# Reference Systems in Environmental Benefits Analysis - Overview and Discussion

## Research Update 8 December 2009

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# Reference Systems in Environmental Benefits Analysis - Overview and Discussion

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- What is an ecosystem reference?
- Why are reference systems important?
- Reference condition as a framework for EBA
- Challenges to the community of practice
- Reference Systems Work Unit
- Regulatory framework in brief
- Reference condition concepts, terms and definitions
- Evolution of reference condition concepts
- Application of Reference Concepts – Corps-Partnered Example Projects
- Ongoing issues, considerations and Work Unit initiatives

# Reference Condition Concepts – What is an Ecosystem Reference?

- An ecosystem “reference condition” represents some target, benchmark, standard, model or template from which or to which another ecosystem is compared
- Highly variable number and character (resolution, accuracy, precision) of parameters can be chosen
- Qualitative, quantitative, biotic, abiotic
- Single vs. multiple sites, data points vs. ranges, analog vs. model

# Why are Reference Systems Important?

- Environmental Benefits Analysis (EBA) Program
  - ► Determination of a preferred approach for characterizing benefits consistent with the Corps' Ecosystem Restoration (ER) mission – to restore aquatic ecosystem structure, function and dynamic processes
  - ► Strengthening the understanding among the planning community of the linkages between hydrologic-geomorphic manipulation and ecological outcomes
- Metrics Research Theme within the EBA – assess benefits across eco-regions and scales, provide state of the science and practice, interim tools and scientific guidance
  - ► Use of reference-based concepts enables analytical methods that might streamline or reduce cost for the planning process
  - ► Reference Condition may provide a framework for Environmental Benefits Analysis

# Reference Condition as a Framework for Environmental Benefits Analysis

- Every aquatic ecosystem has reference conditions from which project benefits can be assessed
- “Reference Condition” is a concept that can be clearly understood and communicated
- Can be applied at every stage of project planning – assessment, alternative formulation, prioritization, and to design
- Operations, monitoring and regulatory applications
- Can enable comparison across types and scales
- Benefit Transfer potential – a characterization of different types of systems based on a subset of examples, to which each new project can be compared to assess benefits

# Benefit Transfer Method

- Benefit transfer method is used to estimate values of ecosystem services by "transferring" available information from existing studies to the system of interest
  - ► For example, referring to existing studies demonstrating benefits of oyster reefs to provide justification for or benefits of a proposed oyster reef restoration project
- Benefit transfer is often used when it is too expensive or there is too little time available to conduct an original valuation study
  - ► Using existing information about a particular ecosystem type can reduce project planning and design costs
  - ► Reference condition can represent optimal benefits achievable by a restoration project

# Benefit Transfer by Ecosystem Type


- A well-populated database of reference condition information for major ecosystem types could streamline project planning and design
- The finer the resolution in ecosystem classification, the greater the opportunity for individual project benefits analysis
- Benefit transfer is only as good as the original study…

# Challenges to Community of Practice and Corps Project Planning

- Which reference target to choose
- Which parameters to measure
- How to address projects of differing scale or type
- How to reconcile reference condition characterized by different metrics
- How to compare projects of differing scale or type at a regional level, at a programmatic level
- How to incorporate reference condition comparisons into a national ecosystem restoration program

# Reference Systems Work Unit

"The objective of this work unit is to develop and present clear, concise, and scientifically-based methods for the selection or development of reference systems for ecosystem restoration projects, with an emphasis on the use of these references for the purpose of assessing project benefits."

# Reference Systems Work Unit

- ERDC, District and Academic subject-matter experts convened to frame the role of reference condition concepts in Environmental Benefits Analysis (EBA)
  - ► Assess state of the science and practice
  - ► Discuss reference condition concepts and application for aquatic ecosystems – streams, wetlands, lakes/reservoirs, coastal zones
  - ► Attempt to resolve terminology, scale, and approach
  - ► Document Corps-partnered efforts using reference concepts with planning, assessment, design, evaluation, monitoring, regulatory applications

# Reference Systems Regulatory Framework

- National and International focus on aquatic ecosystem restoration – biological integrity and the reference condition
  - National Environmental Policy Act (NEPA) 1970 – national environmental policy and goals for the protection, maintenance, and enhancement of the environment
  - Clean Water Act of 1972 – concept of "naturalness" key to biological integrity
  - Council of Australian Governments Water Reform Framework 1994
  - European Union Water Framework Directive 2000 – emphasis on ecological monitoring to assess departure from "natural" condition

# Reference Systems – Regulatory Framework Issues

- Share a definition of an undisturbed or “natural” condition representing the goal of restoration
- Leads to difficulty in defining, identifying, characterizing and comparing appropriate reference conditions
- There is a need for a set of terms and methods to unify the approach
- Further need for a specific scientific framework for incorporating EBA at project through program level

# Reference Condition Concepts, Terms and Definitions

- An ecosystem "reference condition" represents some target, benchmark, standard, model or template from which or to which another ecosystem is compared
- A Reference Ecosystem can be characterized by form or function – this varies widely in opinion and application between and within restoration approaches and ecosystem types
- Many definitions for what precisely is a reference condition, where is it, how to find it, how to characterize it, how and where it should or can be used, etc.
  - Highly variable number and character (resolution, accuracy, precision, predictability, certainty) of parameters can be chosen
  - Qualitative, quantitative, biotic, abiotic, "real" (analog, historical or present), "artificial" (composite or modeled)
  - Bioassessment, project design, project ranking or prioritization, monitoring

# Reference Condition Concepts, Terms and Definitions

- There are well-developed frameworks with specific guidelines – e.g., HGM – but one size does not fit all
- Recent literature points out the lack of consistency in definition of reference condition and related terms, and many propose more standardized terms
- Those who call for standardization differ widely even where similar terms are used, and our understanding of concepts and implications is continuously evolving…

Table 1. Synonyms for reference ecosystem and reference condition in the literature. (from Smith (ERDC EL) et al. in press)

| Category | Term / Phrase | Literature Citations |
|---|---|---|
| Reference Ecosystem | Regional Reference Sites | Hughes et al. 1986, USEPA 1990 |
| | Reference Sites/Reaches | USEPA 1990, White and Walker 1997, Demetry 1998, Findlay et al. 2002, White and Walker 1997, Rosgen 1996 |
| | Reference Ecosystems | Egan and Howell 2001, SERI 2004, Dibble and Rees 2005, Cortina et al. 2006 |
| | Reference System | Fureder et al. 2002, Nilsson et al. 2005, Hughes et al. 2005, Kolka et al. 2000 |
| | Reference Wetlands | Smith et al. 1995, Collins et al. 2007, USEPA 2002a |
| | Reference Standard Wetlands | Smith et al. 1995 |
| | Ecosystem of Reference | Aronson 1993a |
| | Reference Standards | Niedowski 2000 |
| | Reference Location | Bates-Prins and Smith 2007 |
| Reference Condition | Reference Condition | Hughes 1994, Reynoldson et al. 1997, Karr and Chu 1999, Moore 1999, Findlay et al. 2002, Bailey et al. 2004, Nijboer et al. 2004, Dibble and Reese 2005 |
| | Reference States | Nilsson et al. 2005, Chessman and Royal 2004 |
| | Regional Reference Conditions | Gerritsen et al. 1993 |
| | Reference Criteria | Flotemersch et al. 2006 |
| | Reference Information | Walker and White 1997 |
| | Benchmark State | Angermeier and Karr 1994, Nilsson et al. 2007 |
| | Reference Standard Condition | Smith et al. 1995 |
| | Reference Variation | Reynolds and Hessburg 2005 |
| | Reference Condition for Biological Integrity (RCBI) | Stoddard et al. 2006 |
| | Historical Condition | Fule et al. 1997, Hughes et al. 1998, Swetnam 1999, Keane et al. 2002, Stoddard et al. 2006 |
| | Least Disturbed Condition | Hughes et al. 1986, Stoddard et al. 2006, Hruby 1975 |
| | Minimally Disturbed Condition | Stoddard et al. 2006 |
| | Best Attainable Condition | Stoddard et al. 2006 |

## Table 2. Definitions ascribed to reference condition. (Smith et al. in press adapted from Stoddard et al. 2006)

| | |
|---|---|
| Reference Condition Biological Integrity (RCBI) | A condition representing the absence of human disturbance at the local, regional, and global spatial scales. Preserves the original Karr and Dudley (1981) definition, "…the ability of an aquatic ecosystem to support and maintain a balanced, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat within a region." |
| 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.). |
| Historical Condition (HC) | A condition prior to an historical point in time:<br>1. HCPS: Pre-human disturbance or pre-settlement meaning prior to the presence of indigenous peoples whom, evidence increasingly indicates, impacted the landscape of the Americas extensively through their agriculture practices, use of fire, and manipulation of water resources (Denevan 1992a, Denevan 1992b, Redman 1992, Vale 2002, Mann 2005). This condition is equivalent to RCBI;<br>2. HCPC: Pre-Columbian meaning prior to the influence of European explorers in the Americas (McCann 1999);<br>3. HCPA: Pre-intensive agricultural 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); and<br>4. HCPI: Pre-industrialization and urbanization. |
| Least Disturbed Condition (LDC) | A condition representing the least amount of human disturbance in the current landscape context. In other words, the best of what is left. |
| Best Attainable Condition (BAC) | The condition representing the least amount of human disturbance in the current landscape context coupled with the use of best management practices for a period of time that is long enough for desired conditions to be established and sustained. |

# Evolution of Reference Concepts – Historic Condition

- Emphasis on “natural” conditions as a reference – an undisturbed Historic Condition
  - ► Pre-industrial or Pre-Settlement
  - ► Pre-intensive agriculture
  - ► Pre-disturbance
- Data of sufficient type, accuracy or precision
- Data collection method-dependent

# Evolution of Reference Concepts – Historic Condition

- Undisturbed conditions may pre-date data collection
- May not account for current off-site pressures – climate change, landuse changes, other regional influences
- Often a snapshot – one of many possible sets, may not represent the full distribution of condition
- Changes in condition may create a forecasting situation – can't apply a current reference analogue to a future set of driving conditions

# Evolution of Reference Concepts – Existing Reference Sites

- Existing "undisturbed" settings – primarily an analog approach
  - ► Allows a distribution of conditions rather than a single state
  - ► Accounts for changes in climate
  - ► Focus on functional and process attributes under current climate/landuse conditions
  - ► Ad hoc development
  - ► Often depends on professional judgment
  - ► Where present, most often represents LDC rather than MDC
  - ► May not exist at all in some settings

# Evolution of Reference Concepts – Virtual Reference Condition

- Composite, artificial or virtual reference – a modeling approach
  - Allows a distribution of conditions rather than a single state
  - Accounts for changes in climate
  - Focus on functional and process attributes for current/future conditions
  - Allows application of reference concepts where historical or current analogs are not appropriate or non-existent
  - Accounts for unparalleled changes or settings that cannot be mimicked by existing or historic conditions


# Emerging Reference Concepts

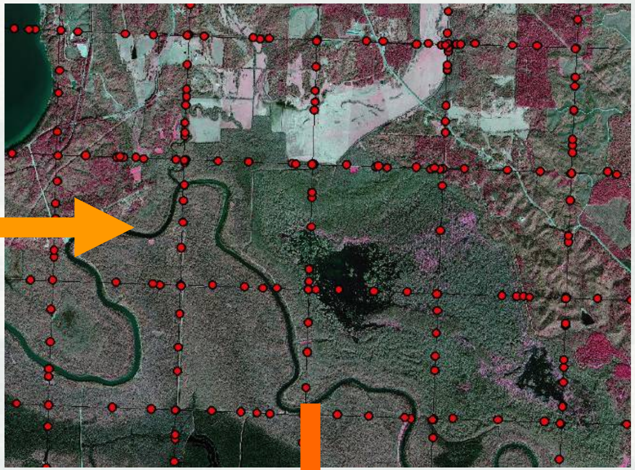
- **Virtual Reference Condition (VR)**: any one of a number of stakeholder Desired Future System Condition alternatives (i.e., environmental objectives) modeled the same as the other reference conditions to estimate change in ecosystem indicators (i.e., benefits). Models may range from expert opinion to computer simulations. (Theiling 2009 LTT briefing)
- Shift in paradigm from characterizing a single state or distribution to include trajectory
- Growing recognition of subjectivity and value judgment – what is important culturally, politically, or economically steers selection of reference condition

# Historical Reference Application to Ecosystem Restoration

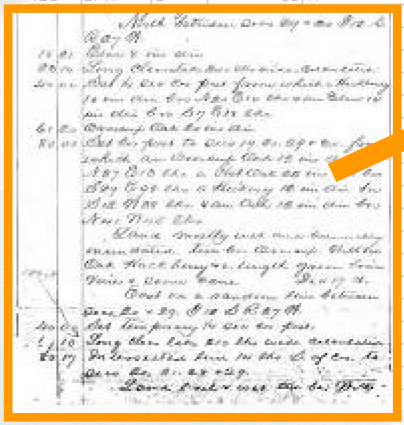
- Characterizing Baseline Conditions as a Fundamental Step in Establishing Ecosystem Restoration Targets and Potential – Grassy Lake Ecosystem Restoration-Feasibility Study (Little Rock District). M.M. Perkins (EL), C.V. Klimas (EL), J.B. Dunbar (GSL)
  - ► Authorized under Section 1135 of WRDA
  - ► Hydrologic and Hydraulic analysis showed ecological degradation due to federal reservoirs
  - ► ERDC field studies initiated in cooperation with stakeholders
  - ► Establish historical baseline (pre-dam) condition (hydrology, geomorphology, native vegetation communities)
  - ► Describe current (post-dam) condition
  - ► Determine "potential condition" for restoration based on historical condition

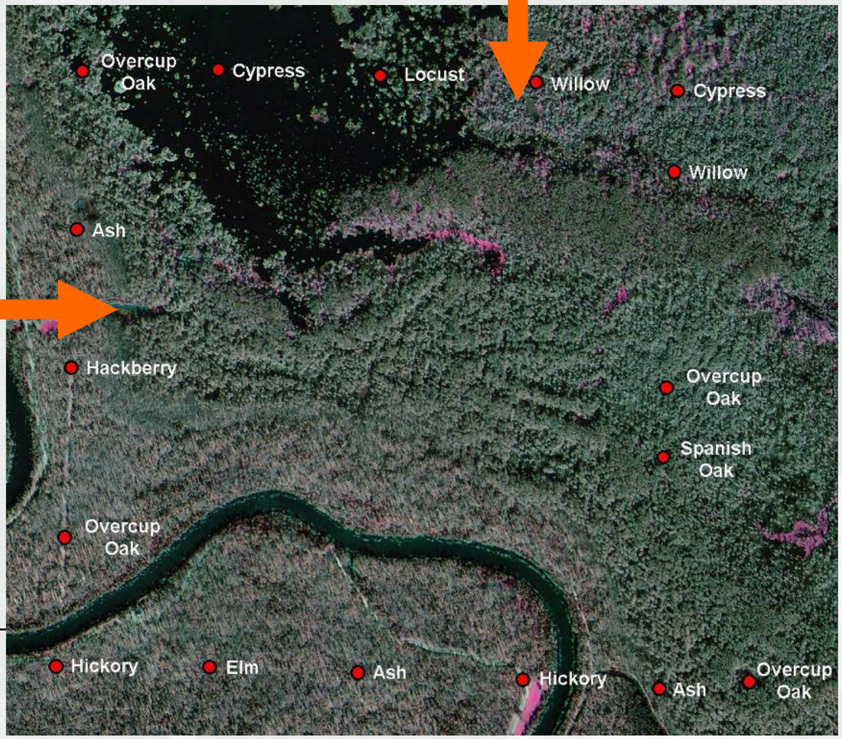
# Historical Reference Application to Ecosystem Restoration – Grassy Lake

**General Land Office (GLO)** notes can be used to determine historical forest composition and structure, geomorphic features, aquatic and hydrologic features



| Twp | Rge | Line | Section | Dir of survey | Dist | Species | Dia | Direction | Dist | Hydro Name | Width |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 12S | 27W | E | 31 | N | 40 | Hackberry | 7 | N38E | 29 | | |
| 12S | 27W | E | 31 | N | 66.23 | Willow Oak | 32 | | | | |
| 12S | 27W | E | 31 | N | 80 | Post Oak | 14 | N50E | 69 | | |
| 12S | 27W | E | 31 | N | 80 | Post Oak | 16 | S43E | 15 | | |
| 12S | 27W | E | 31 | N | 80 | Post Oak | 12 | S23W | 60 | | |
| 12S | 27W | E | 31 | N | 80 | Post Oak | 18 | N64W | 94 | | |
| 12S | 27W | S | 29 | E | 79.92 | | | | | | |
| 12S | 27W | S | 29 | W | 15.17 | Hackberry | 11 | | | | |
| 12S | 27W | S | 29 | W | 39.96 | Hackberry | 7 | N8E | 17 | | |
| 12S | 27W | S | 29 | W | 39.96 | Elm | 8 | S14W | 14 | | |
| 12S | 27W | S | 30 | W | 19.57 | Ash | 8 | | | | |
| 12S | 27W | S | 30 | W | 40 | Ash | 6 | S | 8 | | |
| 12S | 27W | S | 30 | W | 40 | Ash | 11 | N42W | 10 | | |
| | | | | | 55.24 | Ash | 8 | | | | |
| | | | | | 84.14 | Ash | 10 | N69E | 47 | | |
| | | | | | 84.14 | Willow Oak | 12 | S79E | 43 | | |
| | | | | | 18.21 | Elm | 8 | | | | |
| | | | | | | | | | | Long Clear Lake | 340 |
| | | | | | 40 | Hackberry | 10 | N20E | 14 | | |
| | | | | | 40 | Elm | 14 | S7E | 18 | | |
| | | | | | 61.2 | Overcup Oak | 20 | | | | |
| | | | | | 80 | Overcup Oak | 12 | N37E | 13 | | |
| | | | | | 80 | Post Oak | 22 | S29E | 98 | | |
| | | | | | 80 | Hickory | 12 | S12W | 58 | | |
| | | | | | 80 | Ash | 12 | S12W | 58 | | |
| | | | | | 80 | Ash | 12 | N41W | 45 | | |
| | | | | | 67.1 | | | | | Long Clear Lake | 210 |
| | | | | | 80.17 | | | | | | |
| | | | | | 17.19 | Hickory | 10 | | | | |
| | | | | | 40 | Hickory | 12 | N18E | 20 | | |
| | | | | | 40 | Overcup Oak | 19 | S20E | 11 | | |





# Reference Condition Application to Design, Evaluation and Monitoring – Esopus Creek, NY

## Focus:

- Restoration Planning
- Ecological Engineering
- Post-implementation monitoring



## Challenges: Multiple objectives and many stakeholders

- ► Water quality and turbidity reduction – EPA, NYC DEP
- ► Streambank and bed stability – Resource conservation
- ► Recreation and aesthetics – landowners, local business
- ► Private property and infrastructure – town/county DPW


## Solution:

- Model erosion and avulsion risk
- Combined traditional and "natural channel design" methods – analog "Stable" reference stream reach blueprint
- Public outreach and information kiosk
- Comprehensive monitoring and O&M guidelines based on project goals, adaptive management

# Analog Reference Considerations

- A Cautionary Note on Area Similitude in Stable Channel Design by Analog Methods

  J. Fischenich (EL) and S. McKay (EL), 2007

  - ►Highlight errors associated with analog methods of stable (natural) channel design due to nonlinear differences in drainage area or width-depth ratio between reference and project reaches.
  - ►Nonlinearity of these scaling methods has been demonstrated to be significant, with error from 25-75% depending on method and size disparity.

# Hydrogeomorphic (HGM) Approach

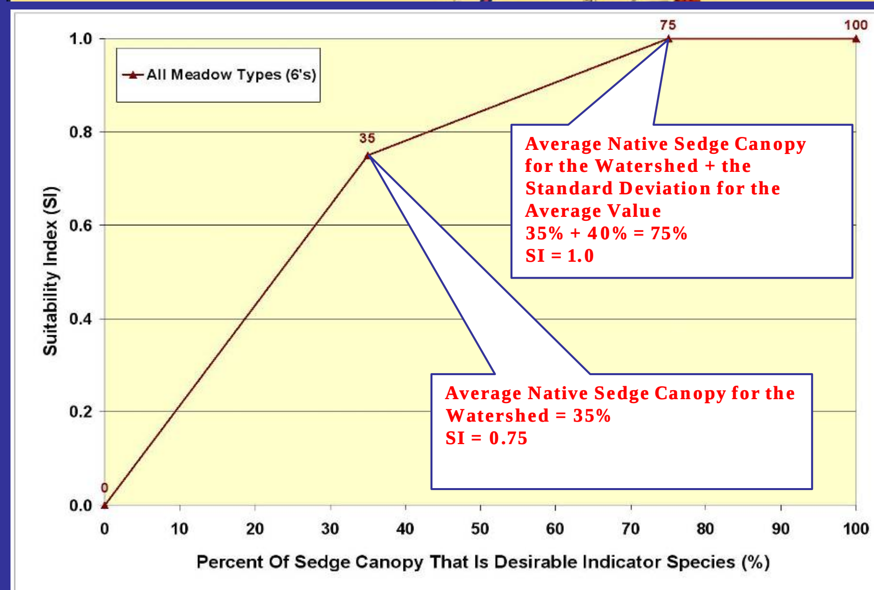
- The Hydrogeomorphic (HGM) Approach is a method for developing and applying indices for site-specific assessment of wetland functions.
- The HGM Approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review process to
  - analyze project alternatives,
  - minimize impacts,
  - assess unavoidable impacts,
  - determine mitigation requirements, and
  - monitor the success of compensatory mitigation.
- A variety of other potential uses have been identified, including the design of wetland restoration projects, and management of wetlands.

# Using Reference Data to Calibrate Habitat Models

- Case Study: Middle Rio Grande Bosque Ecosystem Restoration Feasibility Study (Albuquerque District)
- Reference conditions for the model
  - Must be politically palatable and reasonable
  - Must include a large number of sites from the region
  - Must represent important aspects of pre-historical conditions
  - May use minimal disturbance as the surrogate for pre-historical conditions, given the difficulty of establishing pre-historical conditions
  - Must be uniform across political boundaries and bureaucracies (e.g., Federal, State, and local).
- **30 sites** were considered either reference standard (optimal) or sub-optimal and were chosen to represent the range of conditions existing within the reference domain
- Data was normalized (scaled 0-1) and used to calibrate the model

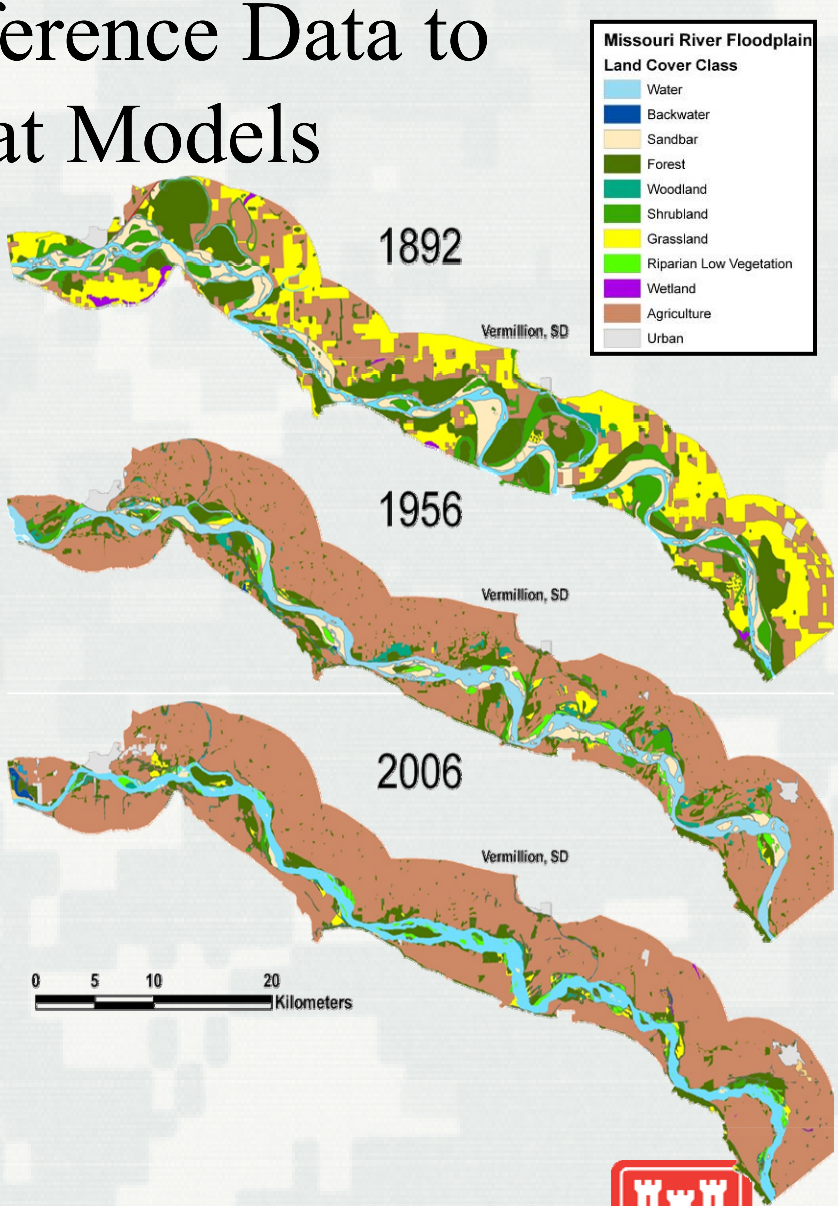
*Burks-Copes, K. A., and A. C. Webb. 2009. A Bosque Riparian Community Index Model for the Middle Rio Grande, Albuquerque, New Mexico. Model Documentation Draft Report. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.*

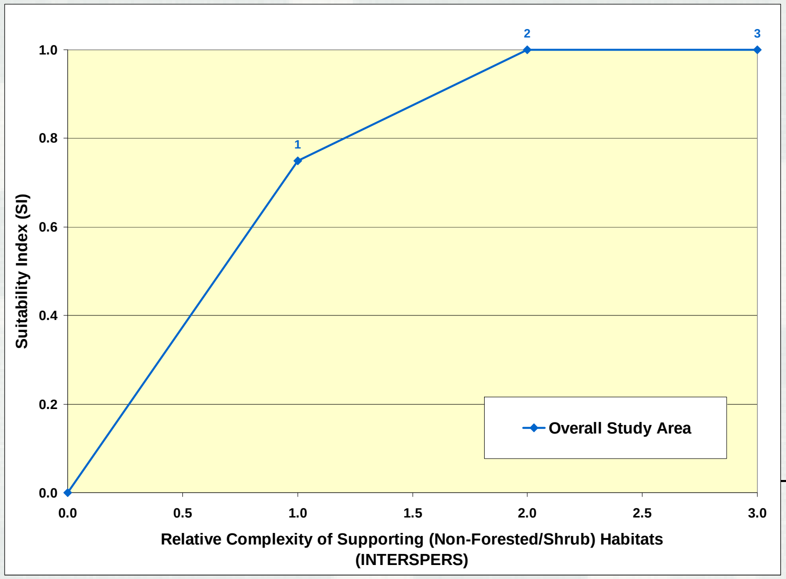
Reference Sites for the MRGBER Study's Bosque Community Index Model Assessment

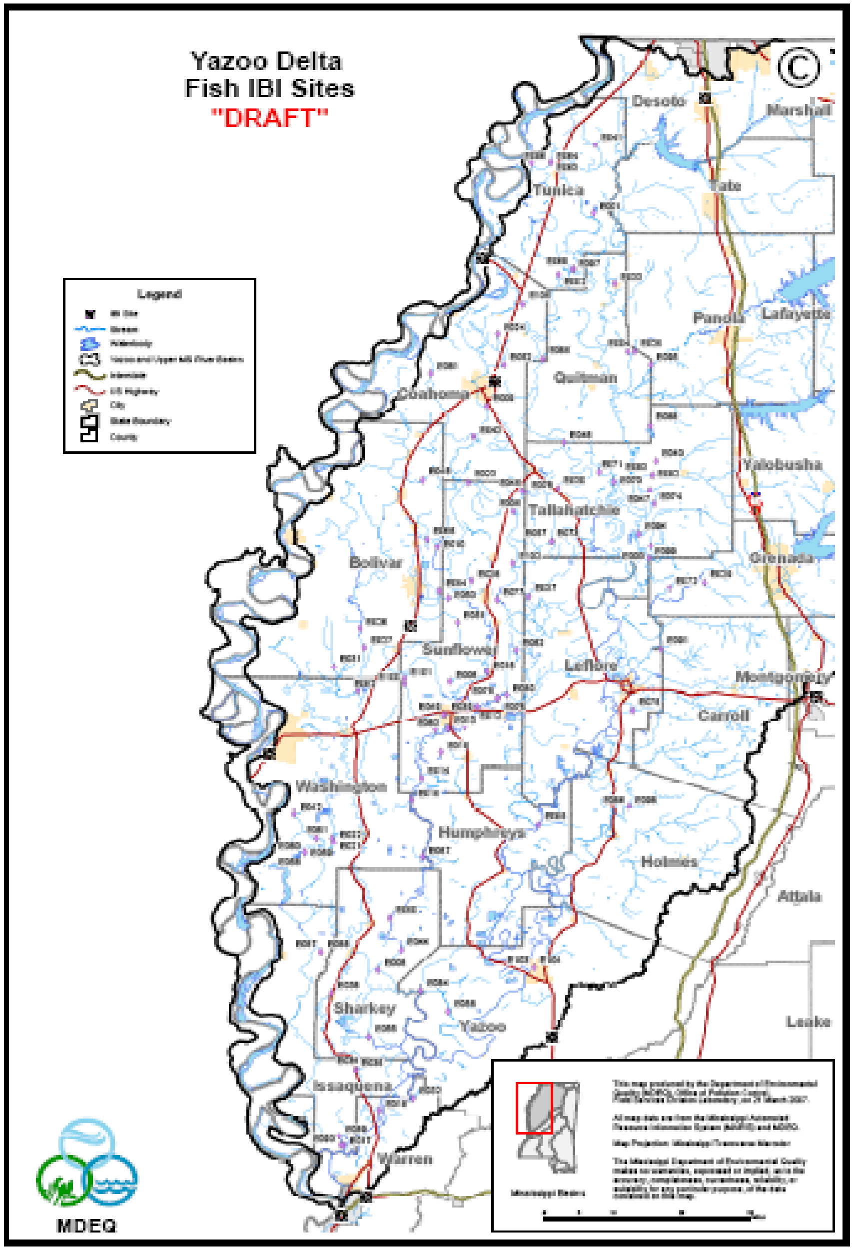



# Using Historical Reference Data to Calibrate Habitat Models

- Case Study: Missouri River's Cottonwood Management Plan (Omaha/Kansas City Districts)
  - Reference conditions for the model based upon GLO-based vegetative data and GIS representation of landuse conversions over time
  - Data was normalized (scaled 0-1) and used to calibrate the model






# Application of Reference Concepts to Yazoo Delta – Design Applications

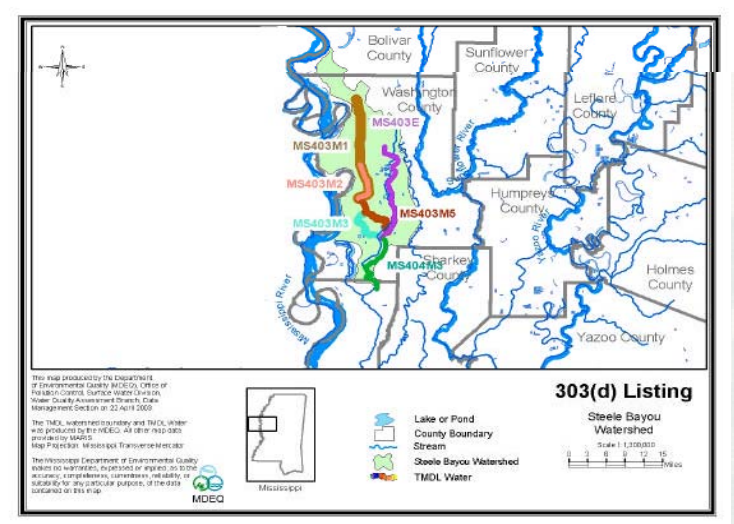
- J. Killgore (EL), working in Yazoo Delta in cooperation with MDEQ, USGS, Delta Council, ULM, MS Museum of Natural Science
- Using Index of Biotic Integrity (IBI) researchers were able to propose design modifications for USACE Vicksburg District Upper Steele Bayou Flood Control Project Design & Modification

# Reference Conditions in Yazoo Delta, cont'd

Best Attainable Condition (BAC) – can be achieved at Least Disturbed Sites if best possible management practices are in place for some period of time. Used a combination of Historical Condition and Minimally Disturbed sites to set BAC

**USACE Vicksburg District – Upper Steele Bayou Flood Control Project Design & Modification**

| **Flood Control Component** | **Purpose** | **Design Modification & Potential Benefit** |
|---|---|---|
| Channel cleanout and enlargement | Reduce flood damage by reducing stage | Removal of soft sediment improves habitat quality in low-gradient streams and removes legacy pesticides |
| Weir construction | Water management and in-stream control of vegetation during low flow season | Low-crest, gradually sloping weirs pool water at low flow, create artificial "riffles" during normal flow, and are passable by fish at high flow |



# Reference Concepts in Watershed Assessment

- A Watershed Assessment Tool for Evaluating Ecological Condition, Proposed Impacts, and Restoration Potential at Multiple Scales
  - *R. D. Smith (EL), C. V. Klimas (EL), and B. A. Kleiss (MVD) (2005)*
  - Model developed for Los Angeles District using Hydrologic, Water Quality and Habitat Integrity Indicators developed by Smith (2000, 2004).

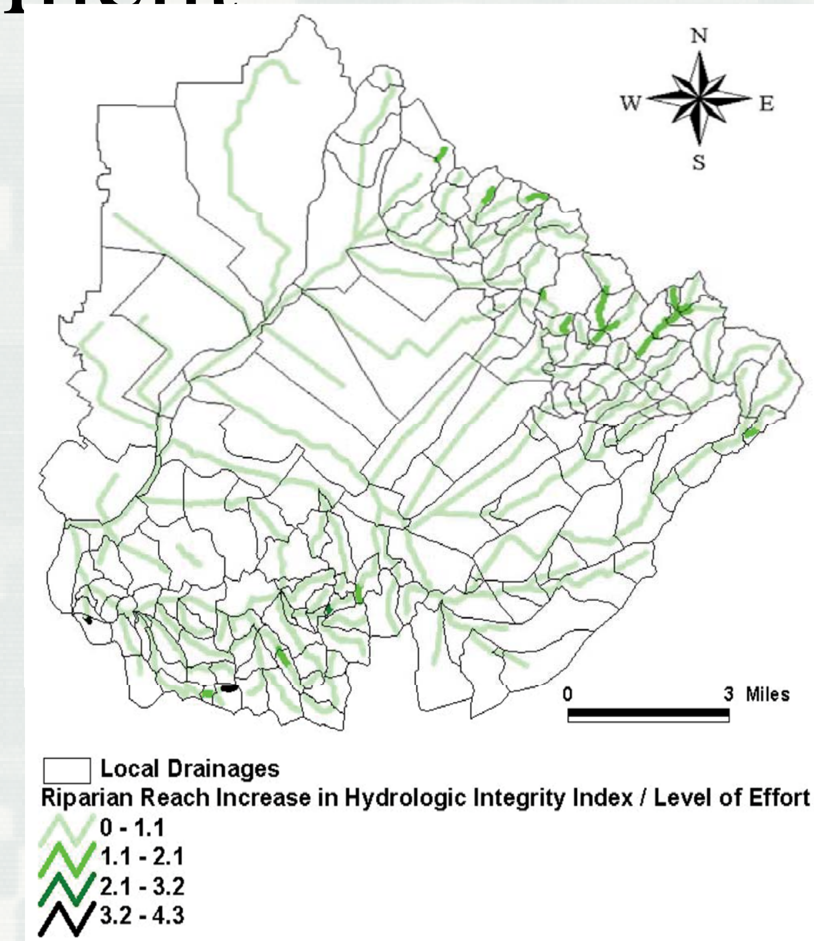
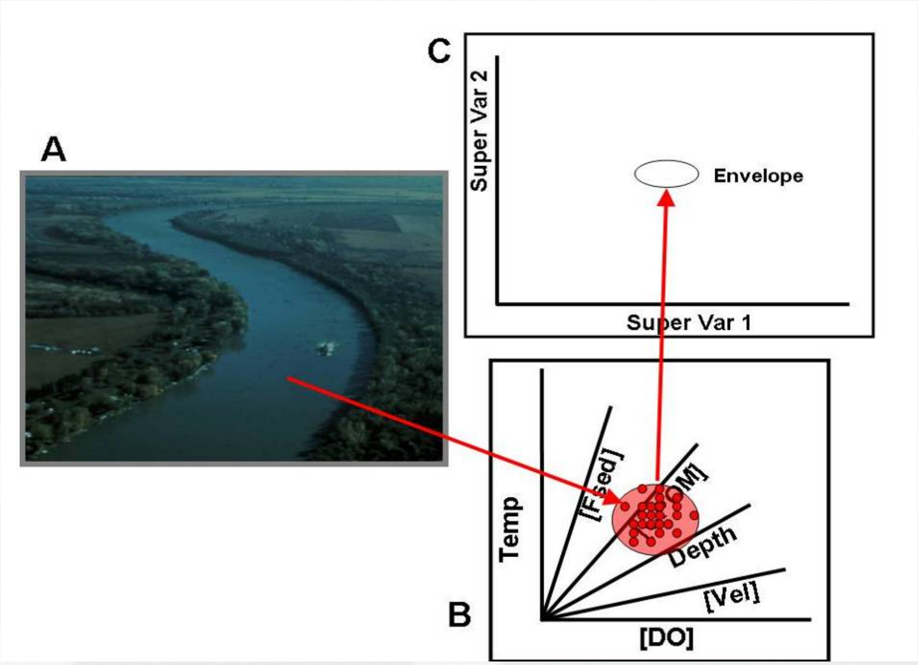



Figure 13. Hydrology index increase divided by level of effort following restoration for riparian reaches

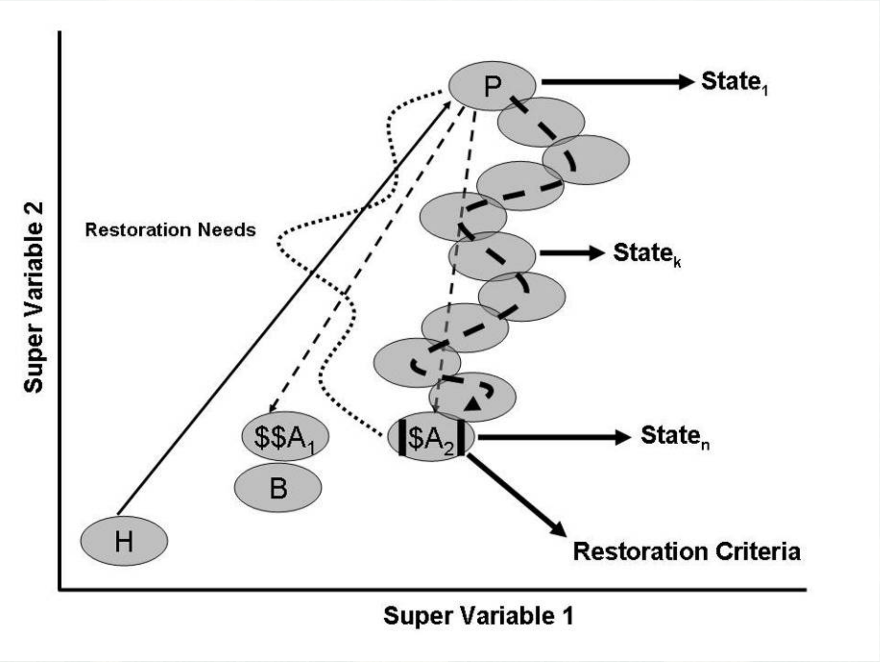
# Reference Condition – Application to Planning

- Reference Condition Approach to Restoration Planning
  - J.M. Nestler (EL), C.H. Theiling (Rock Island District), K. Lubinski (USGS), and D.L. Smith (EL)
- Hydrologic Drivers of the Upper Mississippi River Ecosystem: A Multiple-use River System
  - J.M. Nestler (EL) and C.H. Theiling (Rock Island)

# Geomorphic, Hydraulic, and Land Cover Characteristics of the Upper Mississippi River System – C. Theiling USACE Rock Island District/University of Iowa IIHR Hydroscience




Multiple Reference Condition Analysis: Each reference condition can be characterized by multiple environmental parameters that likely fall within a narrow range of values represented by an envelope




**Tracking Ecosystem Condition Trajectory Among Multiple Reference Conditions**

Legend: H = Historical (“Natural”), B = “Best Achievable”, Ai = Competing Alternatives, P = Present.

# Ongoing Issues and Considerations

- Strategies and approaches differ widely, one size does not fit all
  - Rift in the stream restoration community as an example of disagreement and criticism over methodologies – can present a barrier to implementation
  - Strongly depends on correct *identification* and *characterization* of appropriate analog reference setting
  - Design and Community of Practice and industry limitations, contention, lack of consensus, similitude and other issues
  - What are the consequences of choosing the wrong reference condition?
  - How do we avoid this pitfall? – better documentation of resources and methods: technical assistance

# River Restoration Reference Rift

- Rosgen (1996) provides a stream classification system, and a procedure for characterizing an analog reference reach to set river restoration design parameters
- The Rosgen approach, widely termed “natural channel design,” has come under criticism, primarily from the academic community
  - Infers function from form
  - Discrepancies in the classification system
  - Discrepancies in evolutionary sequences of stream form
  - Reliance often on a single site and professional judgment for selection, assessment and data collection
  - Lack of published data or research studies on the methods and success of projects – primarily a practitioner-based approach, not represented in the literature

# Additional Work Unit Initiatives…

- Ongoing research to document range of Corps-partnered projects using reference condition concepts, compilation into a database of case studies to highlight application and detail methods
  - Include successful as well as unsuccessful case studies for application of reference concepts of differing type, setting
  - Document specifics that will lead to guidance for application of analog and modeled reference systems
- Continue to work toward EBA Gateway online as a clearinghouse for reference condition data, models, methods, sites and technical assistance – currently compiling these resources

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QUESTIONS?