SIDE CHANNELS OF THE IMPOUNDED AND MIDDLE MISSISSIPPI RIVER: OPPORTUNITIES AND CHALLENGES TO MAXIMIZE RESTORATION POTENTIAL

DRAFT FINAL: RESULTS OF A WORKSHOP TO DEVELOP A CONCEPTUAL MODEL TO AID SIDE CHANNEL CONSTRUCTION AND REHABILITATION FROM PROJECT TO SYSTEM-SCALE MISSISSIPPI RIVER RESTORATION

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CONCEPTUAL MODEL TO AID SIDE CHANNEL CONSTRUCTION AND REHABILITATION FROM PROJECT TO SYSTEM-SCALE MISSISSIPPI RIVER RESTORATION

INTRODUCTION

General Background

River ecosystems like the Mississippi are broad in spatial scale and complex in their arrangement and connection of subsystems. In their unaltered states they are driven by climatic and hydrologic rhythms that structure their biotic communities and control their functional processes. Often the relationships between the physical, chemical, and climatic drivers in these systems and subsequent biotic responses are unclear or unknown. The inherent complexity of such systems produces uncertainties that defy standard approaches to water resources planning; moreover, uncertainties may be compounded when the systems are altered by factors such as dams, channelization, levees, and bank stabilization. To successfully manage and restore these systems (defined as relaxing human constraints on the development of natural patterns of biodiversity (Ebersole et al. 1997, and Frissell et al. 1997) can require the application of rigorous guiding principles, knowledge about past system states and how they changed to the current states, and a knowledge of possible restoration actions that could shift the present ecosystem state to a more desirable state. In such settings management action and subsequent performance monitoring must be conducted in a way that knowledge about the system and how it responds to management intervention is systematically increased and uncertainty systematically reduced.

The preferred method for conducting large-scale ecosystem restoration is Adaptive Environmental Assessment and Management (AEAM – Walters and Holling 1990). AEAM organizes restoration into a stepwise framework that optimizes informed restoration decision-making over time through the sequential reduction of uncertainties about ecosystem response to management actions. The individual steps in AEAM are well known (Williams et al. 2007) and have been applied and refined by many others, (King et al. 2010, Lindenmayer and Likens 2009, McFadden et al. 2011, Williams 2011a, Williams 2011b) initially as a symbolic narrative useful for concept organization, communication, and visualization. More recently the qualitative nature of AEAM has been translated into quantitative protocols suitable for restoration program development including decision analysis systems (Gregory and Long 2009, Linkov et al. 2006, Lyons et al. 2008, McFadden et al. 2011). Over a period of about 2 ½ years, planners, managers, regulators, and researchers working on Middle Mississippi River (MMR) restoration have been cooperating to develop an effective restoration protocol based on AEAM as described in Williams et al. (2007). Such a protocol would enhance water resources planning for the MMR including the critical step of evaluating trade-offs among resource categories, such as native biodiversity, recreational fishing and hunting, navigation, water quality, flood control, and agricultural production. Moreover, it would help identify the types and resolutions of simulation tools needed to forecast the responses of diverse resource categories to different management actions.

AEAM, as conceptualized herein, involves a systematic approach to understanding environmental and biological dynamics (change) resulting from outcomes of a set of management policies and practices. The uncertainties inherent in management actions go beyond the ecological to the social and the political. In this workshop, however, we purposefully omitted the social and political implications and attempted to lay the foundation to improve our ecological knowledge. To do this, we asked workshop participants to develop sets of conceptual models that would be used to create practical criteria that would eventually help decision-makers make thoughtful choices in selecting environmental problems that would be appropriate for the application of the AEAM approach. Therefore, the MMR side channel ecological conceptual models would represent potential problems and restoration actions at the system level. A system level approach to restoration negates the "one-size-fits-all" recipe for side channel restoration and fittingly abides by the principle of AEAM by implementing a set of management actions to be evaluated. To obtain meaningful results from the management actions, carefully designed experiments and long-term monitoring programs will be required to improve ecological knowledge. Such a holistic approach that incorporates the stochastic, non-linear, dynamic nature of this biophysical and socioeconomic system will help ensure an efficient AEAM process.

Background of the Workshop

The MMR partnering agencies, stakeholders, and NGOs generally embrace AEAM as a broadly defined strategy of organizing the complexities of water resources and restoration management into a protocol that supports wise and effective decision-making particularly for side channel restoration (as described below). Historically, ideas about side channel restoration of the MMR can be traced to an initial vision document (U.S. Army Corps of Engineers 2001) that focused on structural restoration based on restoring some level of natural channel morphology and complexity. While excellent for the time period in which it was produced, evolving understanding of large river processes indicated that partial restoration of physical structure of the river system did not necessarily lead to commensurate restoration of process and function. Additionally, the full importance of AEAM to restoration planning emerged after the publication of the initial vision document. The recognition by many that structural restoration was an incomplete path to biodiversity conservation led to the realization that the original vision document should be revisited and a new vision document should be created in a multi-agency, multi-disciplinary workshop founded on the principles of AEAM. This new vision document would lay the groundwork for future restoration and management actions in the MMR. A scoping meeting to organize a workshop to create a new vision document was held in Cape Girardeau, MO on 20-21 January 2010 (attendees in Appendix A). The following general conclusions and needs coalesced during the scoping meeting:

- Side channels are one of the few potentially effective management actions for restoration in the middle river because levees typically bound the main channel and reduce the effectiveness or physically eliminate many other restoration actions (e.g., island building or reconnecting to the floodplain unless substantial land purchases are made).

- Side channels are also common features in other reaches of the Upper Mississippi River, but because of the existence of large backwater areas, the emphasis in these other reaches has been on backwater restoration.

- In the middle river, side channel construction is typically associated with either a bend way cutoff or a break in a dike field. Upper and lower hydraulic closing structures are used to prevent the side channel from capturing excessive flow and thereby jeopardizing the main navigation channel.

- In the present river, side channels are usually, but not always, temporary river features that eventually fill with sediment and become colonized by terrestrial vegetation. Therefore, over time, most side channels and the restoration potential they represent will be largely lost from the system or will require maintenance to sustain their restoration potential.

- ➢ The opportunistic nature of side channel construction/enhancement, lack of understanding about large river processes, and monitoring challenges have in the past precluded development of detailed conceptual models of how side channels could be used to contribute to overall biodiversity enhancement in the Middle Mississippi River.

- ➢ Studies to document the contribution of side channels to river biodiversity use large–scale habitat classification to coarsely stratify each side channel into sampling units generally consistent with the way the main channel is sampled. The large scale at which monitoring is performed may be too course to describe important processes.

- ➢ Finer scale environmental fluid dynamics or biogeochemical cycling studies are not conducted in side channels so that process-level information is not generally available.

- ➢ Methods to maintain side channels as a restoration feature or to control their succession (i.e., prevent their loss through sedimentation) have not been developed.

- ➢ There is a need to better understand the potential of side channels to contribute to system-level sustainability both through the analysis and integration of existing data and through the learning phase of adaptive management.

Most importantly, the attendees of the scoping meeting concluded that a follow-up workshop was necessary to address the needs identified during the meeting. These needs were identified as a series of questions that were consolidated in Appendix B. A subset of the attendees of the scoping meeting formed themselves into a planning team which subsequently proposed the following specific objectives for the workshop:

1) Convene a focused workshop lasting about 2.5 days attended by regional managers and experts, aided by invited stakeholders, with sufficient knowledge of the Mississippi River to develop a conceptual model and decision-tree describing the likely optimum contribution of side channels to Mississippi River environmental sustainability. A decision-tree will supplement the conceptual model by focusing on uncertainties. The conceptual model and decision-tree will be used as the basis for restoration decision-making by natural resource managers as well as the point of departure of models that will forecast the likely outcome of competing management actions. Conceptual model building is a critical step in the early phase of AEAM because it is foundational for all subsequent steps in the planning evaluation of alternatives. The final conceptual model and decision-tree will be prepared after the workshop is completed and distributed to workshop participants for their concurrence.

2) As part of the workshop, hold ½ day of training to ensure that workshop attendees are all conversant in necessary foundational technologies. These foundational technologies include:
   a) Evolving concepts in large river ecology,
   b) Environmental fluid dynamics,
   c) Fish tagging technologies and their use in monitoring large river fishes, and
   d) Using fish monitoring data to understand and forecast the relationship of fish to the river physical and chemical environment.

Setting of goals and objectives is a foundational step of AEAM and a critical step in water resources planning in general. However, goals and objectives setting were not addressed directly during the workshop because of scale considerations. Goals and objectives are usually established for well-defined geospatial domains that exhibit either natural (e.g., natural elevation breaks or other changes in geological or landscape pattern) or institutional (e.g., state or regional) boundaries. Three hierarchical scales are typically recognized in the MMR: system, reach, and project. In the MMR, system and reach scales are geographically well defined and recognized institutionally. This recognition facilitates long-term restoration planning at these two larger scales that can include setting of goals and objectives. For example, at the system geospatial scale, goals and objectives for the Upper Middle Mississippi River (UMRS) are described in Galat et al. (2007) and more refined goals and objectives at reach geospatial scales are described in U.S. Army Corps of Engineers (2011; see Table 1). However, the focus of this workshop was side channel restoration which typically occurs at the project geospatial scale. We believe it was important to separate the geospatial scale of project footprint from the geospatial scale of project effect because a project footprint may be relatively small and well defined, but project effects may be more difficult to define and extend much further downstream or upstream. Project goals and objectives cannot be defined *a priori* because there is not typically an existing, clear-cut project geospatial scale of impact that can establish boundaries to focus setting of project goals and objectives. In fact, the scale of influence of a project is typically a variable that is considered during project planning by a Project Delivery Team (PDT – multidisciplinary or interagency teams that plan Corps projects). Consequently, setting of goals and objectives at the system and reach scales was outside the mandate of the workshop because those have been established by previous meetings. Setting of goals and objectives at a project level is impossible without the focus provided by a specific project. Therefore, the workshop did not attempt to define goals and objectives for side channel restoration; rather, the workshop adopted the view that side channels should scale up to satisfy goals and objectives at the reach scale.

The follow-up workshop entitled "SIDE CHANNELS OF THE IMPOUNDED AND MIDDLE MISSISSIPPI RIVER: OPPORTUNITIES AND CHALLENGES TO MAXIMIZE THE RESTORATION POTENTIAL OF A COMMON ENVIRONMENTAL MANAGEMENT ACTION" was held in Cape Girardeau, Mo from 9-13 January of 2011, but with a considerably expanded attendee list from the scoping meeting. The goal of the workshop:

"In a collegial, interagency, and multi-disciplinary setting, develop a comprehensive conceptual model (supplemented by a decision-tree) of potential side channel functions, processes, and structures that would allow them to maximally contribute to Mississippi River restoration consistent with the system-wide goals and objectives of the UMRS (Galat et al. 2007)."

The workshop organizers hoped that the workshop participants would converge on a single optimum conceptual model. However, if a single conceptual model could not be developed then the organizers were committed to accurately report the products developed by the workshop and then to integrate them into a synthetic whole (if possible) or to at least reconcile the different products to one another if integration was impossible. The agenda, designed to achieve the workshop goal, and attendee list are attached as Appendices C and D, respectively.

Table 1. Example reach objectives for the unimpounded MMR organized by Essential Ecosystem Characteristic (EEC) (from U.S. Army Corps of Engineers 2011).

Geomorphology: Manage for processes that shape a physically divers and dynamic river floodplain system	**Hydrology and Hydraulics: Mange for a more natural hydrologic regime**	**Biogeochemistry: Manage for processes that input, transport, assimilate, and output material within UMR basin river floodplains, e.g., water quality, sediments, and nutrients**	**Habitat: Manage for a diverse and dynamic pattern of habitat to support native biota**	**Biota: Manage for viable populations of native species within diverse plant and animal communities**
Restore hydro-geomorphic processes that create, maintain, and improve connectivity, bathymetric diversity and flow variability of channel borders, side channels, islands, sand bars, shoals, and associated habitats.	Restore hydraulic connectivity (surface and ground water) between rivers and their floodplains, especially backwater flows into lakes, wetlands, sloughs, swales, abandoned channels, and back swamp depressions.	Enhance water quality parameters (e.g. nutrients, dissolved oxygen) sufficient to support native aquatic biota and consideration of designated uses.	Restore, expand, and maintain the amount and diversity of floodplain terrestrial habitats emphasizing contiguous patches of plant communities to provide a corridor along the UMR and riparian buffers.	Maintain and restore viable populations of native species and communities throughout their range in the UMRS in suitable geomorphic areas of the landscapes.
			Restore habitat types most reduced from their pre-settlement extent (e.g., Bottomland and mesic prairies, Savanna, Floodplain Lake, Floodplain Forest, and Bottomland Hardwoods) and the ecological processes and functions to support them.	Reduce the adverse effects of invasive species on native biota.
			Protect, restore and manage complex wetland areas (including within levied areas) to provide diverse habitat	Provide nesting, feeding and resting habitat for migratory birds.
			Increase the extent and number of sand bars, mud flats, gravel bars, islands, and side channels towards a more historic abundance and distribution.	Provide habitat for all life stages of native fishes and other aquatic biota.

This report summarizes the ideas and concepts generated at the workshop at two levels. For clarity and brevity, the diverse and wide-ranging discussions of the workshop are crafted as a synthetic whole described as a single conceptual stream, but at the expense of chronological order or fidelity to the individual discussions held by each breakout group. Discussions held by each breakout group were captured in standalone text boxes to document how the most important ideas of the workshop were derived; these ideas were works in progress and not necessarily complete, yet they reflect the breadth of thought and creativity that guided workshop results. This synthesis represents the authors' attempt to organize these breakout group products into an integrated view of restoration planning and AEAM.

Workshop Organization

The workshop training session was held from noon to 5:00 PM on January 10 and attended by about 30 professionals from a variety of agencies and organizations. We will not describe the training session any further. The main workshop was held from the morning of 11 Jan 2011 until noon on 13 Jan 2011. The main workshop was separated into plenary and breakout sessions. The first plenary session began in the morning shortly after the workshop was convened and lasted about five hours. In this session, the attendees were presented with:

- Historical context of the workshop culminating in a concise list of goals, objectives, and desired outcomes at reach and system scales.

- A general description of the Middle Mississippi River.

- The restoration and management perspective of both the Corps of Engineers and the Missouri Department of Conservation, and

- A primer on conceptual model building.

With this background the attendees were then given the option of how best to achieve the desired workshop outcomes. The idea of the decision-tree was dropped early and the groups decided to focus primarily on conceptual model building. The organizers were concerned that workshop participants would need all available workshop time to think through and prepare a side channel conceptual model. Many participants were unfamiliar with the decision-tree concept and additional time would be needed to train participants in decision-tree creation. After the general framework was decided the workshop organizers then allowed the attendees to sign up for one of three separate breakout sessions with each breakout group having a facilitator and recorder (see last column of Appendix D). Each subgroup was composed of approximately 8-12 participants (the number varied slightly from day to day because of schedule demands of some of the attendees). Such a size range is small enough to allow each participant to engage in active discussion but large enough that multiple disciplines can contribute to the subgroups conclusions. A small amount of redistribution was necessary to prevent either a critical discipline from being underrepresented or domination by a single discipline. Three senior members of the workshop "floated" among the three breakout sessions to answer questions or resolve procedural issues that arose during each subgroup's deliberations. After receiving their instructions, each subgroup reconvened in concurrent breakout sessions to progress towards their respective breakout group goals. Each breakout group met in their own room supported by audio-visual aids, flip charts on tripods, and computers.

Deliberations were divided into 5 breakout sessions interspersed with "report backs" to the combined workshop over a 3-day period (Appendix C). Each subgroup was given substantial flexibility to self-organize to adjust to their own unique professional composition and group character so long as they made progress toward the workshop goal. The workshop culminated in a final plenary session in which each breakout group presented their products to all of the workshop attendees with the idea that such a setting would be conducive to a multi-disciplinary, holistic synthesis of the workshop deliberations. At the end of the workshop hard copies and e-copies of all products were collected and archived for future use.

Background and Definitions

Identifying a proper range of temporal and spatial scales to describe and assess the state of the MMR is an early and critical step in developing a useful conceptual model. Recent advances in the scientific literature describing large rivers have focused on ecosystem processes and functions. River geomorphologists created a useful hierarchical spatial classification system for rivers (Table 2) that also has ecological significance. The finest resolution for assessment should occur at the functional unit scale (spatial scale of approximately 100 m and temporal scale of about 1 month). This scale is of ecological interest because it is a common sampling scale at which abundance of river biota are assessed and it is also the approximate scale at which many river physical or chemical processes are typically monitored and evaluated. Also, it is the approximate scale of species or guild habitat delineations. Therefore, a functional unit would be a logical scale to assess condition of the Mississippi River at the process level or determine habitat availability and a scale at which information could be accumulated to describe ecological function at broader scales. To assess the contribution of side channels to reach and system objectives information would be integrated up to functional channel set or river-reach scales. Of course, the general scaling guidelines presented in Table 2 should be revisited by future planning efforts and made specific to the inherent scaling of the Mississippi River. For example, the average width of bankfull discharge could be a more precise and accurate spatial scale ratio for assessing the MMR. A useful range of temporal scales to be considered could vary between monthly to seasonal periods at the finest resolution to temporal scales associated with climate change at the coarsest scales.

Table 2. Hierarchical spatial classification of rivers (from Thoms and Parson 2002):

Scale	**Spatial extent (km)**	**Temporal extent (years)**	**Description**
Functional process zone	10^3–10^2	10^4–10^3	Lengths of the river system that have similar discharge and sediment regimes, can be defined from major breaks in slope and from style of river channel or flood plain
River reach	10^2–10^1	10^2–10^1	Repeated lengths of river channel within a process zone that have similar channel style
Functional channel set	10^0	10^0	Units associated with specific landforms such as major cutoffs, aggrading flood plains, main channels
Functional unit	10^{-1}	10^{-1}	Characterized by a typical aquatic community that is indicative of the habitat conditions present at a site

The second step in creating the broader synthesis is definition of critical terms such as project, ecosystem function, ecosystem process, and essential ecosystem characteristic. Unfortunately, there is a bewildering array of definitions for these terms. Therefore, for purposes of this document we offer definitions of these terms reflecting how they were used during the workshop:

Project area/site: A project is one or more management actions affecting condition of the river ecosystem. Management actions typically have a defined geographic area called a project site or footprint, but the area affected by the project can be much larger.

Ecosystem Process: The physical, chemical and biological actions or events that link organisms and their environment (Source: Green Facts http://www.greenfacts.org/glossary/def/ecosystem-processes.htm). Ecosystem processes include decomposition, production [of plant matter], nutrient cycling, and fluxes of nutrients and energy (Source: Millennium Ecosystem Assessment). We propose that ecosystem processes are typically described as rates or fluxes using differential calculus and would constitute the state variables in a computational model of the system. The ability to define terms in a simulation context is important because assessment of the future impact of alternative management actions, including the no-action alternative, will be based on model forecasts. Therefore, the language and terms used to describe and assess the existing system must be translatable into a simulation framework.

Ecosystem Function: A function defines the dynamic attributes of ecosystems, including density of organisms, interactions among organisms, and interactions between organisms and their environment (adapted from Society for Ecological Restoration 2004). An ecosystem function is typically a broad, narrative (non mathematical) description of an ecosystem attribute typically from a resource management or economic perspective. We propose further that ecosystem functions would not be calculated directly from the output of a computational simulation model, but would be estimated by accumulating and integrating process level information over broader time and space scales. That is, any effort to evaluate how an ecosystem function might change over time or space in response to management action must include analyses of the ecosystem processes used to determine the value of an ecosystem function.

Essential Ecosystem Characteristic: Broadly defined categories of environmental features are termed essential ecosystem characteristics (EECs). The definition of an EEC is described specifically for the UMRS in Lubinski and Barko (2003) as generally derived from (Harwell et al. 1999) and applied as well to the Missouri River (Jacobson and Berkley 2011). EECs identify ecological components thought to be critical in sustaining ecological systems (e.g., energy flow, material cycling) and those aspects of ecosystems valued by various stakeholder interests. Five EECs have been identified for the UMRS: Geomorphology, Hydrology and Hydraulics, Biogeochemistry, Habitat, and Biota (Lubinski and Barko 2003). During the workshop, participants considered a grouping of similar functions to be equivalent to an EEC. For example, variables describing habitat for different species of fish are represented by the Habitat EEC.

WORKSHOP RESULTS: AN INTEGRATED VIEW OF RESTORATION PLANNING AND AEAM

The products from each of the separate break out groups were complementary and lent themselves to an integrative treatment. Below is a brief description of the product of each group emphasizing their complementary nature. This report synthesizes the break out group’s products into a functional process-based approach that largely capitalized on Group A’s output as a foundation.

Breakout Group A: Functional Unit Inventory and Gap Analysis

Description

Breakout Group A (Text Boxes 1 and 2) focused on the "big picture" from a system-wide planning context. They identified that a critically important missing step was the transition of system level goals and objectives to project level goals and objectives. That is, on the Middle Mississippi River there have been no procedures to allow Project Delivery Teams (PDT) to move sequentially downward from system- or reach-scale to project-scale goals and objectives settings. This missing step has a substantial effect on restoration planning because the PDTs are generally created specifically for each project and are disbanded after project completion i.e., they have little or no long-term corporate existence and therefore, can have little or no corporate memory. Procedural methods (protocols) must be created to give each newly formed PDT the ability to consistently develop project-scale goals and objectives that will connect to the broader system and reach goals and objectives.

The primary contribution of Breakout Group A was development of a planning concept that allowed alternative side channel restoration actions to be considered at the reach- to system-scale that we named the Functional Unit Inventory and Gap Analysis (FUIGA). "Functional Unit" is derived from the fluvial geomorphology literature (Table 2) and represents a relatively clearly delimited area having approximately uniform conditions as indicated by the presence of a representative species or guild of biota. That is, a functional unit is delineated conceptually by the presence of target biotic groups, guilds, or life stages that can be quantitatively associated with values of geophysical or biochemical variables that are thought to have functional significance. An example of a functional unit would be shallow, warm, slow water where particulate organic matter and muddy sediments are deposited; such a unit would potentially support food-web requirements of many species and could be associated with the presence of various fish species. The FUIGA system-level hierarchical scale of analysis deals with spatial categorization and accumulation of Functional Units (see Table 2) necessary to craft an assessment of how the existing system works (or could work if the system were intact).

The FUIGA was developed based on a monitoring perspective because most of the participants had a natural resource management perspective and not a simulation perspective. However, the FUIGA could be used to identify broad categories of state variables and important resource categories for computational or simulation model development. That is, the spatial discretization (grid or mesh structure) of a simulation model must map back to the distribution of functional units. Similarly, the state variables selected for a model must relate to the resource categories (e.g., fish and organic matter in the example in the previous paragraph) on which FUIGA categorizations are based. The FUIGA could also help structure a reference condition analysis. That is, planners would develop a concept of an ideal condition on which they would base their functional inventory and audit. The concept of an ideal condition would be a critical step in establishing a reference condition analysis.

FUIGA bears some resemblance to the widely used Habitat Evaluation Procedures (HEP) (U.S. Fish and Wildlife Service 1980) for target species or guilds in that it accumulates spatially explicit subareas having averaged attributes. However, FUIGA is based on functional units that can be quantified using physical, chemical, and biological variables from maps or other spatial data sets. Because we do not define these functional units as habitat of specific species or guilds, functional units may be used flexibly to represent functional processes operating within the aquatic ecosystem. This avoids the many pitfalls of using habitat inferences to compare system conditions. This is an important

Breakout Group A (continued) Text Box 1

The group first listed and described characteristics of side channels that make them essential to the ecological integrity of the MMR system (Table 1). From this foundation, they considered how management actions could modify these characteristics at one site and then how these effects could cascade throughout the entire MMR. Although different than a conventional CM, it was quickly clear that this hierarchical structure could effectively span project-to-system restoration planning. The group also categorized factors that affected essential characteristics into those that agencies could effectively influence through authorized management actions (e.g. dredging) from those that could not be effectively influenced (e.g. modify land use).

Table 1. Abbreviated list of characteristics, modifiers of characteristics, and restoration actions.

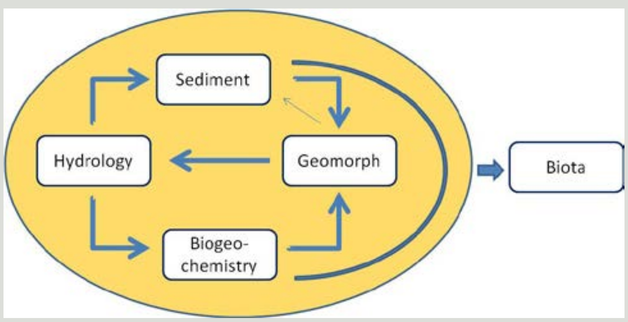
Characteristics	Modifiers (that can be manipulated)	Modifiers (that cannot be manipulated)	Potential restoration actions
Sediment dynamics	Flatten hydrograph	Land use (agriculture)	Alter land use or land use hydrology
Migratory habitat	Bathymetry	Water levels	Dredging
Spawning and Nursery habitat	Erosion or deposition	Climate shifts	Island building
Nutrient dynamics	Connectivity		

The group next developed a visualization of linkages in Table 1. However during this discussion, the biggest debate arose not about the shape and layout of the CM, but about how much information should be included. The final consensus was that level of detail should depend on pragmatic considerations like:

- What is the purpose of a CM (e.g., stakeholder communication versus synopsis of state of the science)?
- For whom is the CM for (e.g., stakeholders versus science panel)?
- How much detail is needed for a specific purpose (e.g., concept explanation versus structuring numerical simulations)?

The group concluded the amount of detail should be flexible enough to be adaptable for a variety of specific projects and audiences. For example, Figure A-1 represents how hydrology links sediment, biogeochemistry, and geomorphology adequate for communicating with stakeholders. In contrast, more detail would be appropriate for engineers.

Figure A-1. Conceptual model linking characteristics of side channels.



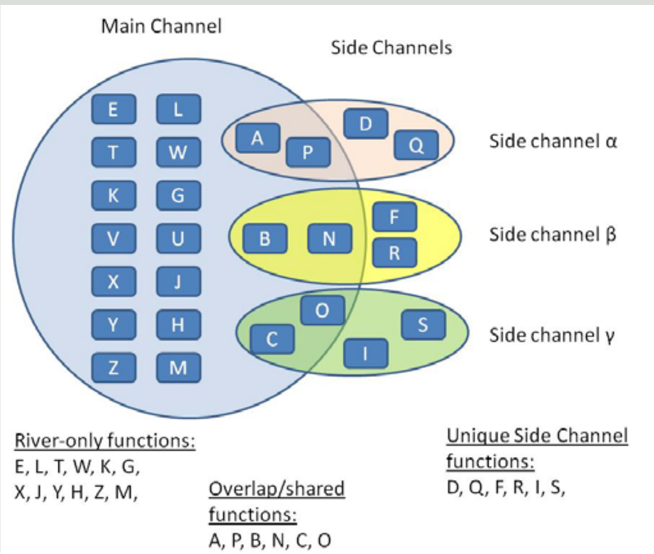
distinction for several reasons. First, the same functional unit can contribute to the habitat requirements of many different species or guilds. This attribute allows assessments using the FUIGA to be made at a system level instead of at a species or guild level because it is based on currency of ecosystem processes and not individual species or guild habitat requirements (many of which are either unknown or the subject of ongoing debate). Of course, the assumption being made is that restoration of a similar regime of processes to a reference condition or a set of standards will conserve or restore impacted species or guilds (i.e., “build it and they will come” perspective). Second, habitat requirements of rare, threatened, or endangered species are often poorly known, resulting in a high uncertainty that can make distinguishing among alternative plans/actions problematic. This appears to be particularly true for large river fish species whose relationship to physical and chemical environmental characteristics is still speculative or largely unknown (Nestler et al. 2011). Third, rare, threatened, or endangered species are usually relegated to a small portion of their historical range. Consequently, habitat requirements must

Breakout Group A (end) Text Box 2

A group realization was that each individual side channel could potentially contribute a different suite of functions to the MMR system. Thus, it was unlikely that a generalized CM (Figure 1) could represent the often unique combination of attributes of each of the many individual side channels in the MMR. Instead, each side channel should have its own detailed conceptual model constructed by tailoring the basic CM in Figure A-1. Importantly, the group acknowledged that functions of individual side channels are cumulative, not simply redundant. Also noted was the idea that some functions are unique to specific side-channels, meaning that even a single side channel may disproportionately contribute to overall ecological health of the MMR. These two points are important to communicate to stakeholders and decision-makers as side channel restoration projects are developed and prioritized.

To convey these two concepts, the group created a second framework depicting how individual side channels could contribute to system ecological status (Figure A-2). In this depiction, functions are represented as letters and individual side channels (or clusters of similar side channels) as different colored circles. Overlapping portions of two circles indicate a function is provided by both main channel and particular side channel(s). In contrast, a function unique to side channels is only found in the side channel portion of a circle. This framework faithfully conveys the spatial and functional complexity of the MMR and how this complexity can be envisioned at a system level. Importantly, the framework communicates that side channels provide both a sub-set of the functions that overlap with main channel habitats (e.g. shoreline habitat), but also unique functions (e.g. low velocity refugia for fish nursery). Further, the model is sufficiently flexible to capture differences in geomorphology and orientation seen among existing side channels, even suggesting that side channels could be clustered into categories. This communicates both the general functions and benefits of side channels as a habitat category to the MMR system while also conveying that specific side channels have disproportionally large roles in the system.

Figure A-1. Conceptual model integrating of side channel habitat functions with the MMR system.



be inferred from restricted species distributions and therefore may be of limited use in large-scale ecosystem-level planning. Fourth, the FUIGA is similar in many respects to the widely used Hydrogeomorphic (HGM) approach (Brinson et al. 1995, Smith et al. 1995) for delineating and assessing wetlands in that it keys to spatial or structural attributes of the system. Finally, the conventional process of creating habitat portfolios to describe physical habitat is a computationally unnecessary intermediate step for a system level analysis. For example, HSI curves for species or guilds are typically developed from habitat utilization data collected at a relatively intact system. These HSI curves can be thought of as a filter through which the physico-chemical patterns of a relatively intact system can be interpreted. To use the same filter to interpret physico-chemical patterns in a range of alternatives is computationally unnecessary. It is more mathematically efficient to simply directly compare the patterns of physicochemical conditions to a reference condition using dimensional reduction techniques such as cluster analysis, PCA, or similar tools and avoid the habitat analysis (Nestler et al. 2010), particularly when HSI curves reflect uncertain associations of biota with physic-chemical conditions.

The most important attribute of the FUIGA that separates it from HEP-like approaches is its compatibility with the Reference Condition Concept (Nestler et al. 2010). In contrast to the limitations of HEP-like approaches, the reference condition concept can be applied to generate system-level physical, geomorphic, and chemical (the most difficult to obtain) summaries of the differences in conditions between one or more reference conditions and different alternative futures. For example, the flow-weighted frequency distribution of important functional units can be described for reference conditions and one or more project alternatives. Restoration need can then be defined as the difference between the frequency distributions of the conditions describing a reference condition and an alternative future. Therefore, it could be used to identify important ecosystem functions that could be used to compare alternative forecasted conditions against one or more consensus reference conditions. Nestler et al. (2010) demonstrate the use of the reference condition concept for the UMRS. The process of using FUIGA to systematically inventory existing versus reference conditions (either historical or other conditions) also causes the user to identify, or at least bound, the desired future condition. That is, reasonable restoration alternatives that balance cost and environmental benefit should emerge during the FUIGA process.

Fortunately, the MMR is one of the most studied large rivers in the world and consequently, a wealth of spatially discrete graphical information is available collected over long time periods that can be used to develop appropriate reference conditions. Examples of candidate functions and processes, some of which could contribute to a FUIGA are listed in Text Box 3. The FUIGA, like conventional approaches to project planning (e.g., acres of habitat produced by a project for a target species or guild), is spatially explicit so that it should be compatible with the present water resources planning process used by the Corps of Engineers (Figure 1). That is, it spatially accumulates project benefits and impacts for environmental benefits analysis. It is important that scientific advancements in ecosystem restoration not outpace the requirements of the water resources planning process.

The inventory phase of FUIGA is inherently multi-scaled because it can be fit to meet the needs of the planning process from a system scale to a functional unit scale because the length of river to be considered is arbitrarily determined by a system-level PDT. As discussed earlier, this raises the institutional issue that a dedicated system-level PDT may be needed to address ecosystem-scale issues and to ensure that reach-scale planning be compatible with system-level planning. In the UMRS, the Regional Support Team associated with the Science Panel performed this function under the Navigation and Environmental Sustainability Program (NESP).

Implementing a FUIGA Synthesis

We recommend the following steps to implement the FUIGA. A multi-disciplinary panel comprised of agency representatives and stakeholders should be convened to build the system-level component of the FUIGA. This component should address the following system-level planning needs (Summarized in Figure 2):

1. Create or reiterate existing system-level goals and objectives and demarcate the system with longitudinal and lateral boundaries. This demarcation can occur at two levels, management action boundaries and scientific effects boundary. The management action boundaries are the spatial

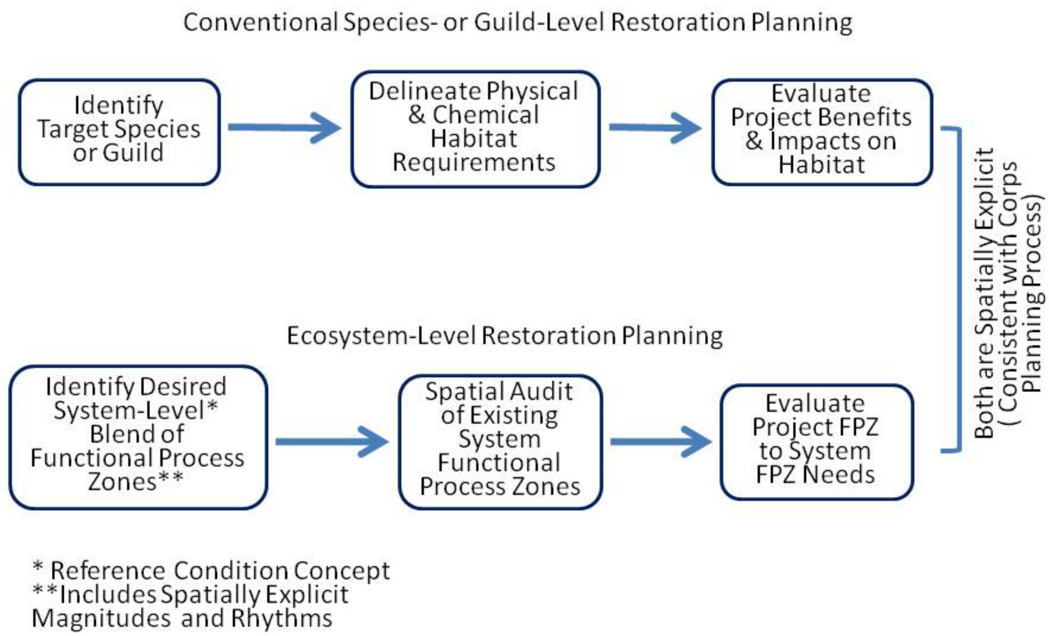


Figure 1. Comparison of conventional planning methods to quantify impacts and benefits of restoration action to the Functional Unit Inventory and Gap Analysis (FUIGA). Note both are spatially explicit and can be accumulated for upwards summary, although the FUIGA is founded on reference condition concepts and not on HEP

bounds within which partnering agencies can implement management actions. The scientific effects boundaries are the broader spatial domains that affect the success of management actions (e.g., climate change impacts occur at global or continental scales). The CM built by Breakout Group C (described later) can be examined to help in this determination. In some cases, agency authorities may come into play. For example, nutrients and sediments originating from the watershed where the Natural Resources Conservation Service has primary management authority may affect the riparian corridor where the Corps has primary management authority.

2. Identify the general Essential Ecosystem Characteristics of the system (e.g., Galat et al. 2007) using reference condition concepts (Nestler et al. 2010). That is, the panel should consider various historical, real, or virtual surrogate systems that give insight into the unimpacted state of the system as well as existing status and trends data that document existing deteriorated environmental conditions. This phase may include development of conceptual models that apply to both of the scales identified above.

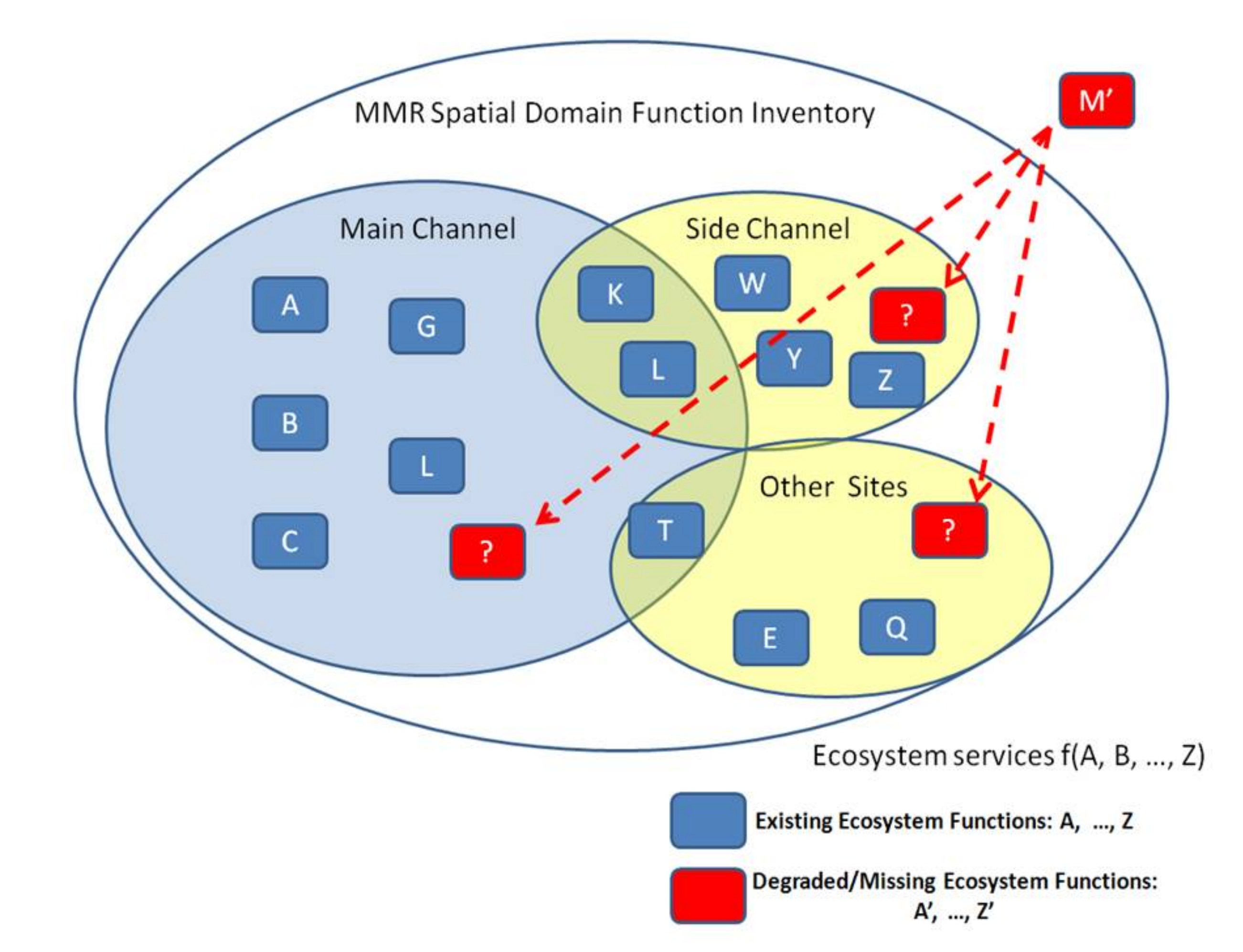


Figure 2. Representation of generic FUIGA procedures. Identified functions have been spatially distributed into main channel, side channels, and other sites (e.g., islands). In this example, each of the functions is assumed to be based on a roughly similar geographical area. At a system scale, the analysis indicates that hypothetical function M' is degraded. Restoration planning can then focus on identifying side channel restoration actions that restore or enhance the M' function. As shown, the system is considered in steady-state, it is important that the system be understood to be in a perpetual state of succession so that the time domain component of all functions should be considered. That is, it may be necessary to "renew" side channels according to a schedule to prevent them all from filling with sediment and becoming terrestrial habitats.

3. Using the EECs as a guide, identify all relevant system functions expected from the restored system by stakeholder interest and agency mandate. These functions must be associated with specific structural features or geographic areas so that the functions can be later spatially accumulated and summarized to create a system-level function audit in a manner parallel to the accumulation of habitat units.

4. Perform a system-level function audit with functions separated into main channel and side channels so that the effects of individual side channels can be visualized (Figure 2). Those functions associated with the main channel should be separated from functions provided by side channels or other types of management actions.

5. From the audit, identify those functions that have been eliminated or degraded at the system level (e.g., rounded rectangle **M'** in Figure 2).

6. Canvas and evaluate existing and potential SC sites (and other management actions) to determine likely candidate sites that can provide the identified degraded functions.

7. Identify important processes associated with each function and interactions of functions to guide the creation of a detailed CM. The more detailed CM can then be used to guide the selection of additional modeling or assessment tools that can be used to further select candidate side channels or to develop engineering design criteria

Importantly, the FUIGA should be considered to be part of AEAM. That is, data collected for the inventory phase of FUIGA should be considered as a supplement to status and trends, process, and function data (e.g., data collected by MDC (e.g., Barko and Herzog 2003 or McCain et al. 2011) and under the Long Term Resource Monitoring component of the Environmental Management Program for the Upper Mississippi River) collected to support regional AEAM. Examples of how data collected under FUIGA could supplement AEAM include: sequential mapping to describe change dynamics, creation of multiple reference conditions to understand the system at different levels of basin and channel modification, inventory different habitat categories over time to help explain population dynamics of individual species, infer the size and distribution of different functional process zones as a function of hydrologic patterns that together offer insight into the system dynamics of the MMR, and analyze this inventory to identify missing or heavily impacted functional process zones in the present river. This "inventory and analysis" phase is the first step in developing a unique planning tool for the MMR that can be made quantitative.

As originally, developed the FUIGA focused on ecosystem functions, but not ecosystem processes. Addressing this missing step (and others) by connecting ecosystem processes and functions is the topic of the next section.

Breakout Group B: Integrating Ecosystem Process, Function, and Essential Characteristics

Unlike the product from Breakout Group A, which had a strong spatial (and therefore structural) perspective, Breakout Group B was more focused on ecosystem function and the attendant processes that contribute to ecosystem functions. In fact, this group warned against the dangers of taking too much of a structural perspective in side channel restoration. Breakout Group B (Text Boxes 3 and 4) identified, organized, coarsely quantified (see different sized dots across management actions in Figure B1), and communicated the complex interrelationships among essential ecosystem characteristics, ecosystem functions and multi-scaled ecosystem processes associated with side channel restoration alternatives (e.g., Figure B1).

From the perspectives of the report authors, Breakout Group B described a concept that could smoothly transition from system level goals and objectives to ecosystem functions and, most importantly, to relatively fine-scale ecosystem processes and to describe how this transition differed

Group B (continued) Text Box 3

This group began with concerns and expectations from a CM. There was procedural concern of how side channels already planned and prioritized related to CM development at this workshop. Some felt the workshop could be repetitious and therefore a step backwards. Others felt that the workshop was an opportunity to continue the discussion on side channels and update restoration planning with new information and understanding. Objectives for the CM developed through this workshop included its use to communicate side channel restoration to a wide range of audiences, with different levels of detail required by each specific audience. In particular, the group identified the need to communicate the dynamic nature of side channels. There was a concern that all stakeholders were not represented at this workshop. Therefore, the group should make an effort to identify interests of those not attending. The group also emphasized the importance of restoring functions over the importance of restoring structure. There was a hope that the CM could be used as a mechanism to develop performance criteria, e.g., how many, how much, when, where and what is needed. The group then identified important, often unique, roles and functions of side channels. The group concluded that side channels are the best "floodplain" available in the contemporary MMR.

Side channels provide:

- connectivity with off channel habitat
- flood storage
- refugia from high water velocity
- bird nesting and feeding areas
- fish spawning, nursery, and overwintering habitat
- mussel habitat that is different from main channel (MC)
- heron rookeries on island
- wood debris and substrate different from the MC
- associated sand bar habitat
- island depression pools used by herptiiles, shorebirds and other wildlife
- good sturgeon habitat on tips of islands
- tertiary channels
- isolation from many common main channel disturbances

Side channels have important roles for human use:

- isolation and refuge for recreational activities
- can separate recreation user from navigation traffic
- out flow from SC may affect tow boat navigation

Side channels support important river processes:

- nutrient sink/cycling area
- nutrient mineralization (when drying)
- primary/secondary production
- true riparian corridor (as opposed to reveted bank)
- provides for successional gradients
- reduced turbidity from the MC
- side channels feed MC

The group decided that the evolving CM was not useful for priority setting. The group then attempted to prioritize roles and functions using graded dots as shown in Figure B1. The group then identified important management questions and decisions needed over the next 5 years.

- Possibly re-prioritize the list of SC that need work
- Can a maintenance free side channel be created/develop?
- Or manage the succession of side channels, providing a good diversity of succession stages throughout a geographical range (or across a "portfolio of SCs")
- How much connectivity needed at various river stages?
- Will future navigation water needs affect SC restoration?
- How and where to increase public and private connection to the floodplain?
- Levee setbacks potential – where?
- Can create sandbars with spoil. Where?
- Where could we (or should we) dredge out the sediment plugs on the lower ends of SCs.
- Carefully monitor river response to management changes to determine if 1) natural processes are being restored, and 2) differences can be detected at a system level

among contrasting management actions (see listings in Text Box 3). We add some additional interpretations to their concept that make it more consistent with the CMs from the other groups and therefore easier to integrate into an overall synthesis. In their concept they envisioned a set of "valued ecosystem components" (side channels in this example, but other components are possible such as main channels or floodplains) that reside at the center of the graphic. The center could be decomposed loosely into a set of concentric circles each of which represents ecosystem functions based on structures or processes associated with the selected valued ecosystem component. Selected ecosystem functions

Group B (end) Text Box 4

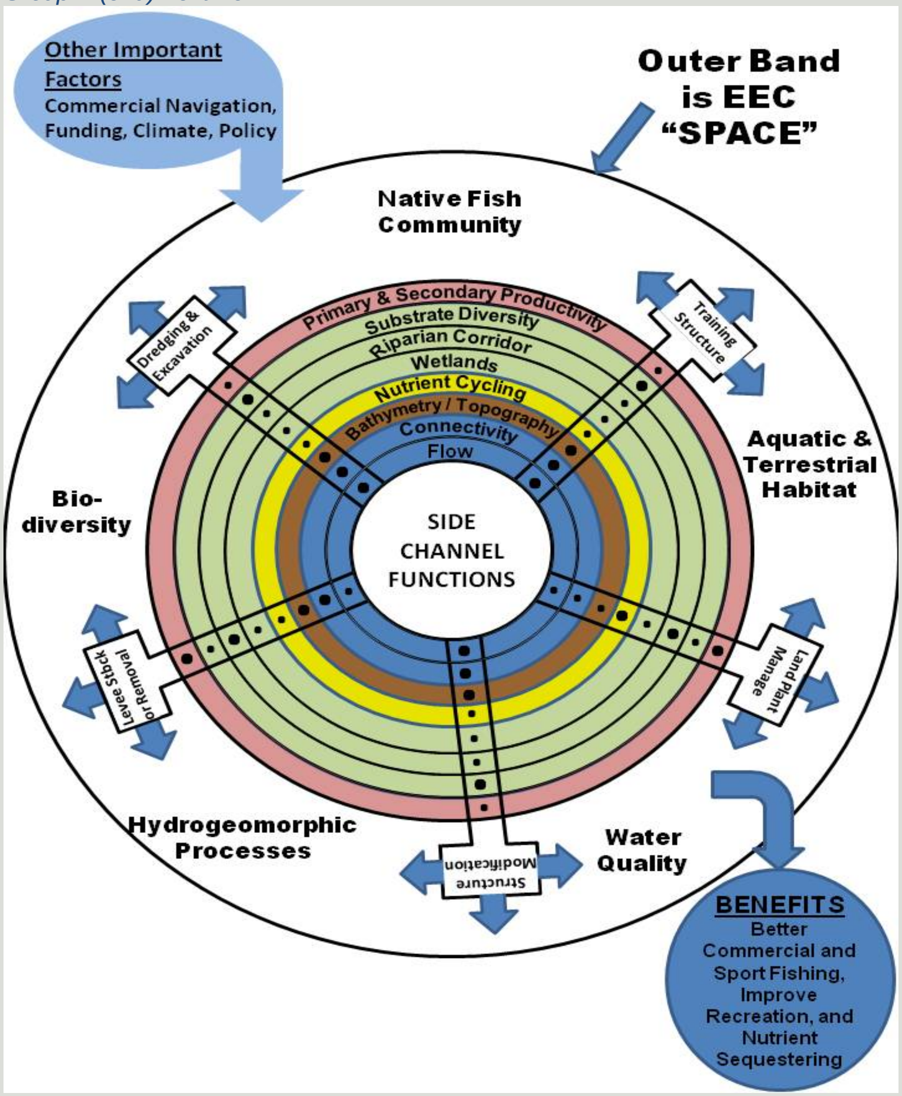


Figure B-1. Group B Conceptual Model.

The group then proposed spatial boundaries for the CM that extend longitudinally to the unimpounded reach between St. Louis and Cairo and laterally from levee to levee or from levee to bluff. The group acknowledged that there was scientific reason to include connection to the floodplain, but that would extend the CM outside current agency authorization. The components of the CM should include island geomorphology, fish community, side channel geomorphology, sediment, forage, flow, water quality, vegetation, and wildlife.

Finally, the group identified uncertainties associated with the CM and to propose ideas to reduce these uncertainties.

- How do time scales of natural cycles compare to time scales of management decisions?
- How much of a commercial fishery could be supported?
- How much floodplain should be reconnected? What is the relationship between reconnected floodplains and system nutrient cycling? Are acres of floodplain connected a surrogate for nutrient reduction?
- Best floodplain use: corn, wetlands, cottonwoods, other?
- What is the benefit of SC restoration by scale – local, reach, vs. system scale? The group felt uncertainty in benefits increased with increasing spatial scale.
- How much of the biotic diversity in the Mississippi River is due to the presence of SCs?
- Funding to do any of this is an uncertainty.
- How can SC restoration benefit users?
- What are the trade-offs among management decisions environmentally, economically, and socially?
- What are economic casual mechanisms – e.g., does increased recreational fishing result from increased fish abundance or improved access?

are partially determined by the contribution of the valued ecosystem component to the system dynamics. To help maintain organization, relatively similar ecosystem functions could be grouped by color into similar categories based on their affinity to specific EECs (i.e., habitat is green, hydrology is blue, water quality/biogeochemical cycling is gold, and biota is pink). The different actions that could be used to manage side channels are represented as radii that intersect the concentric circles that represent ecosystem functions. The magnitude of effect of each management action can be symbolized by the relative size of the dot at the intersection of the management radius and ecosystem function. For example, the management action "structural modification" (i.e., modify the control structure) has significant (large dots) effects on side channel hydrology EECs whereas the management action "management land plants" minimally (small dots) affects the hydrology EECs. "Other Important Factors" are variables that affect valued ecosystem components that are largely outside of program influence. "Benefits" are socioeconomics values (ecosystem services) provided by implementing management actions on side channels.

As was the case for the Breakout Group A products, the outputs from Breakout Group B also can be reconciled with the existing conceptual model for the UMRS (Lubinski and Barko 2003). The outermost circle intentionally represents the EECs of the existing CM where native fish community and biodiversity are reflected in the "Population" EEC, Aquatic and Terrestrial Habitat is equivalent to the "Habitat" EEC, Hydrogeomorphic Processes is similar to the "Geomorphology" and "H&H" EECs, and Water Quality is equivalent to the "Biogeochemistry" EEC. The uppermost blue dialogue balloon would be approximately equivalent to the "Drivers" of the existing CM. Unlike the existing CM, the Breakout Group B CM identifies possible benefits that could be achieved through various management actions (lower blue dialogue balloon), although the benefits are not directly associated with a particular management action. In other words, the Breakout Group B CM is a compatible with the existing CM, but presents an alternative format with greater detail.

The sunburst visual representation is comprehensive and intuitive to some audiences. The construct developed by Breakout Group B to semi-quantitatively accumulate ecological processes into ecological functions also is an effective way to communicate how different management actions affect ecosystem functions and processes to both lay and scientific audiences. For lay audiences, scientific charts and graphs are often confusing or incomprehensible, whereas the Figure B1 may be more intuitive and conveys a very large amount of planning and scientific information in a simple format. For science audiences, the semi-quantitative representation of management actions and how they affect ecosystem process is conducive to generate hypotheses. The size of each dot associated with each management action is the best guess of the planning group as to the expected benefits and impacts of a management action. That is, the size of each dot is a testable hypothesis that can be evaluated with a well-conceived monitoring program as part of AEAM. Further, the connection of ecosystem function with ecosystem process is the foundation for building a computational model of sufficient accuracy, realism, and precision to effectively evaluate alternative management actions. In the hands of an experience modeler, the information in Figure B1 is a good model planning aid to identify state variables and help determine model complexity and spatial and temporal resolutions.

The primary message from Breakout Group B complemented the primary message from Breakout Group A because it emphasized the importance of extending the FUIGA to consider processes. The last connection is critical to science-based planning because empirical science is typically performed at the process scale (i.e., the scale of monitoring and the scale of the functional unit within the FUIGA). Therefore, only after the functional unit level of hierarchical organization has been addressed can planners move to the ecosystem function level of organization or higher levels if they intend to use a science-based approach. Process information can then be accumulated to higher hierarchical levels where functions are quantified to support an ecosystem services approach (i.e., monetize ecosystem functions to compare alternatives) or a reference condition analysis (i.e., contrast ecosystem functions of competing alternatives among themselves and to the functions of a desired future system condition). Importantly, the extensive discussion supporting the importance of scale in the section describing the FUIGA also applies to this section.

The recognition that ecosystem process is important in addition to ecosystem function is critical for the learning phase of AEAM. Restricting AEAM focus primarily to function, recognizing that functions are typically associated with natural (water quality) or living resource (sport fishes) categories, will work only if a management action is successful. If a management action is unsuccessful, then function monitoring by itself will likely not inform the next round of decision-making because all that will be learned is that the management action did not work. Process level information is needed to understand why a particular management action if not successful and to redirect management action in a more positive direction.

The CM of Breakout Group B is useful as a communications device and as a method to list benefits and impacts in a general way. However, the starburst format of Figure B1is not conducive to a mathematically rigorous accumulation of benefits or summarization of impacts. The starburst format is inherently inflexible in book keeping context because each radial array begins (see “side channels” at the core of Figure B1) and ends (see outer band of EECs in Figure B1) in broad, overlapping categories which prohibit quantitative analysis of specific endpoints. Converting the starburst format into a spread-sheet (matrix) format expands its utility because the rows and columns of a spread sheet are more conducive to sub-setting, summarization, and accumulation. In Table 3, the essential ecosystem characteristic “Habitat” has been decomposed into several major target taxonomic groupings. These groupings can be scored by comparing the percent change in habitat relative to a reference condition to obtain an estimate of a habitat benefit associated with a specific alternative. Additionally, a spread sheet format allows each function to be described by its constituent processes or taxonomic groups or to link processes across multiple functions. This level of detail cannot be easily obtained using the starburst format. However, in a matrix format the simple elegance of the starburst format as a communication tool is lost. We recommend that the starburst format may be a useful construct to begin the process of coupling together essential ecosystem characteristics, ecosystem functions, ecosystem processes, and benefits into an internally consistent and meaningful construct. This usefulness may be particularly pronounced for lay audiences or mixed audiences. Once complete, the starburst can then be reformatted as a matrix to obtain another level of detail useful for developing computational modeling strategies, defining monitoring plans to implement AEAM, or to develop a scoring system based on reference condition concepts.

Breakout Group C: “Influence Effects” Generalized Conceptual Model

Breakout Group C prepared a conceptual model for side channel restoration that was both simple and general (see Text Boxes 5 and 6). Their product could be considered an “influence effects” CM because they were primarily interested in describing how different issues encountered during the planning process, from rigorous scientific uncertainties to social dimensions and economics, would influence one another and therefore affect the efficiency of side channel restoration planning. Their CM could be considered a relational map of the issues that have to be considered during project planning.

Table 3. Simple example of Figure B1 reformatted as a matrix using the habitat EEC. Note that considerably more decision-making information can be contained in the matrix than in the sunburst figure, but at the cost of simplicity of presentation and intuitiveness.

Change in habitat as a percent relative to a reference condition for "Aquatic and Terrestrial Habitat" of different animal groups*					
Resident Fish	% change	Migratory Fish	% change	Birds	% change
Largemouth Bass	-6	Blue Catfish	-10	Puddle Ducks	-5
Bluegill	+20	Sturgeon	-20	Wading Birds	-10
Walleye	-2	Paddlefish	+35	Raptors	0
Total Relative Habitat Change Score for Alternative A	+12		+5		-15

* All numbers are for illustrative purposes only

Although listed as the third CM in this proceedings, this CM (or one very much like it) should probably be considered as a starting point for CM construction because of its generality and broadness.

Breakout Group C's CM also was sufficiently broad that it could incorporate the more detailed CMs developed by Breakout Groups A and B (Figure 3). Importantly, Breakout Group C's CM does not require a scale specification allowing it to be applied at a single scale, several scales, or iteratively at a hierarchy of scales (as listed in Table 2). Selection of scales should be related to the inherent scaling of the EECs considered most critical. For example, functional units scaled to wading birds may differ considerably from functional units scaled to bluegill habitat. Alternatively, functional units may be scaled to physical or chemical EECs thought to be important to the habitat of target biota. In this case, scaling should be related to physical or chemical process variables. Once selected, then one or more scales could be used to parameterize the FUIGA application. An iterative application of FUIGA across a range of scales could generate a detailed and comprehensive comparison among a reference condition and a range of alternatives. Analysis of the results of the FUIGA should identify the most substantial differences among one or more reference conditions and a range of alternatives (including the no-action alternative). These differences would then become the criteria (i.e., necessary changes in EECs) to guide restoration action. By going through the FUIGA process, a PDT would also be able to relate the drivers to the potential magnitude of various management actions to ensure that management action would exceed natural variability. For example, climate change may result in hydrologic variability that might overwhelm the benefits expected from relatively small elevation changes obtained through water level management.

Group C (continued) Text Box 5

This group started with fundamental questions about and values of side channel restoration:

- What functions can side channels restore or enhance?
  - Habitat for native fishes only or also for-
    - threatened and endangered species?
    - mammals, herptiles, and birds?
    - recreational values?
  - What other functions are missing or degraded that side channels can restore?
  - How can the cumulative benefit of side channel restoration be assessed singly or as a system?
- What is a reference for side channel structure and function?
  - Historical side channels?
    - Is there enough quantitative information?
    - Is a historical reference relevant to contemporary conditions?
  - Should designs target habitats of specific species?
  - Should designs be based on ecological theory or simple concepts like maximizing habitat diversity?
- How linked are functions of main- and side-channels?
  - Can a side channel function if the main channel does not?
  - Can the main channel function without side channels?
  - Are side channels necessary or can their functions be designed into main channel restoration?
- Are fundamental barriers to side-channel restoration surmountable?
  - Land availability constraint.
  - Do-no-harm to navigation constraint.
  - Institutional and funding constraints.

Next, this group discussed properties of a CM necessary for planning side channels. They decided the CM should be based on a spatial unit concept because unit- based data can be analyzed to address lateral and longitudinal spatial variations and accumulated to assess system-wide effects. They recognized two main types of side channels, flow-through and backwater, and that there might be an optimum spatial distribution of these along the river. They also decided that the CM should be hierarchical, with layers representing physical/chemical processes, biologically informed templates of habitat, and biological responses. Within the biological response layer, they recognized the need to consider multiple classes of response categories to capture trade-offs including native biota, non-native biota, and human costs/benefits.

At a finer level resolution, the group considered possible ecosystem services of side-channels. They consolidated their exhaustive list into groups of functions that could apply to many taxa:

1. Support healthy food chains: geochemical and energy processing, primary production and secondary production.
2. Create migration pathways that minimize energy expenditure and maximize food acquisition.
3. Restore reproductive potential – including provision of bare sediment for vegetation colonization.
4. Provide rearing and growing habitats for early life stages with low predation risk and high food production.
5. Provide foraging and growing habitats for adults
6. Provide refugia for overwintering or predator escape.

The product from Breakout Group B could be considered an expansion of the EECs and “Human Benefits” component of the Breakout Group C CM. The Breakout Group C CM can be altered to capture the likely effects of specific management actions (e.g., land plant management vs. dredging and excavation in Figure B1) by replacing generic quantities in the EECs with specific descriptions or quantities. For example, dredging would directly affect the Geomorphology EEC which would interact with existing flow regime (Hydrology EEC) to create a new spatial/temporal distribution of depth and velocity in the Physical Template EEC. The strength of effects and processes are depicted as the arrows in the CM. Similar examples of CM application are shown in Jacobson and Berkley (2011). Once a generalized CM like that of Breakout Group C is developed for a specific action then it can be transformed into a tabular accounting sheet using ideas from the Breakout Group B CM. The specificity can take one of two forms. For a scientific audience, a matrix format would likely be best because effects can be quantified and accumulated more easily. However, for a lay audience, the original sunburst format may be better because it is intuitive and comprehensive.

Group C (end) Text Box 6

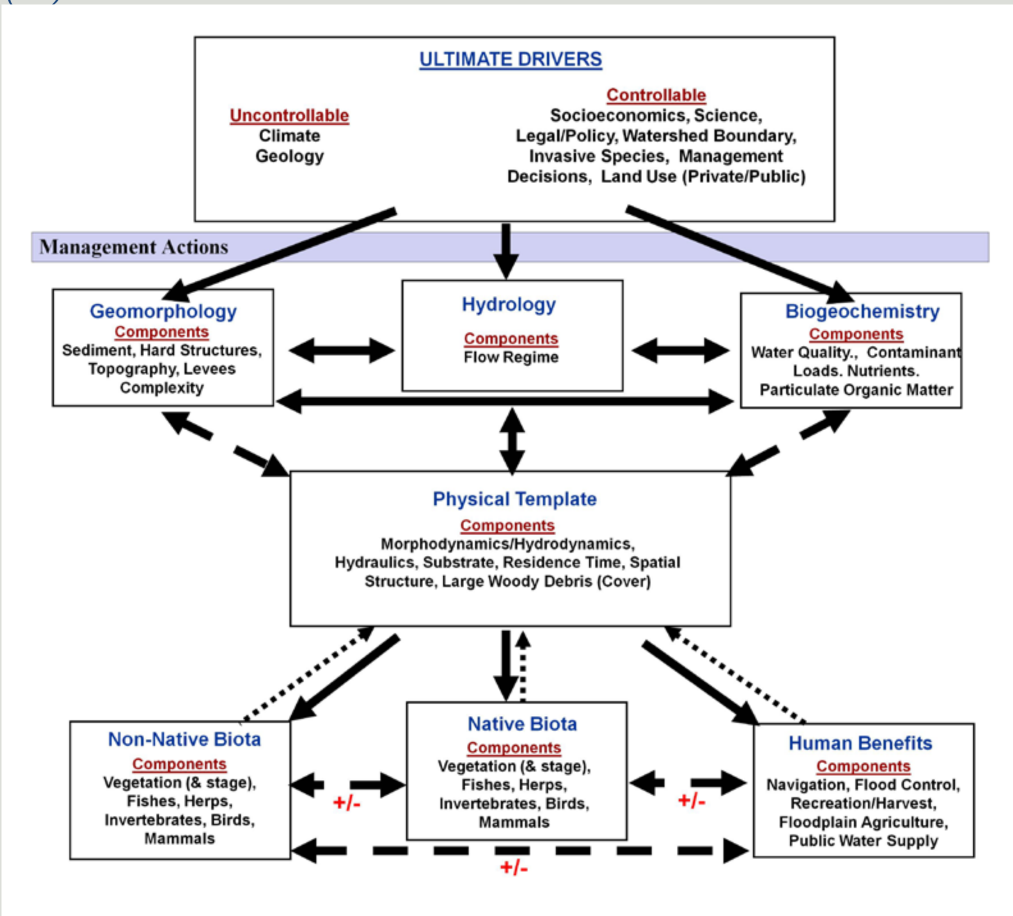


Figure C1. Group C "Influence Effects" Conceptual Model. Lines represent hypothesized strength of effect: heavy solid = strong, heavy, dashed = moderate, and light dashed=light with the +/- symbol indicating that the effect can be positive or negative for native ecosystems. Arrows are double headed when the effect is two-way at the same level. Parallel arrows with opposite orientation indicate two way effects at different levels.

The group then evaluated the evolving hierarchical conceptual model (above) to determine if these functions were evident. They concluded that they were represented in the hierarchical layer described above as "biologically informed measures of habitat". This conclusion led to discussions of monitoring and assessment that raised questions such as:

- What were optimum indicators to cost effectively evaluate various levels in the hierarchy?
- How should monitoring investment be partitioned among chemical and physical process, habitat, and biotic indicators?
- Can keystone species be defined so that their presence or absence would be a powerful indicator of side channel value?

The last bullet generated further discussion on appropriate target species. For example, should side channel design criteria be focused on the reproduction and survival of an endangered species such as pallid sturgeon or would paddlefish or catfish be better indicator species.

At the end, discussions turned to the lingering questions about appropriate reference conditions. The group decided that historical data were incomplete and possibly irrelevant under modern constraints. The Marquette side channel was suggested as an example of the best attainable condition. The group determined that it would be useful to perform a gradient study to characterize physical, chemical, and biological indicators along a range of side channels, from low-functioning ones to the best (Marquette). Notably, an informed minority held that none of the side channels functioned well enough to be used as a best-attainable reference condition.

The group agreed that creating a conceptual model was useful for focusing and organizing thought about how side channels function. The conceptual model exercise also helped identify data gaps and provided a roadmap toward a design, monitoring, and assessment program.

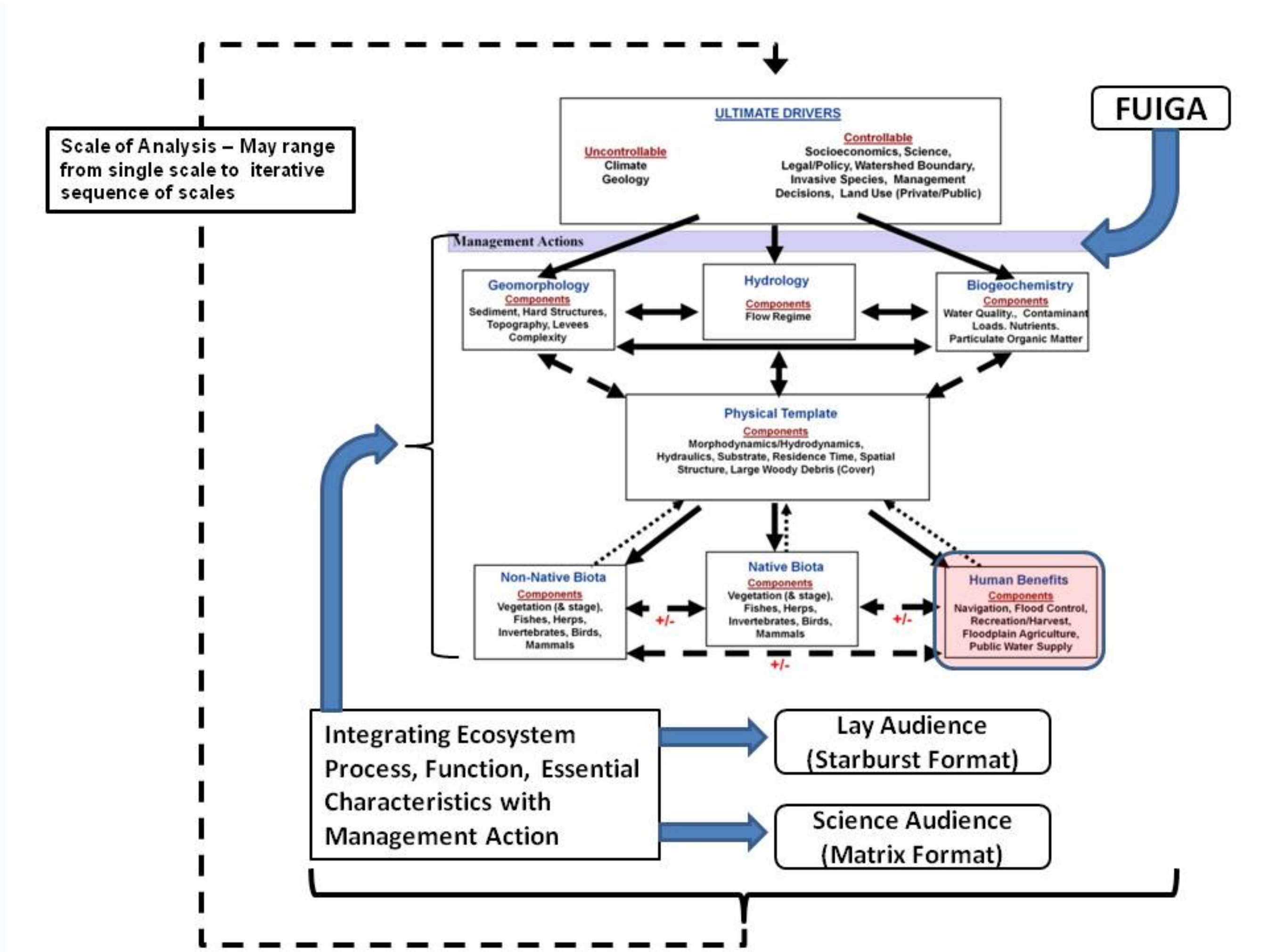


Figure 3. Merging the three CMs created by the three Breakout Groups. Breakout Group A created an approach to filter project-scale management actions to system level ecosystem needs. Breakout Group C created a basic CM structure that broadly identifies elements of ecosystem management that planners should consider. Breakout Group B expanded on the essential ecosystem characteristics of the system (bracketed), (with the exception of the "Human Benefits" balloon highlighted in red) for either a lay or scientific audience.

Breakout Group C's CM for side channels was consistent with the CM crafted by a NESP Science Panel (Lubinski and Barko 2003) for environmental management of the UMRS (Figure 4). The NESP CM is more comprehensive because it has to address all possible management actions, not just side channels and it was crafted primarily by an academic/scientific panel with attendant strengths and weaknesses. For example, the NESP SP CM barely fit on one page and required extensive description and indoctrination to understand it and use it efficiently. In contrast, the workshop breakout group's participants were composed primarily of agency staff and stakeholders that would participate in the PDTs that would perform the necessary planning for side channel restoration. As a consequence, the

CMs developed by the Breakout Groups were more attuned to the planning needs of interagency PDTs working on a specific restoration category than a scientific group trying to develop a CM that could be used as a planning aid for all types of potential management actions. The Breakout Group C CM would be much more easily implemented as a planning aid than the NESP SP CM. Encouragingly, the existing CM and the CMs created by the breakout groups are compatible and not exclusionary. They simply each represent slightly different perspectives of the diverse group of creators.

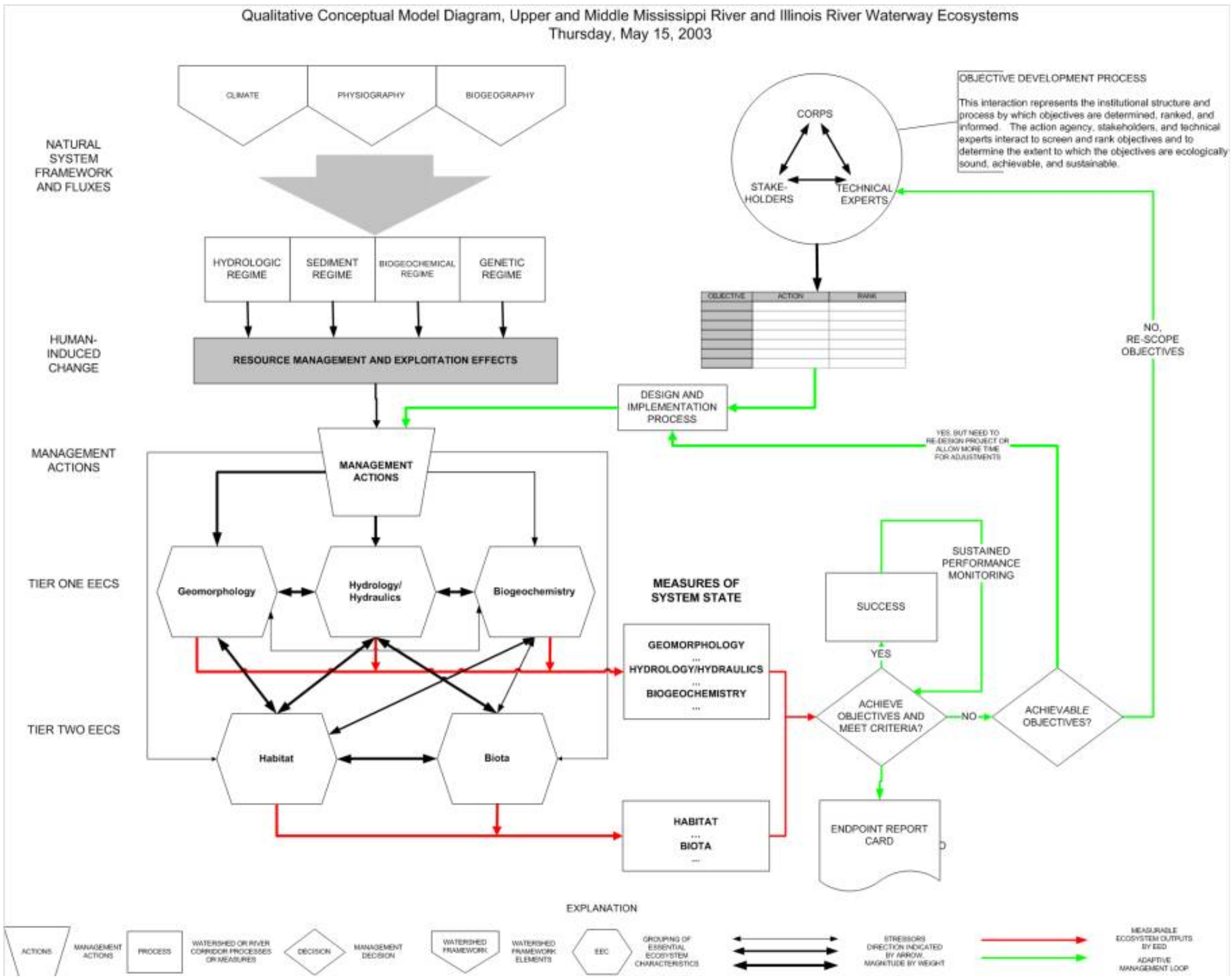


Figure 4. Existing UMRS generalized CM (Lubinski and Barko 2003). This CM can be contrasted to the CM developed by Breakout Group B (Figure B1) or the integrated CM shown in Figure 5 developed by merging the CMs created by the three Breakout Groups.

WORKSHOP CONCLUSIONS

The combined products from Breakout Groups A and B led to an integrated, hierarchical framework that spanned fine-scale ecological process description to system-scale assessment of ecological function. Breakout Group C developed a more conventional conceptual model that organized technical elements of side channel restoration into a framework and therefore provided a structure that could contextualize the products of Breakout Groups A and B. While scale was not explicit in the formulation, it is clear that the Group C CM could be applied at a wide range of spatial and temporal scales. In many respects, their CM was similar to the CM developed by the NESP Science Panel (Lubinski and Barko 2003). This similarity is welcome because it suggests a commonality of thought within the region about how best to contextualize restoration planning. The advantage of the CM developed by Group C is that it displays system organization at the essential ecosystem characteristic level, identifies important drivers of the system (e.g., climate) places potential management actions into a system-level context scientifically, socially, economically, and institutionally.

The workshop was organized under the premise that the individual Breakout Groups would each develop a CM that would be a variation on a theme, and but that the organizers would be able to meld the separate products into a single "consensus" CM. Surprisingly, each Breakout Group developed a unique CM that had value as a standalone product that should be considered on its own merits. Although each CM was different, they were all compatible if viewed from a broad perspective. We concluded that each Breakout Group cut a separate slice through a complex, multidimensional environmental and institutional reality. Therefore, a perfect CM (i.e., a "right" CM) cannot exist, but rather each project will be optimally planned using a unique slice determined by its own reality. In fact, CMs may follow Levins' thesis for population models (described in Odenbaugh 2003) – CMs cannot simultaneously optimize generality, realism, and accuracy; only two of these functions can be optimized for any planning activity. For example, the starburst CM of Breakout Group B emphasizes generality and realism, but at the expense of accuracy; whereas, the matrix embodiment of their CM emphasizes accuracy and realism, but at the expense of generality. For our workshop, the three breakout groups each formulated their own distinct CM that was neither better nor worse than any other groups CM, but only reflected their individual disciplines, experiences, and views on restoration planning as well as their group's implementation of Levin's thesis. Likely, there exist additional CMs not identified by any of the three breakout groups attending the workshop that would also be useful and compatible with the three CMs described herein.

We conclude that it is useful to be aware of different CMs and their relative strengths and weaknesses, but that over reliance on a cook-book CM would probably interfere with efficient planning rather than be conducive to efficient planning. Together, the integrated three CMs create an overall framework to allow planners to move sequentially through a hierarchy of spatial scales from the system-level at the largest scale down to the functional unit at the smallest hierarchical scale. The framework can be used for multiple purposes: to assess existing conditions, to determine opportunities for restoration, and to employ the reference condition concept to prioritize alternative management actions. Moreover, the framework is generally consistent with the water resources decision-making process.

NEXT STEPS

It is important to continue developing interrelated side channel CMs that each meets different planning challenges. That is, a family of CMs should be developed that tradeoff between accuracy and generality at different scales of application, but all of which optimize realism to ensure the scientific foundation of restoration planning. This approach also builds on the workshop finding that there is no single “correct” CM. The future use of these CMs will systematically organize restoration concepts, crystallize environmental issues, and therefore more closely link management actions with ecological response. In addition, these CMs will improve the effectiveness of the dialogue among planners, stakeholders, partners, and the public as terms and concepts become more familiar.

Participants fully realized that important biological disciplines with a vested interest in MMR ecology and restoration were not present during the workshop: forestry, other biological/taxonomic groups, and water quality/limnology expertise. We recommend that future workshops be held that include disciplines that were absent or underrepresented in this workshop.

Once all the natural resources stakeholders and partners are represented or reasonably so, the MMR partnership should be introduced to the concept of a decision-tree (as part of a decision analysis exercise) to help identify a strategy (or strategies) to determine the key uncertainties that must be understood to begin a successful MMR side channel restoration program. Decision-trees are important in modeling possible consequences of chance outcomes that ultimately affect resource costs and restoration program effectiveness. Furthermore, decision-trees can be used in a descriptive way to estimate conditional probabilities of uncertainties. The real work of AEAM begins after this point:

- Identify model analysis studies to estimate uncertainties that affect forecast accuracy
- Develop monitoring programs to provide important data to reduce the uncertainties identified above for robust decision-making
- Develop a simulation framework to accurately forecast effects of management actions
- Select a reference (or ideal) river condition, and
- Develop a protocol for environmental benefits analysis.

Once the CM's developed from this workshop are fine-tuned with additional input from other stakeholders, then the language and terms used to describe and assess the existing system can be translated into a computational model and/or a simulation framework. Descriptive models of the linkage between the functional channel set (ecosystem functions) and the functional unit (ecosystem processes) must be created to structure an inventory phase. This linkage is critical to development of a quantitative planning tool for the MMR. These steps ensure that development of a strong program-level rationale that connects monitoring, forecast simulation, analysis, and decision-making. As stated earlier in this report, the functional units may represent ecosystem processes operating within the system and the frequency and distribution of the functional units can form the basis for a reference condition for the MMR.

The FUIGA which evolved from Breakout Group A may form the basis for a future discussion about an ideal condition (the Best Achievable Condition *sensu* Nestler et al. 2010) for the MMR and its side channels. The next logical step would be to elevate the ideal condition into a reference condition analysis. Important ecosystem functions embedded in the ideal or reference condition forms the basis to compare alternative forecasted reference conditions that would initiate the tenets of AEAM and the process of reducing our uncertainties about ecosystem processes, ultimately to evaluate alternative management actions. Process level information from a carefully considered monitoring plan will be required to understand the results of management action in a scientific context and will set the direction for increasing the success of future management actions.

The final step that we recommend as an outgrowth of the workshop is to develop the protocols for a comprehensive environmental benefits analysis. We anticipate that the AEAM process will identify reasonable restoration alternatives. Environmental benefits analysis will then help decision-makers select actions that best balance cost versus restoration progress for each alternative. The environmental benefits analysis will be best performed using reference condition concepts. Using these concepts, alternatives can be compared to one or more reference condition including the desired future condition. Restoration planning can then be performed at project- through system-level scales through judicious use of multi-scale reference conditions.

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