chu 1999, Fletcher et al. 2003, Bailey et al. 2004).

For example, practitioners determine that an ecosystem has been altered by comparing what they see on the ground to some standard (real or virtual) representing a non-altered condition. Comparison to a standard constitutes use of a reference. This standard might be expressed as a parameter range or index such as a habitat suitability index (HSI), a known threshold such as a limiting temperature, or a measured rate of some process expected in that setting.

The term "reference" is so broad, however, as to be practically meaningless without refinement. Reference is most basically a point of conceptual, spatial, or temporal comparison – a site, condition, state, process, function, etc. – to which one can "refer." Institutionally, however, it has come to represent a high functioning condition or restoration target as discussed above. The European Water Framework Directive (European Communities (EC) 2000) requires stream reference conditions representing "high ecological status;" Rosgen (1994) bases stream design on a "stable reference reach;" the Reference Condition Approach (RCA), in freshwater aquatic ecosystems, variably defines a reference site as "minimally exposed to human stressors" (Bailey et al. 2004), "least or minimally impaired" (Bates-Prins and Smith 2007), "minimally impacted" (Leland et al. 2000) or "unstressed" (Reece and Richardson 2000). The U.S. Environmental Protection Agency (USEPA) Environmental Monitoring and Assessment Program (EMAP) defines reference condition as a set of ecological attributes representing a "condition continuum from the worst possible condition to the best possible condition" (USEPA 2010). This latter, more expansive, definition of reference condition is especially useful for applying reference concepts to EBA. The concept terms *reference domain, reference ecosystem*, *reference condition*, and *reference approach*, defined below, form the basis for the use of the term reference as described herein.

The *reference domain* is a set of reference sites located within a geographic region, ecoregion, or hydro-physiography. Though specific reference sites can function as restoration targets and establish reference standards applicable to development of success criteria and performance standards, reference conditions as related to reference domain represent the range of variability within an ecosystem type or class in a given region or area (Smith et. al. 1995). Consequently, the range of variability can include natural processes and anthropogenic disturbances and associated stressors. This concept sets the stage for development of regional indices – the basis for characterizing regional reference conditions to develop index-based ecosystem models, as for the hydrogeomorphic (HGM) method and others (Brinson 1993, Smith et. al. 1995).

A *reference ecosystem* can be defined as one or more existing, former, or hypothetical ecosystems that serve as a guiding image for ecosystem restoration or mitigation projects. The reference ecosystem is often thought of as the "best" representation(s) of a particular class of ecosystem, but several other constructs are possible. For example, a wetland in a pre-disturbance or pre-alteration state may serve as a reference for an activity that aims to restore that wetland, even if all knowledge is limited to an understanding of the wetland in its altered state. Alternatively, the reference ecosystem for a wetland restoration project might have been drawn from measurements of a number of different wetlands in a similar physiographic region that results in a hypothetical ecosystem representing typical self-moderating conditions.

A *reference condition* is the set of attribute values or quantifiable characteristics of the reference ecosystem. Physical, chemical, or biological parameters of ecosystem structure or function can be represented by a single value or a distribution (Schumm 1988, Swanson et al. 1993, Pickett and Parker 1994, White and Walker 1997, Landres et al. 1999, Nestler et al. 2010). Reference conditions can be developed using current or historical information (Egan and Howell 2005, Perkins et al. 2011), paleoecological data (Brenner et al. 1993, Smol 2008), experimental data (Boerner et al. 2008), conceptual, empirical, or quantitative models (Nestler et al. 2007), or well-documented professional judgment. More detailed descriptions of reference condition types and data for the development of each are provided below.

A *reference approach* is a set of assumptions and techniques for characterizing and applying reference ecosystems and reference conditions to practices associated with ecosystem restoration (discussed in more detail in subsequent sections). Each reference approach can make use of one or more of the reference condition types defined below.

REFERENCE CONDITION TYPES: Alternative definitions representing differences in time from disturbance or alteration, amount of degradation, or departure from a natural condition provide a reasonable, practical set of reference condition types (Table 1, Stoddard et al. (2006)). Of the broad field of definitions, seven are generally and practicably applicable for use in assessment, design, and monitoring components of ecosystem restoration.

Table 1. Reference condition types applicable to aquatic ecosystem restoration (modified from Stoddard et al. (2006)).

Historical Condition Pre-Agriculture (HCPA)	Prior to intensive agricultural activity, meaning, "…very low pressure, without the effects of major industrialization, urbanization and intensification of agriculture, and with only very minor modification of physicochemistry, hydromorphology and biology." (Wallin et al. 2003)
Historical Condition Pre-Industrial (HCPI)	Prior to industrialization and urbanization in areas of influence to the ecosystem (DuFour and Piegay 2009)
Historical Condition Pre-Disturbance (HCPD)	Prior to major impact or specific alteration or disturbance in an ecosystem (DuFour and Piegay 2009)
Minimally Disturbed Condition (MDC)	A condition representing the absence of local human disturbance, while recognizing that minimal disturbance may be present due to human activities affecting regional/global processes (e.g., climate change, deposition of atmospheric contaminants below the threshold required to have measurable impact on an ecosystem, etc.).
Least Disturbed Condition (LDC)	A condition representing the least amount of human disturbance or alteration in the current landscape context. In other words, “the best of what is left.”
Best Attainable Condition (BAC)	The BAC represents a potential condition that could be achieved following the implementation of all available best management practices at a site. The BAC reflects a desired future condition given current constraints; thus, it differs from the other reference conditions.

Historical condition (HC) is a category of reference states that is probably the most used in ecosystem restoration, but is least standardized and must be carefully evaluated in terms of interpretation of various definitions and in availability, organization, quantity, and quality of data. For example, when the HC is characterized as “pristine conditions,” it can be problematic for use in ecosystem restoration programs or for EBA when consistency across projects is required. Additionally, the implications of using an HC as a reference or restoration target include the possibility that the historical state is no longer achievable or sustainable under present or future forecasted conditions. To illustrate this difficulty, consider Stoddard et al. (2006), who describe three historical conditions: pre-settlement, pre-European, and pre-(intensive) agriculture. The first two conditions have relatively little applicability to conventional ecosystem restoration. Historical condition pre-intensive agriculture (HCPA) is defined as a time in the past that represented very low pressure human habitation without industrialization or intensive agricultural practices. In some areas, this condition might only be decades in the past, and could prove practical for field use.

To provide more meaningful definitions for ecosystem restoration, a pre-industrialization and urbanization (HCPI) category and a pre-disturbance or major impact (HCPD) category (DuFour and Piegay 2009) are added. These states describe more recent changes and may be more applicable to practicable restoration as well as having much greater data availability. The term "disturbance" can imply natural or human-induced alterations that result in degradation, though anthropogenic alterations are more commonly associated with persistent degradation requiring restoration intervention. HCPD can be characterized immediately prior to an isolated catastrophic disturbance, so it can be on the order of months to years in the past, whereas HCPI may be decades or centuries in the past, depending on location and the extent to which impacts are significant. Important to any characterization of an HC is appropriate documentation – the capability to adequately characterize a past condition for any application to ecosystem restoration may be limited by data availability and quality control, particularly if an HC is being used to determine ecological trajectory or future conditions.

<u>Minimally disturbed condition</u> (MDC) represents a current characterizable condition in the absence of local human-induced alteration, while recognizing that minimal disturbance may be present due to human activities affecting regional/global processes. The MDC is typically characterized as "really close to pristine conditions." The MDC is a "best alternative" benchmark for reference ecosystem integrity that can be used in ecosystem restoration and EBA, though is often difficult to locate. Truly undisturbed systems may not realistically occur any longer given global climate effects, regional or landscape stressors, and other long-term climatic or geologic change. Where an MDC cannot be found, an appropriately documented HC may be closer to representing a minimal level of disturbance than any current available least disturbed condition (described below). Additionally, caution should be exercised, as it is possible that the MDC may be in transition to a state that has not yet been observed or may be subject to a trajectory of undesired change that has not yet manifested in collected datasets.

<u>Least disturbed condition</u> (LDC) represents a current analogous condition that shows the least amount of degradation. As opposed to the MDC, an LDC represents further departure from a pristine state and is typically characterized as "this is the best we could find." This type of reference is typically used when other sources of data are lacking, though the LDC should not be used if the lowest amount of degradation is still not functional. The LDC is often sought for use in ecosystem restoration to provide a contemporary physical comparison for site conditions (i.e., headwaters, free-flowing river reaches, etc.), though identifying which ecosystem is "least disturbed" might prove challenging, as is whether this condition is fully functional. The LDC is not the same as MDC – the standards for MDC are higher, representing an ideal functional condition. The LDC only refers to the best of what's left and not necessarily an ideal functional

condition. Unless the reference condition is known to represent MDC, this state should be referred to as the LDC, with all appropriate caveats for its applicability well documented.

Best attainable condition (BAC) represents a potential condition that could be achieved following the implementation of all available best management practices at a site. The BAC reflects a desired future condition given current constraints; thus, it differs from the other previously mentioned reference conditions in that it is a conceptual definition, i.e., the BAC does not exist in the landscape, but is nonetheless a critical concept for ecosystem restoration, representing the best possible practicable condition that can be achieved through restoration actions. The BAC can be determined by starting with the LDC existing in the landscape and applying restoration actions or removing stressors within reasonable project constraints. The restoration practitioner considers the best existing condition on the landscape (the LDC) as the baseline, factors in physical, social, economic, political or technological constraints, and estimates the best possible condition that can be practicably achieved through restoration action. The concept of BAC is further illustrated in Engineer Pamphlet 1165-2-502 (USACE 1999b) as a possible constraint worthy of consideration when formulating project goals and objectives (i.e., considering limitations on attainable restoration state). The BAC is intended to be reserved as a title that is given to a reference condition typically characterized as “this is the best we can expect.”

REFERENCE APPROACH: The specific reference approach that is selected for a restoration project will depend upon a number of factors, including the ecosystem type, the application of the reference condition (planning, engineering, monitoring, etc.), and especially the availability of information from which a reference ecosystem or reference condition can be specified (Table 2). In some cases, an existing reference ecosystem dataset might fit project needs and be easily implementable. In other cases, it will be necessary to collect the data and develop a reference ecosystem and associated reference condition for a project.

Table 2. Approaches to characterizing reference condition for use in ecosystem restoration project planning.

Reference Approach	Description	Applicable Reference Condition (Table 1)	Requirements/ Assumptions	Benefits	Limitations
On-site analogous	Use present, on-the-ground conditions within project footprint to determine reference	LDC most likely	Requires enough on-site information to determine degree of function and degradation and to set targets; may require consideration of broader watershed conditions	Low mobilization costs, parallel stressors, many parameters equal (e.g., hydrology)	May not represent target reference condition, may not represent range of condition, may not represent ecological trajectory

Off-site analogous	Use present, on-the-ground, ecologically representative conditions outside project footprint to determine reference	LDC most likely, MDC possible	Requires enough information at a suitable off-site location to determine degradation and set target, comparable class of system with parallel stressors, measurable P/C/B parameters	More likely to find reference that can help define target reference condition with parallel stressors, parameters	May not represent range of condition, may not represent target reference condition, more cost to locate and characterize another site, may not represent ecological trajectory
Historical reference	Use a selected historical reference condition within project area (can be applied as off-site analogous approach if conditions are met)	HCPI or HCPA HCPD if a specific isolated event caused disturbance	Requires the right data type / resolution to set targets matched to objectives; if on-site, may not require classification	Opportunity to characterize adjustment of processes to known stressors, if stressors not in flux or pre-disturbance data are proximal, can represent target reference condition or MDC	Stressors may have changed, other parameters may be changing, constraints may eliminate historical reference from consideration as target reference condition
Virtual (also called *constructed*)	Use a combination of sources to represent target reference condition for given physical setting, other constraints	Any of HCPI, HCPA, HCPD, MDC or LCD in combination with site or other data	Typically requires data from multiple sources, BPJ, and models	Highly flexible if good information is available, high resolution in defining target condition, best for use in settings with many constraints, costs can be low if existing models, BPJ, and collaborative processes are used	Highly dependent on good information, good interpretation/analysis of available information, can be quite reliant on models, and subject to notable debate, costs can be high if requiring new or extensive modeling
Regional Index	Use a range of existing reference sites to reflect a continuum of conditions	MDC	Requires classification and considerable data to characterize the range of the condition to evaluate degradation and set targets	Highly robust representative of full range of conditions, puts projects into context, best characterization of target reference condition	Highly data dependent, can take years to develop and can be subject to high cost

Data availability can often drive the selection of a reference approach – not all projects will have the time, resources, or capability to develop the type of complete dataset required to effectively characterize or predict the reference condition. In fact, data requirements as well as data availability will vary considerably and predictably with project scale, ecosystem type, and institutional context. Additionally, there are some circumstances for which no appropriate reference ecosystem exists. In those cases, it might be possible to construct a reference based upon historical data or through the establishment of a virtual reference.

Careful consideration and management of risk and uncertainty is recommended to ensure that the selected reference approach and characterization of reference condition are both consistent with and best serve project objectives. Uncertainty associated with differing amounts and quality of datasets or models, for example, will result in a different set of potential consequences depending on the application or phase of project planning in which the reference condition is applied. Suedel et al. (2012) outline one method for assessing and managing risk and uncertainty to support decision-making during project planning, with case studies illustrating application of these concepts – this framework may be applied to selection and implementation of a reference approach by helping planners answer questions about the likelihood, consequences, and mitigation of uncertainties associated with characterizing and applying each reference condition type to assessment, design, forecasting, and EBA. Risk assessment methods that are consistent with the complexity and/or requirements of the problem should be used.

On-site analogous

An analogous reference site simply refers to a current, on-the-ground site or set of sites within the project footprint or parcel where data can be collected that represent the characteristics (structural or functional) that are associated with a healthy ecosystem, and preferably reflect the BAC for that type of ecosystem and geographic location. On-site or “within parcel” can be either a location or set of characteristics that represent the footprint of one or more project features, all within a project area or ecosystem associated with a project area. An example might be a patch of vegetation along a hydrologic gradient within a wetland that otherwise has been adversely impacted in other areas of the wetland.

On-site analogous references are frequently restricted to some subset of ecosystem characteristics, because others will have been altered and degraded. Strict classification of the system to ensure similarity in form and function is not necessarily required, though the likelihood of finding structure or processes in balance immediately within a project site is low, especially if the cause of degradation has been persistent, chronic, or widespread. If the source of degradation is highly localized (e.g., a debris jam in a stream channel), functioning units of the system may be readily available nearby. Additionally, if degradation is highly localized temporally (i.e., an earthquake-caused landslide), very recent historical data (HCPD) may be used to represent the unaltered reference condition (see historical reference approach, below). However, an on-site analog reference may not indicate ecological trajectory, particularly in cases involving recent impacts or where processes lag behind a stressor change. As for all projects, restoration targets should consider some historical context, watershed context, and significance of the habitat to be restored, to ascertain whether an on-site reference is applicable. However, if localized disturbances or alterations do not necessitate characterization of a range of conditions or forms to set restoration targets, and if conditions are met for an appropriate reference, an on-site analog can be the most expedient and least costly way to characterize a functioning condition.

Off-site analogous

The off-site analogous reference approach is very similar to the on-site one; the important difference is that the off-site approach has greater flexibility, which allows users to identify a more "appropriate" reference for the system of interest (closer to the MDC, beyond the project footprint, but ecologically representative). This might involve, for example, identifying a stream reach of a similar type in a nearby watershed and similar geomorphic setting that is fully functional and otherwise healthy. Data gathered from this reference system can be used to evaluate conditions at the project site and serve as a guide for project formulation and design. Finding and using the LDC is highly likely with this approach, though as with all analog approaches, the LDC may not be close enough to BAC to enable ready comparison. The need to conduct site investigations, collect field data, and evaluate stressors in order to develop an off-site analogous reference can add cost and time to the project. This approach is more practicable than an on-site reference if the source or cause of degradation is widespread or chronic.

Historical

Using historical, pre-disturbance, pre-alteration, or pre-degradation data as a point of reference is a common approach in ecosystem restoration. Inferring process or ecosystem function from historical data can be challenging, particularly in changing conditions that differ from past to present. Data from several sites over a number of time-steps can help to overcome limitations. The concept of “restoring” a setting implies a return to a previous state, typically assumed or thought of as undisturbed, or less disturbed. This concept is problematic in many cases, however, and a historical reference is oftentimes inappropriate because of changes in physical conditions at a site. The problem stems from the fact that forcing factors that led to the ecosystem degradation may persist, and the "restored" conditions cannot be sustained with the prevailing hydrologic, sediment, climatic, or landscape drivers. A good example of this is the case of urban stream systems, which tend to degrade and widen in response to the altered hydrology associated with urban development. A stream channel returned to its pre-development dimension and condition would invariably cycle through that degradation and widening phase again following project implementation. For this reason, historical conditions are best used to understand how ecosystems respond to physical changes and how those changes may be managed in the future, particularly at a landscape level and in large ecosystems.

Many types and sources of data can be used to represent an ecosystem site or set of sites decades or even hundreds of years in the past. Much of this data has been compiled, digitized, and often analyzed (e.g., aerial photography, flood records, and population studies), though the geographical resolution of these data varies widely and not all documentation is acceptable for civil works review protocols. For example, General Land Office (GLO) or Public Land Survey System (PLSS) notes, widely available in 30 states, can be used to determine historical forest composition and structure, and hydrologic and geomorphic features (Perkins et al. 2011). Data collection and analysis methods vary over time and between states and regions, and precision and accuracy change with updates in technology. Therefore, since GLO and PLSS surveys started in the late 18th century, it can be difficult to use these types of surveys to make comparisons for trend analysis. If stressors are not in flux or can be discerned from the dataset, and if pre-disturbance data are available that match the metrics set to restoration objectives, on-site historical data can be used effectively in describing an MDC to help set restoration targets. The utility of historical references is very site-specific, but most large civil works projects have ample pre-project surveys from the GLO, PLSS, or other regional surveys.

Virtual (also referred to as *constructed*)

A virtual or constructed reference is a composite, conceptual, or numerical model of a functioning ecosystem or systems, developed from a variety of sources. This is a constructed reference, that is, an analog to reference conditions that may or may not presently exist, may or may not have existed in the past, and/or may be reflective of a “negotiated” desired future condition. This approach might involve application of hydrologic and hydraulic (H&H) and other models to simulate past, current, future, or synthetic (i.e., scenario-based) conditions that might influence the target reference condition. Because of the widespread nature of anthropogenic alterations, good existing references are becoming difficult to find. Virtual references are thus becoming increasingly relevant and useful. A virtual reference can be developed using data from several sites or even best professional judgment. This approach is highly flexible, and can be used to represent a distribution of conditions as a restoration target range rather than a single point. However, this method can be complex and costly, depending on data availability and the degree of controversy surrounding a proposed restoration activity. This means that the direction and extent to which important ecosystem elements might be affected by restoration actions may be evaluated differently depending on how much and which kind of data are available and the complexity of the model.

Care must be taken throughout the initial steps of developing a virtual reference to ensure that drivers, stressors, and effects associated with the conceptualized ecosystem are adequately considered. Conceptual models of the subject ecosystem can be useful during construction of a virtual reference. Inputs to a virtual reference vary from expert opinion, to measured data (both current and historical), to the results of computer simulations (or other sources of synthetic/derived data). Furthermore, virtual references offer potential to investigate how watershed uncertainties and/or varying climate conditions might influence target conditions and planning objectives. Analog reference sites can also be used, and a “best of the best” site, constructed from selected optimum parameters from individual sites, can be compiled into a set of conditions and functions that do not exist together in any single setting. Where there are a number of settings with varying disturbance or degradation levels that are nonetheless relatively functional, this can be a useful, though potentially costly and time-consuming, approach. Using the best of the best (one or more LDC sites) as a basis to develop a virtual reference may get close to the BAC by optimizing existing information, theoretically representing a condition better than what has been available in the past.

Regional index

Site-based analogous and historical reference conditions (above) are often used for a restoration reference, but they can become mired in issues concerning site similarity, suitability, and data availability that are difficult to reconcile considering the cost and difficulty of collecting field data (Stein et al. 2009). Regional index-based ecosystem output models (IBI, MBI, HGM) offer alternatives. It is expected that efforts to characterize and quantify the benefits of ecosystem restoration activities will be derived from a thorough understanding of the relationships between ecological state and restoration actions. Ideally, these would be expressed as rigorously tested statistical or process models, but often they are based on limited data or expert opinion. Regional indexes that span the environmental condition gradient, however, offer ways to alleviate such bias by increasing sample size and incorporating survey data across the existing range of environmental quality for a given region (Angradi et al. 2009).

A regional index as a reference approach involves development of a range or gradient of ecological condition that represents regional values of ecosystem parameters of interest in ecological restoration. Aggregated values that enable discrimination between degraded and non-degraded sites are used to build a reference index, set ecological condition gradients, and define functional endpoints. Indexes can be derived for many animal (Hilsenhoff 1988, Karr 1981, Stapanian et al. 2004) or plant communities (Swink and Wilhelm 1994) with sufficient field sampling. Reference sites (e.g., poor, good, excellent, etc.) can be selected or derived quantitatively from among all the sampled sites based on selected parameters (Angradi et al. 2009) or by best professional judgment to set the standard. For example, in Florida's Stream Condition Index (SCI), professional judgment was used initially to define minimally (least) disturbed reference sites and known impaired sites, from which seven metrics were aggregated and statistically analyzed to improve correlation with human disturbance (Barbour et al. 1996). Another example of a regional reference index is the hydrogeomorphic (HGM) method for developing and applying indices for assessment of wetland functions (Brinson 1993, Smith et al. 1995).

CONSIDERATIONS FOR REFERENCE CONDITION APPROACH

Selecting the type of data collection or analysis to best characterize the reference condition is important in choosing a reference approach (Tables 2 and 3). In every case, appropriate project objectives and metrics are required (considering resolution, accuracy, precision, and uncertainty)

Table 3. Considerations for reference condition approach for use in ecosystem restoration project planning.

Reference Approach Considerations	On-site analogous	Off-site analogous	Historical	Virtual	Regional Index
Classification of project and reference site(s)	Recommended but not strictly required	Required	Possibly required	Required	Required
Characterize BAC readily	N	Possibly	Possibly	Y	Y
Represent specific reference condition	Y	Y	Y	Y	No
Allow for distribution of condition, spatial variability	N	N	Possibly	Possibly	Y
Account for temporal variability or process	N	N	Possibly	Possibly	Possibly
Data and time requirements	Low	Low-Medium	Medium-High	Low-High	Very High
Cost requirements	Low	Low-Medium	Medium-High	Low-High	High
Account for scalar differences	N	N	N	Y	Y
Account for influences of climate variability on reference	N	N	N	Possibly	N

and classification of the project site to represent the system of interest in enough detail to satisfy project objectives. The considerations below are categorical and relative, presented as a set of qualitative ranges – quantification of specific costs or time required to perform analyses, for example, is beyond the scope of this technical note. However, relative utility of each reference approach can nonetheless be judged by the ER project planner in the context of specific program, budgetary, or data availability constraints, using Table 3 as an initial guide.

CONCLUSIONS: IMPLICATIONS FOR PROJECT PLANNING

This technical note lays the foundation for reference condition concepts as they apply to ecosystem restoration, planning, and EBA. Reference concepts continue to be applied as a "guiding image" during planning and life cycle management of ecosystem restoration projects. Reference concepts have played a role in mitigation where determining project impacts and benefits is critical.

This technical note defines reference terms that are most amenable to application in ecosystem restoration and outlines six practical reference condition types and five generalized reference approaches. The reference approaches described above and the criteria for choosing an approach are highly project-specific, with many considerations and limitations driven by data quality and availability. Many ecosystem restoration projects are either limited by the cost of data collection or do not specifically require highly resolved condition data. However, developing regional data sets and reference conditions that benefit the Corps' ecosystem restoration and protection mission nationwide might be a worthy consideration. Such an approach would leverage existing state-wide or regional efforts in support of more expeditious planning, review, and implementation of restoration actions. Limitations of all of the above reference approaches can be addressed by continuing to compile organized regional reference datasets and using intentional documentation and adaptive management to steadily improve the quality of tools and techniques for defining robust reference condition databases and models.

Reference conditions can be used to scale the quality of restoration, particularly in cases of partial or incremental restoration, and ultimately might be used effectively in EBA. Applying reference concepts when quantifying benefits from restoration projects is limited to date, particularly with the current focus on changes in habitat condition achieved through restoration, but the potential for success with this approach is high. More refined characterization of the range and quality of the reference condition through a regional approach will enable better identification and description of functional thresholds for ecosystem restoration targets. This should ultimately improve the potential for defining the degree of departure from a functional condition (and perhaps how this relates to MDC), better definition of the BAC, and ultimately enable quantitative scaling of ecosystem project benefits by these parameters (Pruitt et al. 2012).

Ability to quantify percent distance between project alternatives and a minimally disturbed or minimally functional condition, for example, will enable more clear definition of percent improvement from the current degraded condition. Normalizing by percentage departure from MDC would enable better description of what the BAC actually achieves in terms of improvements in ecological condition and the degree of alteration in a system, and thus can be used to compare alternatives as well as projects at a program scale (Pruitt et al. 2012). For example, Pruitt et al. (2012) introduce the concept of a Reference Condition Index (RCI) that scales ecosystem attributes from 0.0 (severely altered) to 1.0 (MDC). This RCI can be applied to calculate relative incremental environmental benefits between projects toward achieving the BAC, say from 0.2 to 0.6 (+ 0.4) or 0.6 to 1.0 (also + 0.4, although this scenario achieves the MDC) versus 0.2 to 0.6 (+ 0.4) or 0.5 to 0.6 (only + 0.1, although the BAC is achieved with less unit effort). Pruitt et al. (2012) present and discuss a number of practicable applications of this concept for comparing alternatives within a single project and for comparing between projects having a similar or differing scale, similar or differing ecosystem type, and similar or differing reference approach.

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REFERENCES

Angradi, T. R. (editor). 2006. *Environmental Monitoring and Assessment Program: Great River Ecosystems, Field Operations Manual*. EPA/620/R-06/002. Washington, DC: U.S. Environmental Protection Agency.

Angradi, T. R., M. S. Pearson, T. M. Jicha, D. L. Taylor, D. W. Bolgrien, M. F. Moffett, K. A. Blocksom, and B. H. Hill. 2009. Using stressor gradients to determine reference expectations for great river fish assemblages. *Ecological Indicators* 9:748-764

Asbjornsen, H. L., L. A. Brudvig, C. M. Mabry, C. W. Evans, and H. M. Karnitz. 2005. Defining reference information for restoring ecologically rare tallgrass oak savannas in the midwestern United States. *Journal of Forestry* 103:345–350.

Bailey, R. C., R. H. Norris, and T. B. Reynoldson. 2004. Bioassessment of freshwater ecosystems using the reference condition approach: Comparing predicted and actual benthic invertebrate communities in Yukon streams. *Freshwater Biology* 39:765-774.

Barbour, M. T., J. Gerritsen, and J. S. White. 1996. *Development of the Stream Condition Index (SCI) for Florida.* FDEP publication.

Barbour, M. T., J. Gerritsen, B. D. Snyder, and J. B. Stribling. 1999. Rapid bioassessment protocols for streams and wadeable rivers: Periphyton, benthic macroinvertebrates, and fish. 2nd ed. EPA 841-B-99-002.

Bates-Prins, S. C., and E. P. Smith. 2007. Using biological metrics to score and evaluate sites: A nearest-neighbour reference condition approach. *Freshwater Biology* 52:98-111.

Boerner, R. E. J., A. T. Coates, D. J. Yaussy, and T. A. Waldrop. 2008. Assessing ecosystem restoration alternatives in eastern deciduous forests: The view from belowground. *Restoration Ecology* 16: 425-434.

Boulton, A. J. 1999. An overview of river health assessment: Philosophies, practice, problems and prognosis. *Freshwater Biology* 41:469-479.

Brenner, M., T. J. Whitmore, M. S. Flannery, and M. W. Binford. 1993. Paleolimnological methods for defining target conditions in lake restoration: Florida case studies. *Lake and Reservoir Management* 7(2):209-217.

Brinson, M. M. 1993. *A hydrogeomorphic classification for wetlands*. Technical Report WRP-DE-4. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Brinson, M. M., and R. Rheinhardt. 1996. The role of reference wetlands in functional assessment and mitigation. *Ecological Applications* 6:69-76.

Busch, D. E., and J. C. Trexler (eds.) 2003. Monitoring ecosystems: Interdisciplinary approaches for evaluating ecoregional initiatives. Washington, DC: Island Press.

Christensen, N. L., A. M. Bartuska, J. H. Brown, S. Carpenter, C. D'Antonio, R. Francis, J. F. Franklin, J. A. MacMahon, R. F. Noss, D. J. Parsons, C. J. Peterson, M. G. Turner, and R. G. Woodmansee. 1996. The report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. *Ecological Applications* 6:665-691.

Costanza, R., B. G. Norton, and B. D. Haskell (eds.). 1992. *Ecosystem health: New goals for environmental management.* Washington, DC: Island Press.

Davis, W. S., and T. P. Simon (eds.). 1995. Biological assessment and criteria: Tools for water resource planning and decision making. Boca Raton, FL: Lewis Publishers.

Dodds, W. K., E. Carney, and R. T. Angelo. 2006. Determining ecoregional reference conditions for nutrients, Secchi depth and chlorophyll a in Kansas lakes and reservoirs. *Lake and Reservoir Management* 22:151–159.

Dufour, S., and H. Piegay. 2009. From the myth of a lost paradise to targeted river restoration: Forget natural references and focus on human benefits. *River Research and Applications* 25:568–581.

Egan, D., and E. A. Howell. 2005. The historical ecology handbook: A restorationist's guide to reference ecosystems. Washington, DC: Island Press.

European Communities (EC). 2000. Directive 2000/60/EC of the European Parliament and of the Council Establishing a Framework for Community Action in the Field of Water Policy (OJ L 327, 22.12.2000).

Fletcher, R., K. M. Somers, and R.A. Reid. 2003. Evaluating biological condition using multiple summary indices and the reference condition approach. In *North American Benthological Society Meeting, Athens, GA.*

Harris, R. R. 1999. Defining reference conditions for restoration of riparian plant communities: Examples from California, USA. *Environmental Management* 24:55-63.

Hilsenhoff, W.L. 1988. Rapid field assessment of organic pollution with a family-level biotic index. *Journal of the North American Benthological Society* 7:65-68.

Hobbs, R. J. 2003. Ecological management and restoration: Assessment, setting goals and measuring success. *Ecological Management and Restoration* 4:S2-S3.

Jensen, M. E., R. L. Redmond, J. P. Dibenedetto, P. S. Bourgeron, and I. A. Goodman. 2000. Application of ecological classification and predictive vegetation modeling to broad-level assessments of ecosystem health. *Environmental Modeling and Assessment* 64:197-212.

Karr, J. R. 1981. Assessment of biotic integrity using fish communities. *Fisheries* 6:21–27.

Karr, J. R., and E. W. Chu. 1999. *Restoring life in running waters*. Washington, DC: Island Press.

Landres, P. B., P. Morgan, and F. J. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. *Ecological Applications* 9:1179-1188.

Leland, H. V., A. R. Selle, and M. B. Griffith. 2000. Reference condition approach to the assessment of biological integrity in streams of the southern Rocky Mountains and its use in measuring the effectiveness of mile-remediation efforts. Presented at *Society of Environmental Toxicology and Chemistry, Nashville, TN, November 12-16, 2000*.

Moore, M. M., W. Wallace-Covington, and P. Z. Fule. 1999. Reference condition and ecological restoration: A southwestern Ponderosa Pine perspective. *Ecological Applications* 9:1266-1277.

Nestler, J. M., C. H. Theiling, K. S. Lubinski, and D. L. Smith. 2010. Reference condition approach to restoration planning. *River Research and Applications* 26(10):1199-1219.

Nestler, J. M., C. R. M. Baigun, N. O. Oldani, and L. J. Weber. 2007. Contrasting the middle Parana and Mississippi Rivers to develop a template for restoring large floodplain river-ecosystems. *Journal of River Basin Management* 5:305-319.

Perkins, M., C. V. Klimas, J. Dunbar, T. Foti, and J. Pagan. 2011. *Using the General Land Office survey records in ecosystem restoration planning*. EBA Technical Notes Collection. ERDC TN-EMRRP-EBA-9, Vicksburg, MS: U.S. Army Engineer Research and Development Center. *http://el.erdc.usace.army.mil/emrrp/emrrp.html*

Pickett, S. T. A., and V. T. Parker. 1994. Avoiding old pitfalls: Opportunities in a new discipline. *Restoration Ecology* 2:75–79.

Pruitt, B. A., S. J. Miller, C. H. Theiling, and J. C. Fischenich. 2012. *The use of reference ecosystems as a basis for assessing restoration benefits.* EBA Technical Notes Collection. ERDC TN-EMRRP-EBA-12-11. Vicksburg, MS: U.S. Army Engineer Research and Development Center. http://cw-environment.usace.army.mil/eba/

Reece, P. F., and J. S. Richardson. 2000. Biomonitoring with the reference condition approach for the detection of aquatic ecosystem at risk. In *Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk, Kamloops, B.C., 15 - 19 Feb.,1999*, 15-19. Volume Two. Victoria, B,C.: B.C. Ministry of Environment, Lands and Parks and Kamloops, B.C.: University College of the Cariboo.

Roni, P. (ed.). 2005. *Monitoring stream and watershed restoration*. Bethesda, MD: American Fisheries Society.

Rosgen, D. 1994. A classification of natural rivers. *Catena* 22:169-199.

Schumm, S. 1988. Variability of the fluvial system in space and time. In *Scales and global change,* ed. T. Rosswall, R. Woodmansee, and P. Risser, 225-250. New York: John Wiley and Sons.

Short, F. T., D. M. Burdick, C. A. Short, R. C. Davis, and P. A. Morgan. 2000. Developing success criteria for restored eelgrass, salt marsh and mud flat habitats. *Ecological Engineering* 15:239–252.

Smith, R. D., A. Ammann, C. Bartoldus, and M. M. Brinson. 1995. *An approach for assessing wetland functions using hydrogeomorphic classification, reference wetlands, and functional indices.* Technical Report WRP-DE-9. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Smol, J. P. 2008. Pollution of lakes and rivers: A paleoenvironmental perspective, 2nd ed. Oxford, UK: Blackwell Publishing.

Society for Ecological Restoration International (SERI) Science and Policy Working Group. 2004. *The SER International Primer on Ecological Restoration*. www.ser.org & Tucson: Society for Ecological Restoration International.

Stapanian, M. A., T. A. Waite, G. Krzys, J. J. Mack, and M. Micacchion. 2004. Rapid assessment indicator of wetland integrity as an unintended predictor of avian diversity. *Hydrobiologia* 520:119-126.

Stein, E. D., A. E. Fetscher, R. P. Clark, A. Wiskind, J. L. Grenier, M. Sutula, J. N. Collins, and C. Grosso. 2009. Validation of a wetland rapid assessment method: Use of EPAs level 1-2-3 framework for method testing and refinement. *Wetlands* 29:648-655.

Stephenson, N. L. 1999. Reference conditions for giant sequoia forest restoration: structure, process, and precision. *Ecological Applications* 9: 1253-1265.

Steyer, G. D., R. R. Twilley, and R. C. Raynie. 2006. An integrated monitoring approach using multiple reference sites to assess sustainable restoration in coastal Louisiana. In *Monitoring Science and Technology Symposium: Unifying Knowledge for Sustainability in the Western Hemisphere Proceedings*, ed. C. Aguirre-Bravo, P. J. Pellicane, D. P. Burns, and S. Draggan, 326-333. Fort Collins, CO: U.S. Forest Service, Rocky Mountain Research Station - RMRS-P-42CD.

Stoddard, J., P. Larsen, C. P. Hawkins, R. Johnson, and R. Norris. 2006. Setting expectations for the ecological condition of running waters: the concept of reference conditions. *Ecological Applications* 16:1267-1276.

Suedel, B. C., J. Valverde, J. Vogel, I. Linkov, J. C. Fischenich, T. S. Bridges, and M. Plumley.2012. *Application of risk management concepts and methods for ecosystem restoration: Principles and best practice*. EBA Technical Notes Collection. ERDC TN-EMRRP-EBA-12-##.Vicksburg, MS: U.S. Army Engineer Research and Development Center. *http://cw-environment.usace.army.mil/eba/*

Swanson, F. J., J. A. Jones, D. O. Wallin, and J. H. Cissel. 1993. Natural variability - implications for ecosystem management. In *Eastside Forest Ecosystem Health Assessment. Vol. II: Ecosystem management: Principles and applications*, ed. M.E. Jensen and P. S. Bourgeron. Portland, OR: U.S. Forest Service.

Swink, F., and G. S. Wilhelm. 1994. *Plants of the Chicago Region*, 4th ed. Indianapolis, IN: Indiana Academy of Science.

U.S. Army Corps of Engineers (USACE). 1999a.*Civil Works Ecosystem Restoration Policy*. Engineer Regulation 1165-2-501. Washington, DC: U.S. Army Corps of Engineers.

U.S. Army Corps of Engineers (USACE). 1999b. *Ecosystem Restoration Supporting Policy Information*. Engineer Pamphlet 1165-2-502. Washington, DC: U.S. Army Corps of Engineers.

U.S. Army Corps of Engineers (USACE). 2000. *Planning Guidance Notebook*. ER-1105-2-100. Washington, DC.

U.S. Bureau of Land Management (USBLM). 1995. Riparian area management: Process for assessing proper functioning condition. Denver, CO: USDI Bureau of Land Management, Proper Functioning Condition Work Group, Technical Reference 1737–9.

U.S. Environmental Protection Agency (USEPA). 2010. Environmental Monitoring and Assessment Program (EMAP). *http://www.epa.gov/emap/*. Accessed July 2010.

Wallin, M., T. Wiederholm, and R. K. Johnson. 2003. Guidance on establishing reference conditions and ecological status class boundaries for inland surface waters. CIS Working Group 2.3 – REFCOND. 7th Version.

White, P. S., and J. Walker. 1997. Approximating nature's variation: Selecting and using reference information in restoration ecology. *Restoration Ecology* 5:338-349.