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Missouri River Effects Analysis

Models, Data and Literature to Support Habitat Analyses for the Missouri River Effects Analysis

Hydrogeomorphic Team

April 2014 Draft

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Models, Data and Literature to Support Habitat Analyses for the Missouri River Effects Analysis

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Abstract

This report outlines the modeling framework for evaluating the Missouri River hydrology, hydraulics and geomorphology as part of the Effects Analysis It also presents an overview of the data, literature and other resources identified to date that can be applied to support modeling of habitat on the river. The report is intended to assist the Effects Analysis Team, the Missouri River Recovery Management Plan (MRRMP) Project Delivery Team (PDT), and the Independent Science Advisory Panel (ISAP) for the Missouri River Recovery Program Implementation Committee (MRRIC) in understanding the modeling and data resources available to support assessment of the effectiveness of various management actions in avoiding jeopardy for the least tern, piping plover and pallid sturgeon.

The framework utilizes several Hydrologic Engineering Center (HEC) models; reservoir operations will be simulated using HEC-ResSim, HEC River Analysis System (HEC-RAS) models of riverine reaches will be used to support hydraulic, sediment transport and water quality analyses, and the Ecosystem Functions Model (HEC-EFM) will be used to integrate time-series flow data from the models with other relevant information to quantify habitat availability. Two-dimensional hydrodynamic and sediment modeling of representative reaches will supplement the HEC models, providing critical insight into important processes that cannot be properly assessed using one-dimensional models alone.

Data availability for the habitat analyses is generally good. Hydrologic data is available for numerous gaging stations throughout the basin and two recent studies offer climate change insights. Technical criteria for the reservoir operations are well-established and are being coded into the ResSim models. Frequent hydrographic surveys and recent LIDAR data acquisition efforts provide the needed elevation data for the hydraulic models, though system coverage requires stitching data from multiple dates. Sediment data is more limited, but sufficient for the planned analyses. Imagery older than 10 years and suitable for assessing bar habitat is limited. A few studies underway are providing useful insights into geomorphic processes of interest.

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Preface

The work documented in this report was conducted for and funded by the Missouri River Recovery Program (MRRP). It reflects an ongoing effort by a team of engineers, biologists, ecologists and geomorphologists to assess past and future habitat conditions on the Missouri River System within the study boundaries of the MRRP. The study and this overview are works in progress. We will continue to incorporate additional information as it is published or otherwise becomes available and this report will be updated accordingly.

This report was prepared by the MRRP Effects Analysis Habitat Team. Dr. J. Craig Fischenich, Ecosystem Evaluation and Engineering Division (EE), ERDC-EL was the team leader. Work Group members included Jeff Tripe and Don Meier of the USACE Kansas City District, Dan Pridal of the USACE Omaha District, Stanford Gibson and John Hickey of the USACE Hydrologic Engineering Center, and Tom Econopouly of the US Fish and Wildlife Service (USFWS).

At the time of publication, Antisa Webb was Chief of CEERD-EE. The Director of ERDC-EL was Dr. Beth Fleming. COL Kevin J. Wilson was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

1 Introduction

Background and Purpose

The U.S. Fish and Wildlife Service (USFWS) issued a Biological Opinion (BiOp) in 2000 that found that actions proposed by the U.S. Army Corps of Engineers (Corps) on the Missouri River would jeopardize the continued existence of three federally listed species: the piping plover, interior least tern and pallid sturgeon. The BiOp (amended in 2003) recommended a variety of recovery actions to be carried out by the Missouri River Recovery Program (MRRP).

The Corps initiated an Effects Analysis (EA) for the MRRP in 2013 following a recommendation by the Independent Science Advisory Panel (ISAP) of the Missouri River Recovery Implementation Committee (MRRIC). An EA, as described by Murphy and Weiland (2011), provides a mechanism for quantifying the impacts of actions taken by a federal agency on a listed species or critical habitat. In the case of the MRRP, the EA provides a means to review the efficacy of recovery actions taken to date, allows for the identification of the plan most likely to achieve the MRRP objectives and supports the adaptive management of the recovery efforts through quantitative assessment of endangered species' responses to past and proposed management actions.

The MRRP EA scope specifies the following activities: 1) development of comprehensive, conceptual ecological models (CEMs) illustrating the ecological effects and consequent biological impacts of stressors on the Missouri River mainstem, 2) compilation and assessment of available data, literature, and models evaluated for use in the EA, 3) development of predictive, quantitative models to explore the system dynamics and population responses to management actions, and 4) analysis and assessment of effects of system operations and actions on species' populations and their habitats. Implementation of the EA is being undertaken by three collaborative teams: one addressing the hydraulic, hydrologic and geomorphic modeling needs (Habitat Team), one addressing the pallid sturgeon models (Sturgeon Team) and one addressing modeling needs for the terns and plovers (Bird Team).

This report was prepared by the Habitat Team to document the modeling framework adopted for the EA and to describe the data, literature, and models that have been evaluated to support the effort. It is intended to orient the respective study teams, describe the criteria and decision process for the selection of models and data to drive those models, and provide an opportunity for review of the strategy by the ISAP and others.

Scope and limitations

This report addresses the second and third objectives of the EA (see Appendix A for details). In summary, it provides an overview of the factors driving model selection, presents the resulting modeling framework and identifies the data, literature and related resources that have been or could be used to support the modeling efforts. The emphasis of this report is on the hydrologic, hydraulic, and geomorphic modeling components of those tasks. Companion reports are under development by the Sturgeon Team and the Bird Team. Some redundancy in content is anticipated across the three work teams.

The study and this review are works in progress. We will continue to pursue useful data and to revise the models and modeling framework as necessary to meet the study objectives. As additional information is identified or otherwise becomes available, this report will either be updated or those changes will be captured in subsequent documentation for the EA.

2 Modeling and Data Needs

Overview

As outlined by Murphy and Wieland (2011), an EA requires three essential steps—the collection of reliable scientific information, the critical assessment and synthesis of available data and analyses derived from those data, and the evaluation of the effects of actions on listed species and their habitats. These steps would logically precede the development of a Biological Opinion (BiOp); in this instance, there is an existing BiOp (USFWS 2000, 2003). Thus, this EA can be regarded as a recalibration of those efforts with the inclusion of a more quantitative approach to the third step than may have been previously undertaken.

Part of the recalibration effort and an important component of the third step is the development of an analytical framework that supports quantification of the effects of alternative management plans upon the demographics for the species of interest. Several factors contribute to decisions regarding the makeup of such a framework. Foremost among them is the need or purpose, but the availability of data, time and other resource constraints, and myriad other concerns play an important role in the decision.

Meeting the needs for both the EA and the broader Management Plan to which it contributes requires quantification of the relationships among habitat conditions, habitat requirements, and species' demographics for interior least tern, piping plover, and pallid sturgeon. Specifically, predictions of future population size, growth and distribution must be quantified as a function of past and future management actions such as habitat alteration/manipulation through flow management and habitat creation as well as other drivers and stressors such as climate and predation.

The EA scope includes the development of conceptual ecological models (CEMs) that link the effects of past and proposed Federal actions (and other stressors) with biological responses for the species of concern. These CEMs, when coupled with an understanding of the study needs and constraints provides a foundation for identifying a general model framework. This chapter outlines the factors that helped guide the establishment of the modeling framework, which in turn helps define the needed data.

Overarching Study Needs and Constraints

The purpose of the effects analysis effort is to conceptualize and quantify the effects of the Missouri River Project and operations (dam operations), Bank Stabilization and Navigation Program (BSNP) and BiOp-prescribed actions on the status and trends of the listed species and their habitats, within the background of hydrologic and fluvial processes on the Missouri River. The results of the effects analysis are intended to strengthen the MRRP decision-making process, including both near-term needs of the Management Planning exercise and the long-term implementation of the requirements of the BiOp through adaptive management (AM).

These needs establish two related but different sets of requirements and associated timeframes; the immediate product should be viewed as an initial, fundamental step in an ongoing process. The Management Plan is intended to assess success to date, determine if additional actions (outside the BiOp) are required to avoid jeopardy, and identify the alternative plan that best meets the objectives. The schedule for the Management Plan demands that the EA produce a quantitative modeling framework capable of assessing alternatives by September, 2014, and that it will have concluded most basic analyses prior to then.

However, the products of the EA will be used and modified through time to ensure our understanding and actions are similarly evolving and improving. As management actions are completed and monitored, their results will help test hypotheses, improve models, refine the management plan and guide implementation efforts for many years to come as part of the AM program. This longer vision permits the identification of a modeling framework that can accommodate new models, model enhancements, or the expansion of model scope over time.

In addition to the two timeframes discussed above, the needs of the EA and Management Plan can further constrain the modeling framework and data requirements. For example, the model framework must be capable of simulating the effects of the actions listed in the BiOp on the species and their habitats as well as any past or future natural events, such as significant flow events. The EA scope lists 30 management actions that fall into a few broad categories: mechanical habitat creation or modification, flow modifications, and direct intervention with ecological responses and species performance (e.g., propagation and predator control).

Conceptual Ecological Models

Role of conceptual models

Conceptual ecosystem models (CEMs) are descriptions of the general functional relationships among essential components of a system. They tell the story of "how the system works" with respect to key processes and attributes and, in the case of the MRRP, how the existing and proposed management actions affect species biology. The development of a CEM is recommended as a first step in the planning process, as it provides a key link between early planning (e.g., an effective statement of problem, need, opportunity, and constraint) and later evaluation and implementation. Conceptual models can be invaluable in supporting an EA for a number of reasons (Fischenich 2008):

1. When constructed collaboratively, CEMs facilitate communication, foster consensus, and capture the collective expertise of participating scientists, agencies, and the public, thus making the overall assessment of benefits and final plan selection more likely to gain support from decision makers and the public.
2. During CEM development, uncertainties affecting the system are identified, discussed, and vetted. This initial assessment of key assumptions (hypotheses) sets the stage for subsequent evaluation and documentation of uncertainty in the EA and guides the implementation of actions under an adaptive management approach.
3. A CEM documents, in brief, the scientific rationale for engineered modifications or actions and the externalities (such as climate change) that might affect the degree to which modifications are likely to elicit desired ecosystem responses.
4. A CEM includes the essential ecosystem structure, functions, and processes to be measured, as well as those that may be unquantifiable but need to be considered in the overall evaluation. Thus, the CEM summarizes the rationale for metrics used in EA.

CEMs in the Present Study

The U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service conducted a series of workshops in July, 2013 to support the development of CEMs for each species. Attendees were state and federal agency personnel with expertise in species biology, ecology of the Missouri River, or other related concerns. Through interactions during these facilitated workshops

and post-workshop correspondence, a series of graphical CEMs with accompanying narrative were developed for each species.

The CEMs were distributed for an independent review. Comments were provided to the EA Teams, who then undertook a series of revisions to arrive at the set of models shown in Appendix B[1]. The formats of the models were generally the same for each of the species of interest, but some differences evolved during the process. The general format was along the lines of a driver-stressor-ecological response model, and the relative uncertainty and importance of the various relationships were reflected. Management actions were introduced into the models as well to show their role in affecting potentially favorable responses in species performance.

These CEMs, though qualitative in nature, serve as a useful starting point for development of a quantitative modeling framework. The CEMs were structured so as to link processes and conditions in the system with species performance. They identify the roles of system stressors and management actions in controlling or affecting ecological responses and consequent biological condition. Thus, the CEMs serve as a roadmap to the relationships that must be quantified in order to predict species demographics.

The level of detail in the models was sufficient for the formulation of testable hypotheses about the effects of management actions while avoiding unnecessary complexity. Additional work to identify the most significant hypotheses (referred to as dominant working hypotheses) was underway at the time this report was prepared. The mechanistic detail for the CEMs was aimed at helping identify the elements and relationships necessary to numerically model population dynamics as a function of habitat and other controlling factors.

CEM Components Requiring Quantification

The components of the CEMs and their relationships effectively define the model needs. Recognizing that there are some differences in terminology between the models for the birds and those for the sturgeon, the following list is intended to summarize the factors that need to be addressable within the model framework.

[1] Note: The CEMs shown in the Appendix are the draft models submitted to the ISAP for review in January, 2014. They do not reflect subsequent revisions made as a result of comments by the ISAP. Only the graphical components of the CEMs are presented in the Appendix. The accompanying narratives are not included herein.

Drivers are natural or human-induced factors that directly or indirectly cause change in an ecosystem, but that are independent of other system elements (i.e. they cannot be altered by and there are no feedbacks from the system). Examples include climate, geology and land use. Drivers also include those social, political, and economic factors that have institutionalized the authorized purposes of the system. The reservoir operations rules specified in the Master Manual may be regarded as drivers when considered collectively, but individual operational decisions or rules can take the form of causal factors or management actions in the CEMs. The habitat models must be capable of accounting for the drivers or their effects.

Controlling factors are the actions or conditions that elicit an ecological response (usually physical) on the system and take the place of stressors in many causal network models. The controlling factors in the CEMs include reservoir operations, tributary flows, channel morphology, sediment supply, and structures affecting stability, navigation and water quality. These factors are often the focus of management actions, and the habitat modeling scheme must be capable of addressing changes to the controlling factors.

Primary ecological responses address the abiotic physical and chemical characteristics of the system that are directly influenced by the controlling factors. Primary ecological responses can be broadly categorized in terms of channel morphology, flow regime, sediment regime, and water-quality regime. These are all critical elements of the CEMs in terms of habitat modeling needs.

Secondary ecological responses address the conditions that result from the primary ecological responses. They can be broadly classified as physical habitat, water quality (chemical habitat), and community composition and interaction (biotic habitat, predation, etc.). Physical habitat, chemical habitat, and biotic habitat are each characterized in terms of dynamics - that is, described in terms of how habitat varies over time and over space. The biological interactions can also relate to species movement and behavior. Some of these factors can be (or are) addressed by the species models while others are better addressed within the habitat modeling domain.

Species performance includes the biotic responses of the species to primary and secondary ecological factors. Biotic responses vary considerably

among component models but can be generally classified into three types: growth and condition, reproductive behaviors and synchrony, and direct mortality. Performance is expressed for specific life stages as well as the transitions between these stages. Performance is ultimately expressed in population size. This component of the CEMs is fully within the domain of the species modeling, but informs the habitat modeling needs.

Hypotheses and Management Actions

Efforts are underway to develop hypotheses about the relationships among components of the CEMs. Habitat-based hypotheses that describe the effects of hydrological, geomorphological, and water quality factors on habitat availability and quality help define the modeling needs. Habitat hypotheses for the terns and plovers center on the effects of reservoir releases, but also include adjustments to channel form and sediment supply:

1. Increases in dam releases (if greater than inflows) during the nesting season (May-August) increase the area of suitable nesting/brood rearing and plover foraging habitat on a reservoir.
2. Decreases in dam releases during the nesting season (May-August) increase the area of suitable nesting/brood-rearing habitat and plover foraging habitat on the river.
3. Decreased dam releases year-round increase area of nesting/brood rearing habitat and foraging habitat by reducing loss of habitat to erosion.
4. Increased dam releases at any time of year can increase area of nesting/brood rearing habitat foraging habitat, if flows are of sufficient magnitude and duration, by increasing deposition, assuming sediment is available.
5. Increased width and complexity of channel form increases the area of nesting/brood-rearing habitat and foraging habitat.
6. Increased sediment supply increases the amount of nesting/brood-rearing habitat and foraging habitat, given that flows are occasionally high enough to deposit sediment at elevations normally above the water surface.

These broad hypotheses, which often include multiple elements of a CEM, can be broken down further into intermediate hypotheses that describe each specific relationship (see Figure 1).

ID	Hypothesis/pathway	Intermediate hypotheses	Import.	Uncert.	Notes
H2	**Decreases in dam releases during the nesting season (May-August) increase the area of suitable nesting/brood-rearing habitat and foraging habitat on the river.**		high	low	
		Reduced dam releases decrease the nesting season river stage	high	low	
		Decreased river stage during the nesting season increases the area of suitable nesting/brood-rearing habitat and foraging habitat in the river.	high	medium	
		Decreased river stage can reduce area of suitable nesting/brood-rearing habitat and foraging habitat by connecting sandbars to the floodplain, depending upon channel morphology.	medium	medium	Connected habitat may still be used, but increases predation risk.

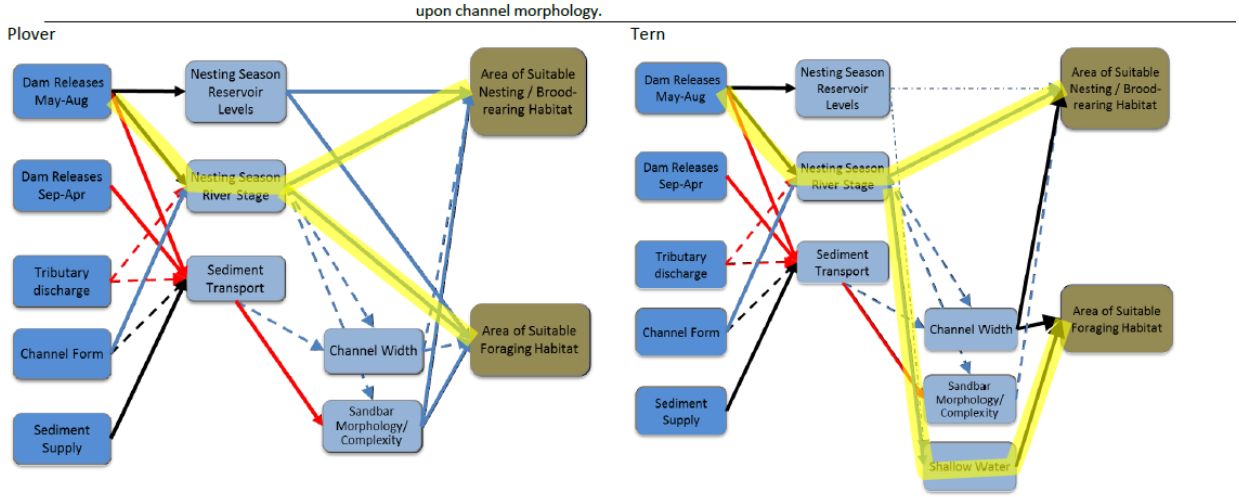

Figure 1. Example of hypotheses and intermediate hypotheses within a CEM that relates habitat with management actions and species needs. These hypotheses help define required modeling capabilities.

While the hypotheses for the birds and sturgeon are both in a draft state, the bird hypotheses are more mature and not likely to change such that the habitat modeling capabilities would need to be adjusted. The draft sturgeon hypotheses have been shared with the Habitat Team, but are not presented herein except that some are referenced later in this report when discussing specific modeling categories.

Species Models and Needs

The species models for the EA are of the population viability analysis (PVA) type. PVA is a species-based, quantitative modeling framework for assessing threats to species persistence, estimating extinction risk and evaluating potential management options (Morris et al., 1999). It is most commonly applied to determine probability of extinction, but the same approach can be used to establish a minimum viable population (MVP) or answer other risk-based questions regarding habitat, management actions and species response(Beissinger, Westphal, & Westphal, 2013).

There is no specific model structure for a PVA; they can be deterministic or stochastic, single- or meta-population, spatially explicit or implicit, for example. The specific structure of the species models are not be certain at present (and may evolve), but we have some insights based on the existing models for the birds and the strategy employed for development of the sturgeon CEMs.

Bird Models

An existing set of demographic models for the terns and plovers serve as a basis for guiding the habitat modeling needs. Both models are driven by the availability of emergent sandbar habitat. The plover model tracks two life stages: fledglings and adults. Adults are assumed to nest in the same river segment each year and productivity (number of fledglings per pair of adult birds) is assumed to decrease linearly with density of adults per acre of emergent sandbar habitat (ESH) suitable for nesting. Productivity declines if river stage fluctuates due to power peaking. Both fledgling and adult survival is computed. Fledgling survival determines how many fledged birds return as adults to breed and a proportion of returning fledglings are assumed to disperse among reaches based on the amount of nesting habitat in each segment that year.

A similar demographic model is employed for the terns. Four life stages are used for terns: fledglings, juveniles, young adults (2-3 year old) and adults (> 3 year old). Both adult stages reproduce equally and productivity decreases with density of adults per acre of ESH and if the upstream dam is power peaking. Like the plovers, adults are assumed to nest in the same river segment each year. A proportion of the 2 year old terns (returning juveniles) disperse among reaches in proportion to the amount of nesting habitat in each reach that year.

The habitat model used to drive the demographic models accounts for both reservoir shoreline and ESH suitable for nesting and foraging (essentially bare sand during the May-July timeframe). The amount of sandbar that is suitable for nesting during a year is the portion that remains above the highest stage in May-July of that year. Stage-bar area curves for each reach are used for this estimate. ESH can be added to account for mechanical habitat creation or the deposition of sediments or scouring of vegetation. A loss function is applied to the ESH to account for annual habitat decline due to erosion and vegetation growth. The loss rates vary by reach, are

independent of discharge, but increase with the total acreage of sandbars in a reach. Losses are applied annually after the nesting season (erosion and vegetation during a season do not affect nesting).

The habitat simulations are based on historic flow and reservoir pool data. For each model replicate, a random sequence of consecutive years of historical flow and storage data is selected. An annual acreage of mechanical or flow-constructed ESH is specified and that figure is added to the baseline acreage while the loss functions are applied to determine the acreage lost to erosion and vegetation. Using the historical river stage data and stage-area curves for each year, the maximum May-June stage is determined and the corresponding sandbar acreage safe from inundation each year is computed. Using historical storage data, the reservoir shoreline habitat available each year is also computed, and the nesting habitat acreages are provided to the bird population models.

From a habitat modeling perspective, the primary need is to quantify the availability of suitable nesting and foraging habitat during the nesting season. This could be addressed within the present model format or with external models. There are a number of simplifying assumptions in the present model that provide opportunities for improvement. Examples include modeling flow variability within the nesting season (higher temporal resolution), modeling individual bars (higher spatial resolution), modeling bar growth and decay, and refining the calculation of reservoir shoreline habitat.

Sturgeon Models

Unlike the terns and plovers, the population model for the sturgeon does not yet exist. However, the approach to the development of the CEMs for the sturgeon provides insight into the anticipated model structure and can help guide the habitat modeling needs. The population-level conceptual model presented by Wildhaber and others (2007, 2011) and refined by DeLonay and others (in press) served as a basis for the organization of the CEMs for the pallid sturgeon and provides insight into the intended structure for the quantitative population model. The framework accommodates the fact that sturgeons use different parts of the river during different life stages. Figure 2 shows the overall structure of the model framework.

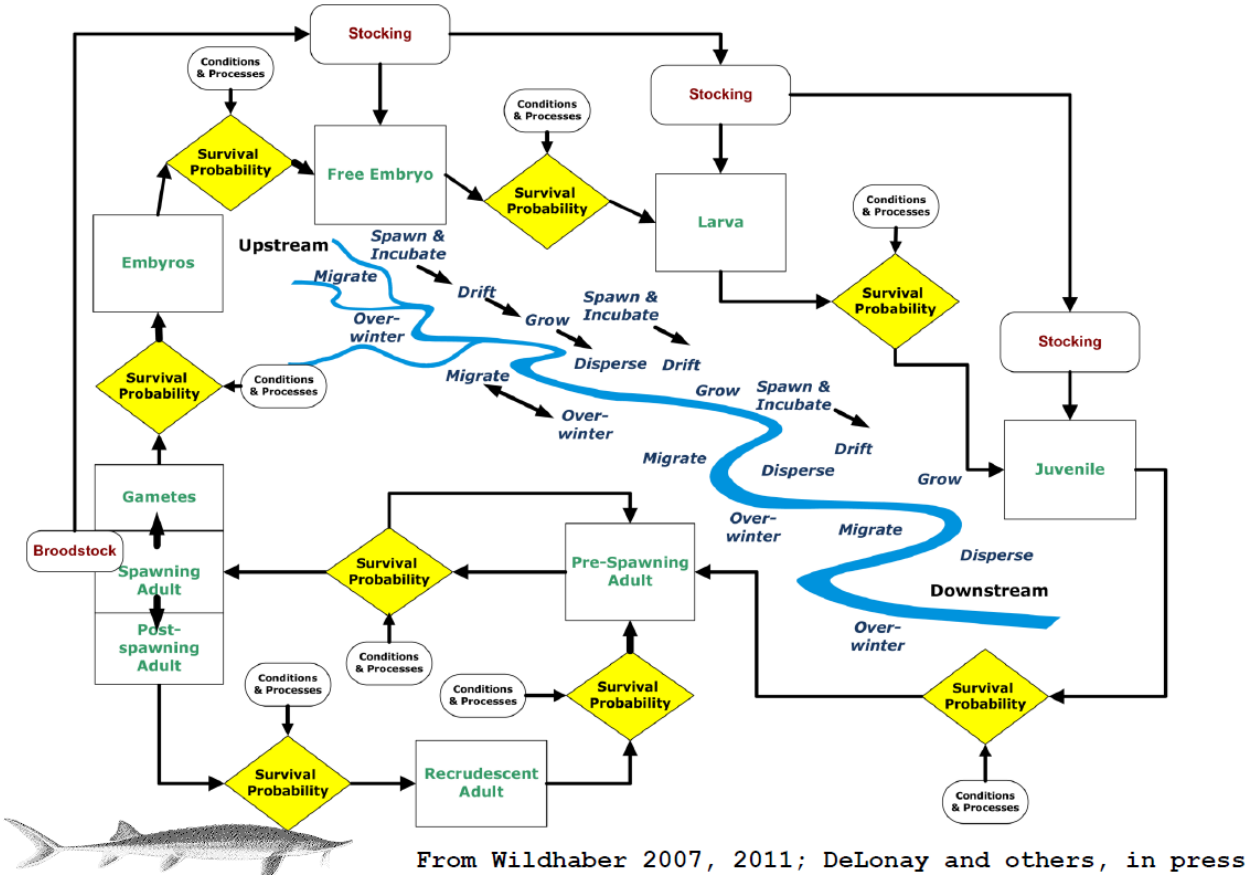

Figure 2. Population-level conceptual model for pallid sturgeon.

The framework is divided into life stages (depicted as boxes) with transitions between life stages (diamonds). The direction of sturgeon development is identified by arrows. Numerous conditions and processes (ovals) determine if an individual sturgeon completes a life-stage transition. The expected model construct will focus on quantifying the transition probabilities shown in the yellow boxes, particularly for the life stages from a spawning adult through the juvenile stage.

The transition probabilities are determined by a variety of conditions and processes that are central to the habitat modeling efforts. They include abiotic factors such as flow cues, velocity, temperature, turbidity and depth, as well as habitat availability at different times of the year and in different locations along the channel continuum. The habitat is determined by a variety factors such as channel morphology, flow regime, sediment load and substrate size. The framework suggests the use of fine-scale, multi-dimensional models of habitat use and availability as well as sturgeon behavior that are nested within a one-dimensional model scheme of the full geographic extent of the study area.

Other Modeling Considerations

Choosing the right model or modeling strategy for a given problem is not an easy task and depends upon several factors. The relationship between required decisions, model type, and available resources (time, data, funding, etc.) can help narrow down the modeling options for a given project. Ideally, the choice should hinge on the usefulness of the tool for the given needs; i.e., the ability of the tool to meet established standards of reliability or acceptance and to provide the necessary information in a suitable form within the allowed timeframe and with the available resources.

Given a choice between multiple, appropriate model types or combinations, the simplest approach that can address the problem sufficiently may be the best choice(Swannack, Fischenich, & Tazik, 2012). Two additional factors help to determine the utility of any model or sequence of models. The first is that model effectiveness may be constrained by the most uncertain component. Achievement of great precision and accuracy in hydraulics, for example, may not be relevant if geomorphic processes that alter hydraulics or species' habitat requirements are poorly quantified. The second factor is that in the context of inherent uncertainties, participants in the decision making process may determine that relatively poor models have enough utility to move forward with management actions. This perspective is particularly justified in cases where adaptive management can be employed to reduce uncertainties and refine models.

Management Plan Requirements

The results of the EA will be applied within a broader management planning context and the models employed for the EA are also needed for analyses that support the Management Plan. The purpose of the Management Plan is to evaluate the effectiveness of current management actions and recommend any needed modifications to avoid jeopardy to the species. Alternative means of achieving objectives will be evaluated including consideration for the effects of each alternative on a wide range of human considerations (HCs) such as flooding, navigation, and recreation. For each HC, one or more objectives with associated metrics were identified. Table C1 in Appendix C summarizes the current objectives and metrics.

Quantifying the effects of alternatives on the HCs will necessitate the use of models that assess hydrologic, hydraulic, and geomorphic conditions, reservoir operations, habitat condition, and a variety of other conditions that also require assessment for the EA habitat modeling. To the extent they are able to do so, utilizing the same set of models for both purposes provides a number of efficiencies. Those efficiencies are of particular importance given that the schedule for the Management Plan sets strict time limits on the application of the modeling framework. From the time that the conceptual models are completed, the No-Action alternative must be assessed within four months and the alternative assessment within six months.

Adaptive Management Considerations

Whereas the timeframe for the Management Plan imposes restrictions on the development of models for the MRRP, implementation of the plan will be under an adaptive management (AM) framework that provides opportunities for model improvements over time as knowledge is gained from monitoring and hypothesis testing. Adaptive management provides a decision-making framework that can adjust management actions based on newly acquired information and monitored outcomes of previous decisions. Importantly, this adaptive decision-making process can increase the chances that management goals and objectives (e.g., ecosystem restoration or sustainability) will be achieved despite uncertainties. The models are intended to be used to help guide decisions during the AM phase and will be applied for that purpose by District personnel.

To be effective for use in support of AM, the habitat models must be useable by the AM teams or at least by support personnel in the Districts and USFWS. The models should lend themselves to periodic updating to reflect new conditions and new knowledge. They would ideally be adaptable to evaluating management actions and stressors that may not have been previously identified. They should support hypotheses testing. And they should be open-source software such that other agencies and stakeholders can understand and even apply the models themselves.

Model Evaluation and Selection

Determining the “best” models to use for evaluating aquatic ecosystems is situational, depending on a number of factors including: the specific processes or conditions needing evaluation, required accuracy, available resources

(expertise, time, funding), needed data, and institutional acceptability. Selecting from available models can be daunting because of the large number and variety of existing models. In many cases, the "correct" model does not exist, and a model must be developed or adapted to meet the needs of the specific project and circumstances. In addition to those factors already discussed, the following criteria were used to help identify a suitable modeling framework and select the preferred models.

- Model(s) should be responsive to the full suite of management actions chosen for evaluation. At this time, the "full suite" was considered to include the elements of the BiOp such as flow-related management actions and mechanical habitat creation, as well as reasonably anticipatory actions aimed at meeting the objectives of the MRRP
- Capable of producing outputs that can distinguish between management actions or alternatives
- Able to be completed within the project schedule (i.e. minimize schedule impact for model review/certification)
- Aligned with other technologies, models, and tools being used for the MRRP
- Produces outputs indicative of effects to the species, their habitats, or other relevant ecological conditions
- Required inputs could be provided by existing data or information to the greatest extent possible

Model Evaluation

Swannack et al. (2012) provide generalized guidance regarding the steps that constitute good practice for evaluating models for technical efficacy. Candidate models screened with the above criteria may be evaluated using the following five steps:

1. Evaluate correspondence between model results and expected patterns of model behavior.
2. Examine correspondence between model projections and data from real system (model validation).
3. Adjust empirical parameters or model coefficients to match a known behavior (model calibration).
4. Determine levels of uncertainty associated with model projections.
5. Identify data gaps and research needs that may not have been obvious during conceptual model development.

Ideally, several candidate models for a particular application would undergo the above evaluation in a side-by-side comparison. In practice, that is seldom possible and the efficacy of modeling options is based on past experience in conducting the above assessments for a given model and developing an understanding of its strengths and limitations. To overcome this issue and parochial concerns, it is usually desirable to engage a team that collectively has broad experience with an array of candidate models for a particular application. Once a tentative model has been selected and the available data is available, it is still advisable to execute the above steps to confirm the model limitations.

In the event that an existing model does not meet the needs of a given study, Swannack et al. (2012) also detail the process of model adaptation and development. The basic approach is to 1) develop a conceptual model of the specific cause-effect relationships among important components of the system, 2) quantify these relationships based on analysis of the best information possible, which can include scientific data or expert opinion, 3) evaluate the usefulness of the model in terms of its ability to simulate system behavior, and 4) apply the model to address needed questions. In practice, model development does not proceed linearly from the conceptual model to model application; rather it iterates through a series of intermediate models of increasing complexity.

Addressing uncertainty

Corps policy requires that uncertainty in water resource planning be evaluated and communicated; the EA modeling strategy should take this need into account. Methods for assessing uncertainty in ecosystem restoration projects continue to evolve, but include sensitivity analyses, scenario planning, and parametric uncertainty analysis. These and other means of identifying, quantifying, evaluating, and otherwise considering uncertainties as part of the planning process provide important information that assists decision-making. Important considerations include the following (J. C. Fischenich et al., 2013):

- Uncertainty should be identified early in planning and efforts should be made to reduce the causes of analytical uncertainty as resources permit.
- Residual sources of uncertainty should be classified as to type, analyzed and documented, and then addressed iteratively throughout the planning process, from CEM development through benefits estimation, plan selection, and adaptive management plan development.

- Uncertainty should be quantified where possible, and confidence intervals or probability distributions used as opposed to point estimates when describing predicted outcomes with and without alternatives.
- The relative uncertainty of alternative plans should be presented, as uncertainty in outcomes may be considered during plan comparison, and is an important part of an overall risk management/communication strategy.
- If the recommended plan has uncertainty that can be practically reduced through post-construction monitoring, assessment and adjustment, an adaptive management plan should be developed to manage risks and maximize realized benefits.

Although uncertainties can arise at any point in a study, the identification, classification, and documentation of uncertainties is critical during the development of a CEM, during modeling and forecasting, and during formulation of the monitoring and AM plan. Sources of uncertainty can include the following (Fischenich et al. 2013):

- *Ecosystem uncertainty*, which is due to incomplete description and understanding of relevant ecosystem structure and function, or unpredictable and highly stochastic events and interactions affecting key processes (e.g., flooding, fire, drought, regional climate change, etc.).
- *Model uncertainty*, which arises from incomplete knowledge, bias, or error in the structure of a model, often as a result of a lack of knowledge or because of approximations used to simplify computation.
- *Quantity uncertainty*, which encompasses the uncertainty in specific parameters or input data used in a model.
- *Scenario uncertainty*, which arises from inaccurate specification of the cause-and-effect linkages between management measures and their predicted ecosystem effects.
- *Implementation uncertainty*, which is due to potential policy, funding, or other external factors that might influence the timing or degree of project implementation.

The ability to quantify uncertainties depends upon a number of factors including the source, available data and tools, and the extent to which the associated phenomena are understood. Some uncertainty is sufficiently tractable that it can be described in terms of statistical probabilities; this situation is ideal because it facilitates easier risk assessment and decision-making. Frequency distributions, statistical variances, coefficients of variation, confidence intervals, and probability distributions are commonly used to

describe the uncertainty in quantities. Of these, probability distributions offer the most complete and compact form of representation. The emerging approach for these situations is essentially probabilistic rather than deterministic (Landres et al. 1999).

3 Proposed Model Framework

Model Structure

Based on the needs described in the Chapter 2, a generalized model structure was derived by the Habitat Team (Figure 3). The framework shown in Figure 3 includes components specific to the Management Plan (sage colored boxes) in addition to those serving both the EA and the Management Plan (blue, yellow and tan colored boxes). Linkages among the model categories show the information flow among the models, including the contribution of the EA modeling outputs to the HC needs. Outputs from the species models and the HC models will feed into a structured decision process to consider impacts, benefits and tradeoffs among the objectives.

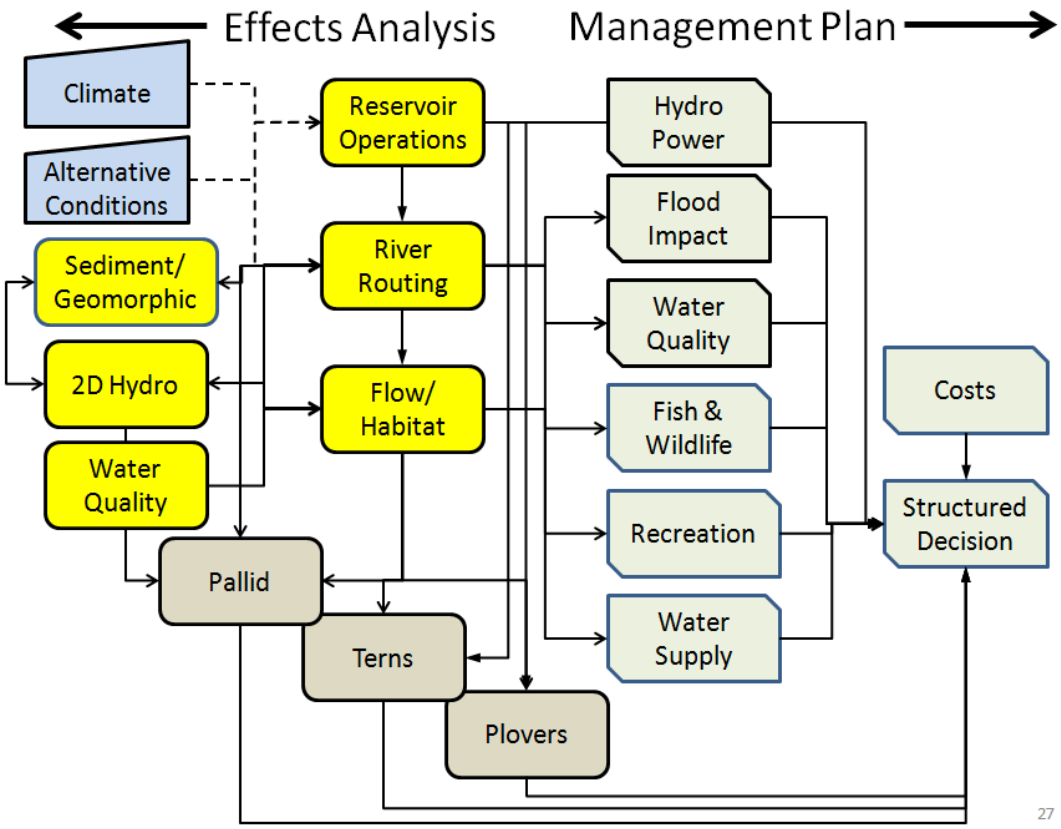

Figure 3. Model framework depicting linkages among model elements for both the EA and the Management Plan. Components in yellow are within the habitat assessment domain.

Modeling Framework Components

The yellow boxes in Figure 3 represent components of the modeling framework that are within the habitat modeling domain. This figure and its constituent elements continue to evolve with other EA and Management Plan activities. For instance, the water quality and geomorphic components of the habitat analysis are dependent upon the outcome of ongoing efforts to refine the dominant working hypotheses in the pallid sturgeon models. The need for water quality and sediment modeling in support of the HCs has also been identified and the details of those needs are being refined. Although there may be some required adjustments, the water quality constituents of interest, needed spatial and temporal resolution and other concerns are thought to be understood sufficiently that they won't necessitate changes in the selection and development of the specific models.

Working groups have been established to consider the needs and recommend approaches (and sometimes specific models) for most of the model components shown in Figure 3. Exceptions include the structured decision component, which is being addressed by the Management Plan PDT. An earlier decision was made to use the PrOACT (Hammond et al. 1998) for this purpose. It is possible that other structured decision making (SDM) methods may be applied, but any approach would necessitate information about the outcomes (benefits and impacts, costs, etc.) for alternatives. This need is sufficient to guide habitat modeling requirements.

The other exception relates to the reservoir operations and river routing models, which were also addressed by an earlier work group. In that case, a multi-agency group considered the long-term needs for hydrologic and hydraulic modeling in the basin to support a variety of needs (including the MRRP). They selected the Hydrologic Engineering Center (HEC) reservoir simulation model, HEC-ResSim, and the River Analysis System model, HEC-RAS, to address the needs. More details on these models are offered in the following chapter, but the Habitat Team considered the efficacy of these tools relative to the needs outlined in Chapter 2 and determined that, within the modeling framework, they will be able to meet the needs.

Model choices and other related decisions made by each working group were based primarily on the needs outlined in the previous chapter coupled with an understanding of resource availability and other factors also described.

Sediment and Geomorphic Work Group

A sediment and geomorphic response team was charged with considering the viability of executing model studies in the near- and long-term that would fulfill the needs outlined in Chapter 2. A draft white paper outlining the proposed studies has been prepared by the group. As of the writing of this draft report, but subject to additional revision, they have proposed that the critical needs include improving our ability to 1) predict morphologic response to flow management and natural flooding, particularly the development and decay of ESH, 2) assess the sediment budget in the reach downstream of Gavins Point to determine the viability of maintaining natural bars in the reach over time, 3) consider the magnitude and impact of degradation trends in critical reaches, 4) establish the evolution and regime condition of SWH features, and 5) otherwise characterize physical habitat changes in support of the species models.

The group is currently emphasizing three limited near-term studies. One would seek to improve discharge-stage-area relations for the ESH in two critical reaches – downstream of Gavins Point Dam and downstream of Garrison Dam. That effort would rely primarily on analysis of empirical data with limited supplemental sediment transport and bed-level modeling and a two-dimensional sediment model of one or more representative sections of the river to explore sediment processes at a finer scale. A second effort would consider the evolution of SWH features, including some general regime assessments, bank erosion modeling and potentially an assessment of entrance conditions at chutes. Finally, larger scale analysis of degradation would be conducted, mainly to assess impacts to HC factors but also to help identify (perhaps quantify) potential implications to the species models.

The group is advocating the use of HEC-RAS for the long-term and large-scale components of these analyses. Some new features may need to be developed within RAS to accomplish this work. The erosion assessment would likely employ the BSTEM model (Simon, Pollen-bankhead, Mahacek, & Langendoen, 2009), which has recently been integrated into RAS. Some of the fine-scale analyses, including bar development and decay processes and sedimentation at chute entrances and exits, would likely require the use of two- dimensional sediment models. Some existing models at Deer Island and within the Gavins Point – Ponca reach are being considered for this purpose.

Multi-Dimensional Modeling

A separate team is considering the need for multi-dimensional hydrodynamic modeling efforts to supplement the use of HEC-RAS as the primary tool for characterizing hydraulic conditions. Many of the flow-regime and channel morphology processes that contribute to the habitat factors of interest operate in complex ways that are very difficult or impossible to represent using one-dimensional modeling alone. Multi-dimensional models would permit the investigation of several key relationships, serving to guide alternative formulation and improving our ability to predict transition probabilities for key life stages of the species of concern. While the development of 2- or 3-D models for the entire study reach may not be reasonable in the near-term, 2D models of representative reaches nested within a broader 1D routing model framework would likely permit the exploration of the necessary evaluations. Results of those more limited efforts would inform the need to expand the spatial coverage of multi-dimensional models over time.

The work group considered whether or not to develop new models for these purposes or to use one or more existing models. Specifically, the issue is the degree to which existing models can be applied to the project. Developing new models ensures that they will be aimed at addressing the specific questions we must pose. However, model development takes time and effort and the schedule for the Management Plan may preclude such an undertaking. On the other hand, the Effects Analysis is focused on developing tools that will be periodically updated and used over a long timeframe in support of the adaptive management of the MRR. Recognizing these two timescales, we would propose an initial effort that relies on the use of existing multi-dimensional models to address several immediate needs. Consideration for the development of additional, perhaps more integrated and useful models, could occur as a later step in the EA process as we move into the implementation and adaptive management phase.

The team identified several existing multi-dimensional hydrodynamic and sediment models that have been applied to portions of the study area and could be used to address various needs (see Appendix D). Although no final decisions have been made, the team has made recommendations on the use of existing two-dimensional models to investigate a few specific questions in the near term, and have identified existing ADH and TUFLOW models that will be investigated further. The team's recommendations include:

1) In addition to the current 1D hydraulic/sediment modeling framework to evaluate segment-scale processes for the baseline (no action) model and models representing alternative scenarios, the EA team should employ one or more 2D models within representative reaches capable of assessing the some of the dominant working hypotheses emerging from the CEMs. Of particular interest are the advection and dispersion of larval pallid sturgeon, characterizing entrance conditions at chutes and the implications for sediment and larval entrainment, and the development and evolution of ESH.
2) The working group will continue their evaluation of existing 2D models with the aim of selecting multiple models that can be readily used (perhaps with some modification) to suit the above needs. Suitability will be determined based on whether models provide information relevant to EA hypotheses, adequacy of geographic representation, and adequacy of components (input data, calibration/validation data, model code, model outputs). If no such models can be identified, the work group should recommend a model development strategy which may include working with existing model components or implementing new modeling to include a proposed code/model, geographic representation, data sources, etc. with sufficient resolution to develop an accompanying schedule and cost estimate.
3) The working group should coordinate their efforts with other groups investigating modeling issues (e.g.,WQ modeling) to address any opportunities for utilizing the same models for multiple purposes or to assess compatibility issues.

Water Quality

A water quality working group was assembled to consider the need and scope of any water quality analyses. The working group has provided a draft white paper outlining current water quality needs for each reach as well as the mainstem reservoirs of the Missouri River system. Several water quality needs related to human considerations have also been identified, but are outside the scope of this report, but CE-QUAL-W2 modeling of Fort Peck, Sakakawea, Oahe, and Big Bend Reservoirs is planned to address those needs. Those needs within the EA scope address various pallid sturgeon hypotheses. Models relating reservoir releases and tributary inputs to cross-sectional averaged water temperature, turbidity, and dissolved oxygen are needed to assess management effects on adults, fertilized embryos, free embryos, and juvenile sturgeon. These models are needed on the Yellowstone (downstream of Miles City, MT), Upper Missouri

(Fort Peck to headwaters of Lake Sakakawea), and Lower Missouri (Gavins Point to St. Louis) on a daily time step. Currently, the EA team is working with the assumption that inter-reservoir reaches (with the possible exception of Ft. Randal – Gavins Point) have little relevance to sturgeon recovery. If that assumption turns out to be incorrect, inter-reservoir reaches may need to be added. Because of hydropeaking and hypolimnetic releases, inter-reservoir reaches would probably need to be modeled on an hourly time step.

Age 0 sturgeon – exogeneously feeding larvae up to first overwintering – are affected by water quality characteristics that are not well-mixed across the channel. Understanding water-quality stressors on fish at age 0 will require spatially explicit (2- or 3-dimensional) water quality models that can predict distributions of temperature, dissolved oxygen, and turbidity across the river channel. CH3D-ICM and EFDC are examples of modeling codes available for application at this scale, however it may be necessary to use statistical models developed from systematic data collection as a substitute or precursor. Most of the hypotheses can be addressed using HEC-RAS with the Aquatic Nutrient Simulation Modules (NSM) (Zhang and Johnson 2014) to model temperature, dissolved oxygen, and turbidity. Reaches for which this modeling strategy apply include:

1) The Yellowstone River from Miles City, MT to the confluence with the Missouri River
2) The Missouri River riverine reach from Fort Peck Dam to Garrison Dam
3) The Missouri River riverine reach from Gavins Point Dam to the confluence with the Mississippi River at Saint Louis, MO

Habitat Statistics and Mapping

Yet another team considered the needs for addressing habitat availability and quality over time and as a function of discharge. This need extends not only to the species modeling, but also to several HC objectives. The Ecosystem Functions Model (HEC-EFM) suite of software was identified and evaluated for application to the MRRP Effects Analysis and for assessing HCs in support of the Management Plan. Strictly speaking, HEC-EFM is not required to meet the study needs. Other tools and techniques can be employed to develop the necessary relationships and quantify habitat for each alternative. However, the HEC-EFM software suite is capable of supporting many technical aspects of the Effects Analysis and Management Plan activities. It significantly eases the computation of multiple spatial and statistical analyses, management of spatial datasets, computation and comparison of habitat areas, and assessment of habitat connectivity.

A primary application of HEC-EFM for the MRRP study would be computation of flow-based habitat availability and development of associated statistics, which will provide inputs to the species models and otherwise assist the comparison of different water and channel management alternatives. The application of EFM to support modeling for the listed species was envisioned as an early need and was funded as part of the EA study. The strategy for application of EFM to other Management Planning HC activities for the MRRP continues to evolve and has extended to many of those objectives.

4 Model Descriptions

Model System Overview

Figure 4 presents the general framework described in the previous chapter, substituting specific models (where they are known) for the topics. Only the EA component of the modeling framework is shown. Components of the model system include two primary inputs reflecting model alternatives and climate scenarios (blue components), the basic EA models (tan components), and the PrOACT process that will integrate model outcomes through the structured decision making consequences and tradeoffs. Descriptions of the individual models follow.

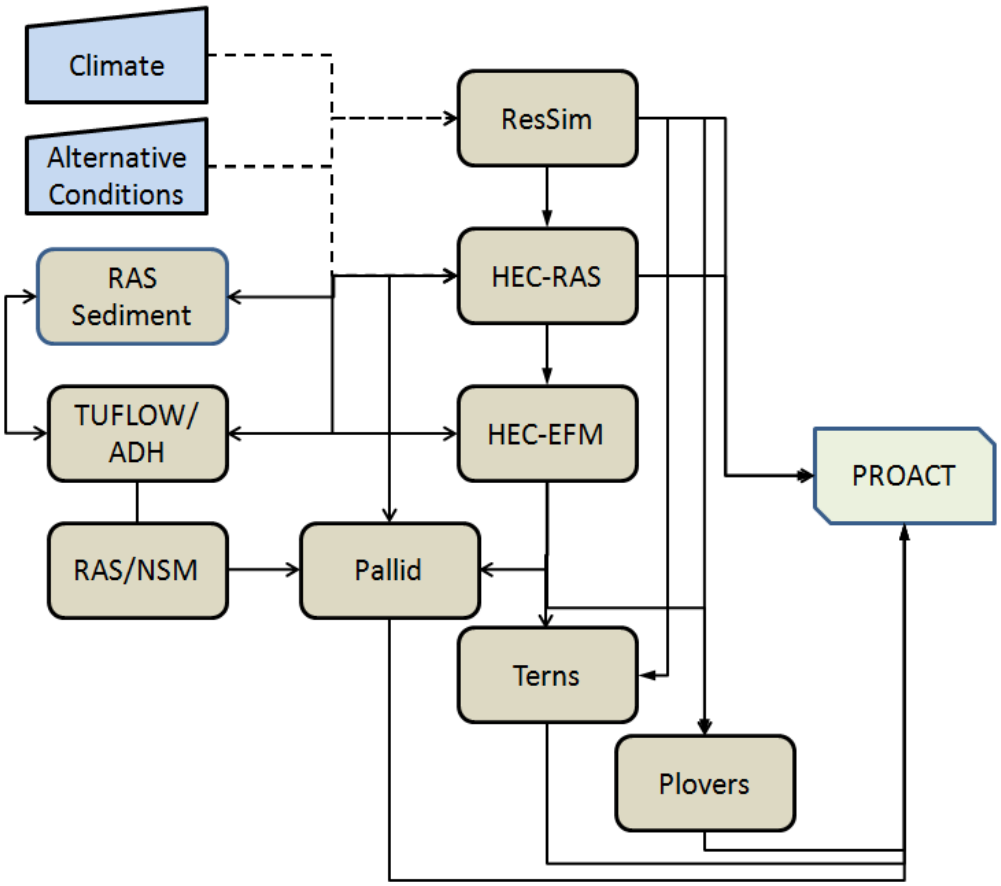

Figure 4. Draft model framework indicating specific models to be used

HEC-ResSim

Description

The Hydrologic Engineering Center's Reservoir Simulation model (HEC-ResSim or ResSim) is used to model reservoir operations given a set of operational goals and constraints. The software simulates reservoir operations for a variety of purposes including flood management, power generation, flow management and water supply, etc. The software can be used for real-time decision support. HEC-ResSim can represent both large and small scale reservoirs and reservoir systems through a network of elements (junctions, routing reaches, diversion, reservoirs) defined by the user. The software can simulate single events or a full period-of-record using appropriate time-steps. HEC-ResSim is a decision support tool that meets the needs of modelers performing reservoir project studies as well as assisting reservoir regulators during real-time events.

HEC-ResSim represents a system of reservoirs as a network composed of four types of physical elements: junctions, routing reaches, diversions, and reservoirs. These elements are combined to build a network representing the system of interest. A reservoir is the most complex element of the network and is composed of a pool and a dam. The pool's hydraulic behavior is defined by an elevation-storage-area table. Dam outlets can be controlled (e.g., with gates) or uncontrolled (e.g., an overflow spillway). Controlled outlets can be used to represent any outlet capable of regulating flow, including gates, valves, power plants and pumps. The software can simulate sophisticated operations involving multiple outlets.

The strength of HEC-ResSim lies in its ability to reproduce the decision making process that reservoir operators use to set releases. It accomplishes this through a rule-based description of the operational goals and constraints that reservoir operators must consider when making release decisions. The same "rules" included in the master manual for the Missouri River are coded into the Res-Sim models and given a set of conditions (pool levels, system storage, inflows and time of year), the software will determine the operation of each reservoir and the system that optimizes performance relative to the rule curves. Thus, the goals and constraints for flood control, power generation, navigation, water supply, recreation, and environmental quality are simultaneously addressed.

Application to Effects Analysis

A set of ResSim models have been developed to represent the Missouri River system. Five separate models are used to represent the system (Figure 5), including:

1. Upper Missouri River and Yellowstone River Basin
2. Missouri River Mainstem
3. Osage River Basin
4. Kansas River Basin
5. Chariton River Basin

The models include the reservoir operation rules outlined in the Missouri River Master Manual (USACE NWD 2006), or the master manuals for the basins in question. ResSim allows computation of unregulated and regulated flow record at downstream common computation points which will correspond to HEC-RAS upstream boundary conditions on tributaries and Missouri River Mainstem, as well as control points that will be used for internal HEC-RAS model calibration and calculations of ungaged inflows.

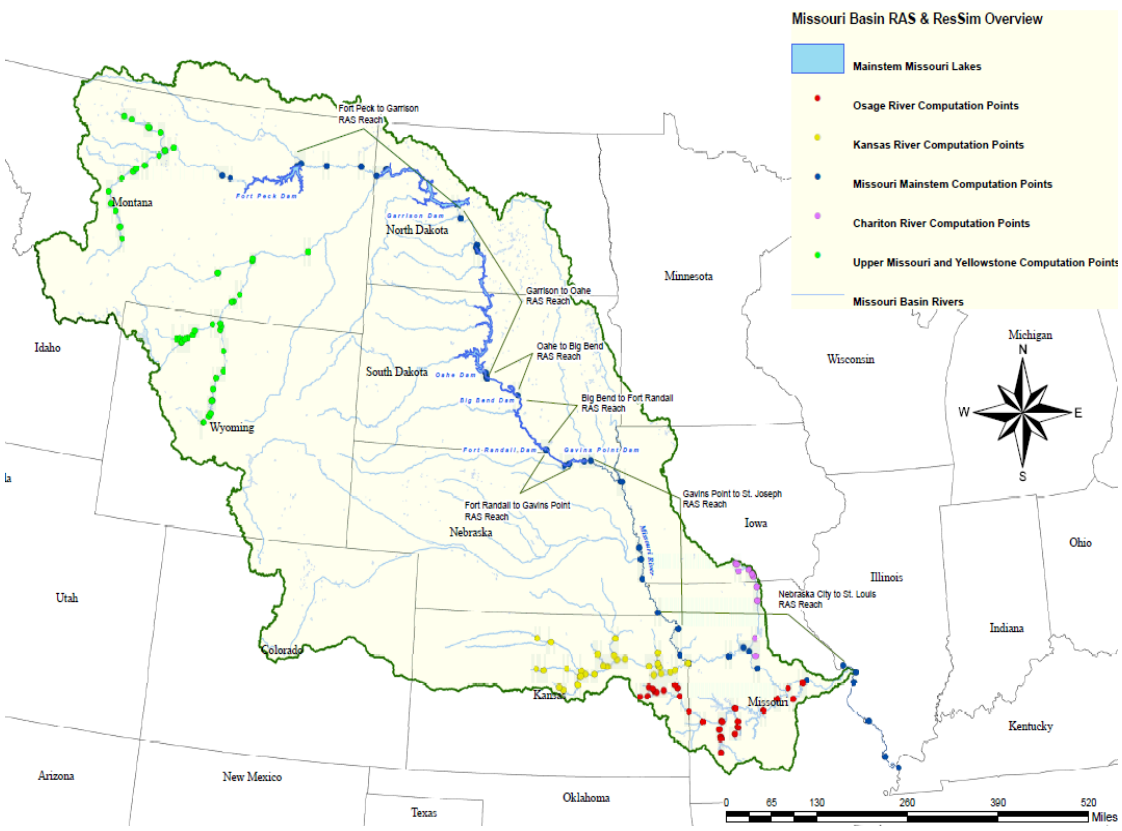

Figure 5. HEC ResSim and HEC-RAS models for the Missouri River Effects Analysis and Management Plan.

The ResSim models will be used to define the hydrology of the system when evaluating the No-Action condition and for each alternative. The hydrology will reflect flows for a 50-year simulation for each analysis. We may employ separate (scenario) analyses representing alternative future conditions so as to take into account climate uncertainty. The ResSim models can also be used to assess alternative conformance to existing operational criteria. Output from the ResSim models will be used to assess reservoir levels (for associated bird nesting habitat analysis) and flows in river reaches, which are used with HEC-RAS and other models to assess habitat in those reaches.

Data and Input Needs

Input requirements for ResSim fall in three broad categories: physical data, reservoir operation rules, and state variables. The physical data are used to describe the system and its operational capabilities. A tremendous amount of information is required to establish the physical details of the system. For reservoirs you need to define the physical characteristics of the pool, set up a hierarchical outlet structure, and also set up the operational plans. Junctions and control points will have inflow, observed, and stage lookup data. Routing Reaches are defined with a connectivity and hydrologic routing. Many more details are required, but that work has been completed for the Missouri River system and there is little need to adjust that information to assess alternatives.

The reservoir operations are characterized by zones, rules and guide curves. A Guide Curve is a seasonal variable target pool elevation. The basic guide curve operation is that within physical limits, the model wants to get the reservoir pool elevation to the guide curve as fast as possible. The Zones divide the storage pool into operational zones. A prioritized set of rules within each zone limits or over-rides basic guide curve operation. In general, rules involve:

- Complex Local and Downstream Flow Objectives
- Release or Pool elevation Rates of Change
- Emergency Gate Regulation and Induced Surcharge
- Local and System Hydropower requirements
- Parallel and Tandem Reservoir Systems
- User-Scripted release objectives
- If-Blocks, include additional constraints of the use of one or more rules

State Variables are user-defined (scripted) model variables for each time step. State Variables can be a function of internally computed ResSim model variables or from external variables (dss files). Examples include BiOp flows that drive rate of change rules as a function of downstream river stage conditions and releases based on maintaining targeted reservoir pool levels.

In general, the models require daily inflows and withdrawal abstractions, losses from evaporation, and other related physical data. The primary outputs of interest (i.e. pool levels and downstream flow routing) can be directly evaluated or passed along to other models (e.g., HEC-RAS or EFM) for processing prior to use as input to the species models.

HEC-RAS

Description

The Hydrologic Engineering Center's River Analysis System (HEC-RAS) is widely used in the United States and around the world to perform one-dimensional steady flow water surface profile computations, unsteady flow simulation, and mixed flow hydraulic calculations for a full network of natural and constructed channels. It can simulate a wide variety of hydraulic structures such as bridges, culverts, , weirs, and spillways, with variable spatial discretization. The system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed. The HEC-RAS system also includes analysis components for movable boundary sediment transport computations and water quality analysis. All model components use a common geometric data representation and common geometric and hydraulic computation routines. Its graphical user interface (GUI) standardizes many aspect of data entry, facilitates an efficient display of model results, data checking, data conversion, and communication between model sub-components. The latest publically-available version of the model is 4.1; a Beta 5.0 version that includes two-dimensional capabilities is being tested by the EA team, but is not yet available to the public.

Tabular output for dozens of user-specified parameters is available. Graphical outputs include X-Y plots of the river system schematic, cross-sections, profiles, rating curves, hydrographs, and many other hydraulic variables. A three-dimensional plot of multiple cross-sections is also provided, and inundation mapping of water surface profile results can be made directly from HEC-RAS. With a digital terrain model, RAS Mapper can use the HEC-RAS geometry and computed water surface profiles to develop inundation depth and floodplain

boundary maps. Additional geospatial data can be generated for analysis of velocity, shear stress, stream power, ice thickness, and floodway encroachment. Data storage is accomplished through the use of ASCII and binary "flat" files, as well as the HEC-DSS. Output data is predominantly stored in separate binary files. Data can be transferred between HEC-RAS and other programs by utilizing the HEC-DSS.

Application to Effects Analysis

Both steady and unsteady HEC-RAS models representing existing conditions on the Missouri River from Ft Peck, MT, to St. Louis, MO have been under development and are currently undergoing technical review. The models were developed from the best available ground, LIDAR and hydrographic survey data, but not necessarily the same data for all reaches. For example, 2009 bathymetry data was used for the model by Kansas City District from Rulo, NE to the mouth, while 2012 data was used by Omaha District for the reaches upstream of Rulo, NE. The Omaha and Kansas City District models overlap between Nebraska City, NE, and St. Joseph, MO. The boundary condition for the downstream model is normal depth approximately 11 miles downstream of the St. Louis gage, permitting a comparison of stages at St. Louis for alternatives. The models include tributaries with active gage records.

These models are capable of reproducing very low river stages, accounting for seasonal flow effects, and reproducing storage effects of levees at very high stages. Model calibration is underway using relatively recent high and low flow events (within bank), as well as recent mid-level flooding, and extreme events to test operation of levee storage areas (e.g.,1993 and or 2011). Flow analysis for the study period will be undertaken to produce hydraulic information that serves as a baseline (No Action condition) against which alternatives will be assessed.

Output from RAS feeds several models. Principle among these is HEC-EFM, which will use the computed water surface elevations (and other habitat conditions) to characterize habitat for any flow condition. Output will also directly feed the geomorphic module and several of the Human Considerations (HC) analyses. It is possible that we will use RAS output directly for some of the species models, augmenting or skipping the HEC-EFM.

Data and Input Needs

Data needed to execute an HEC-RAS model depend upon the system modeled and the components of RAS employed for the simulation. However, there are several basic needs independent of the modeling application. For each HEC-RAS "project", there are three required components--the Plan data, Geometry data, and Flow data. Plan data contains information pertinent to the run specifications of the model, including a description of the flow regime. The geometry data consists of a description of the size, shape, and connectivity of stream cross-sections as well as the overall layout of the system in terms of how the various reaches and tributaries are situated relative to each other.

HEC-RAS represents a stream channel and floodplain as a series of cross-sections along the channel. Each section is described by station-elevation pairs along the section. These data are typically obtained by field surveys, but LIDAR, existing elevation models and other sources can be used. The resolution and accuracy of the elevation data is critical to the quality of the final model. Manning's roughness coefficients (n-value), reach lengths between adjacent cross-sections, left and right bank station, and channel contraction and expansion coefficients must be defined for each section as well.

If structures such as bridges, culverts, gates, etc. are included in the system, the user must characterize several aspects of those features such as their geometry. Similarly, if the sediment, water quality, or other features of RAS are used, there are additional data requirements. HEC-RAS has a robust user interface and a number of utilities that make importing data from various sources fairly easy, but does not reduce the requirements for the quality of the geometry and flow data used for the analyses.

Flow data contains discharge rates (for steady analysis) or paired discharge and time data to represent a hydrograph for unsteady analysis. The flow data can be defined by the user by any means; in the case of the EA and the Management Plan a wide range of flow conditions will be evaluated for some analyses and the ResSim model output will be used to describe hydrographs used in evaluating long-term performance of alternatives. Users must also define boundary conditions with the flow data. Several options are available; those that require external data include a starting water surface elevation or a rating curve.

Significant coordination between Kansas City, Omaha, St Louis Districts, NWD Water Management, the Hydrologic Engineering Center and the

National Weather Service's Missouri River Basin Forecast Center has occurred and is underway in association with developing the HEC-RAS models (along with the ResSim models). The intent is assuring that the model accurately captures the functioning of the basin. The coordination has contributed to the following products relative to flows:

a) Extended period of record statistical methods document. As proposed, the methodology will mirror that of the 2003 Upper Mississippi River Basin Flow Frequency Study with slight variations.
b) Extended period of record observed data set, including depletions, for use in creating the unregulated and regulated record and for assessing potential effects of changes to reservoir operations. Data from 1898 to 2012 is available, though 1930 has been determined to be the earliest date of reliable and consistent data.
c) ResSim models of the Missouri River basin. Models include reservoir operation rules, input / output of daily inflows and outflows, losses from evaporation, pool levels, hydropower, and downstream flow routing. A report summarizing the model creation and calibration will be generated.

Water Quality

HEC-RAS/NSM Description

This component of the modeling system is intended to allow the user to perform riverine water quality analyses. This new module uses the QUICKEST-ULTIMATE explicit numerical scheme to solve the one-dimensional advection-dispersion equation using a control volume approach with a fully implemented heat energy budget. Transport and Fate of a limited set of water quality constituents is now also available in HEC-RAS. The currently available water quality constituents are: Dissolved Nitrogen (NO3-N, NO2-N, NH4-N, and Org-N); Dissolved Phosphorus (PO4-P and Org-P); Algae; Dissolved Oxygen (DO); and Carbonaceous Biological Oxygen Demand (CBOD).

The HEC-RAS – NSM model will serve as the primary assessment and management tool for water quality in the Missouri River. The HEC-RAS system contains four river analysis components: (1) steady flow water surface profile computations, (2) unsteady flow simulation, (3) movable boundary sediment transport computations; and (4) water quality analysis (via Nutrient Simulation Modules [NSM]). An advection-dispersion module is included with version 4.1 of HEC–RAS, adding the capability to model water temperature.

NSM is a set of nutrient water quality dynamic link libraries (DLLs) developed at U.S. Army Engineer Research and Development Center (Zhang and Johnson, 2014). Each NSM represents different biogeochemical processes and respective water quality variables. The levels of NSM are determined by the number of interacting dependent variables involved in aquatic nutrient simulation and the degree of their interactions. The current nutrient simulation modules include three levels: NSM-I, NSM-II and NSM-III. NSM-I simulates algal biomass, organic and inorganic nitrogen and phosphorus species, biochemical oxygen demand and dissolved oxygen using ten state variables. NSM-II simulates multiple algal biomass, nitrogen, phosphorus, and carbon cycles, chemical oxygen demand, dissolved oxygen, pathogen, and alkalinity using twenty-one state variables, as well as numerous derived water quality constituents in the water column. NSM-III accounts for the deposition of organic matter from the water column to the sediment bed of the water body, its subsequent diagenesis, and the flux of resulting end-products back to the overlying water column. The additional sixteen bed sediment state variables are included in NSM-III. Fig. 6 shows the schematic of water quality state variables and kinetic processes included in NSM-I.

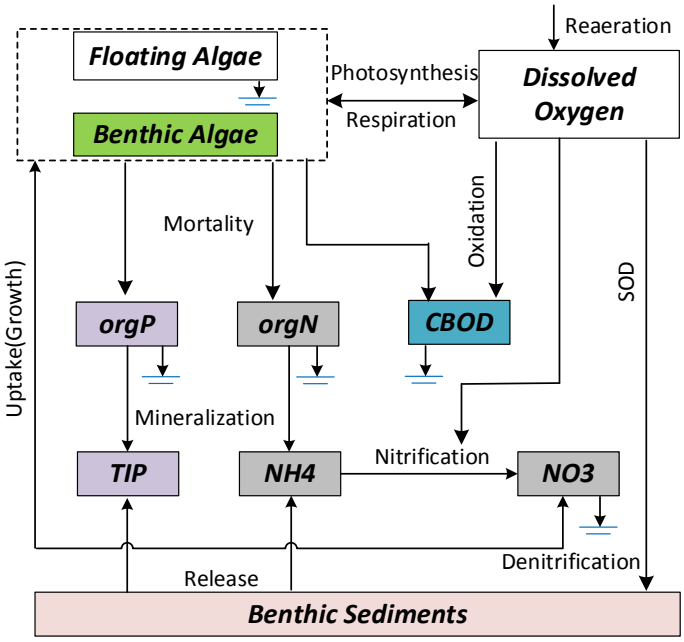

Figure 6. Water quality processes and kinetic interactions of the variables in NSM-I

Initially HEC-RAS – NSM-I will be developed for four Missouri River reaches using the data collected specifically for model support in order to develop a management tool for water quality in the river. If ongoing studies indicate that NSM-II or NSM-III are required to capture the important controlling

mechanisms for water quality, then HEC-RAS – NSM-I will be updated to satisfy the project needs.

Table 1. HEC-RAS – NSM-I water quality state variables to be simulated for the Missouri River.

No.	Name	Symbol	Unit
1	Temperature	TEMP	^{o}C
2	Inorganic suspended solids	ISS	mg L^{-1}
3	Floating Algae	A_p	mg-A L^{-1}
4	Organic Nitrogen	orgN	mg-N L^{-1}
5	Ammonia Nitrogen	NH4	mg-N L^{-1}
6	Nitrate-Nitrite Nitrogen	NO3	mg-N L^{-1}
7	Organic Phospherous	orgP	mg-P L^{-1}
8	Total Inorganic Phospherous	TIP	mg-P L^{-1}
9	Carbonaceous BOD	$CBOD_i$	mg-O_2 L^{-1}
10	Dissolved Oxygen	DO	mg-O_2 L^{-1}

Data and Input Needs

Following is a list of data required for the water quality simulations with the RAS/NSM models.

- Meteorological data for appropriate stations including air temperature, humidity, solar radiation, cloud cover, and wind speed
- Observed time series water quality concentrations for each point source and tributary discharge into modeled reach, potentially including
    - Temperature
    - Algae
    - Dissolved oxygen
    - Nitrogen (organic nitrogen, ammonium, nitrate)
    - Phosphorous (organic phosphorous, inorganic phosphorous)
    - CBOD or carbon
    - Suspended solids
    - Turbidity

Sediment and Geomorphic Models

The geomorphic model group is currently emphasizing three near-term studies. One would seek to improve discharge-stage-area relations for the ESH in two critical reaches. That effort would rely primarily on analysis of imagery and survey data to develop an empirical model (e.g., Strong, 2012) with limited supplemental modeling using the sediment transport features in HEC-RAS and a two-dimensional sediment model at one or two

representative sites. Existing models at Deer Island (Buesing, 2010), Boyer Bend (Abraham, 2012) and Hamburg Bend (Boyd, 2011), among others, are under consideration. A second effort would consider the evolution of SWH features, including some general regime assessments, bank erosion modeling using the NRCS' BSTEM model (Simon et al., 2009) and potentially an assessment of entrance conditions at chutes. Finally, larger scale analysis of degradation would be conducted, mainly to assess impacts to HC factors but also to help identify (perhaps quantify) potential implications to the species models.

HEC-RAS Sediment

HEC-RAS has the capability for the simulation of one-dimensional sediment transport and movable boundary calculations resulting from scour and deposition over moderate time periods (typically years, although applications to single flood events are possible). The sediment transport potential is computed by grain size fraction, thereby allowing the simulation of hydraulic sorting and armoring. Major features include the ability to model a full network of streams, channel dredging, various levee and encroachment alternatives, and the use of several different equations for the computation of sediment transport.

The model is designed to simulate long-term trends of scour and deposition in a stream channel that might result from modifying the frequency and duration of the water discharge and stage, or modifying the channel geometry. This system can be used to evaluate deposition in reservoirs, design channel contractions required to maintain navigation depths, predict the influence of dredging on the rate of deposition, estimate maximum possible scour during large flood events, and evaluate sedimentation in fixed channels.

Input requirements for the sediment module include selection of the transport function, sorting method, fall velocity method, sediment control volume and the bed gradation at each cross section. The user can define an inflowing sediment load in the form of a sediment rating curve, or he model can assume an equilibrium load at the upstream boundary. Similarly, a number of sediment properties require definition, but default values are specified. A uniform lateral flow can be specified to account for sediment inputs from bank erosion or overland flow. In general, a good understanding of the channel geometry, bed level, sediment gradation for the bed, and characteristics of inflowing and bed sediments are required to run the model.

HEC-EFM

Description

The Ecosystem Functions Model (HEC-EFM) was designed to help quantify and assess ecosystem responses to changes in the flow regime of a river, reservoir or wetland. Analyses with EFM generally involve: 1) statistical analyses of user-defined relationships between hydrology and ecology, 2) hydraulic modeling, and 3) use of Geographic Information Systems (GIS) to display results and incorporate other relevant spatial data into an analysis. This process helps to visualize and define existing ecologic conditions and assess and rank alternatives according to predicted changes in conditions of the ecosystem (generally habitat, but any time-series flow relationships can be evaluated).

HEC-EFM is a very flexible tool. It was developed to work harmoniously with HEC-RAS and readily uses outputs from that model as a basis for characterizing the time-series flow data of interest. Though useful, HEC-RAS is not needed to apply EFM; it can utilize data from other sources. Although developed for environmental analysis, it can be readily applied to socioeconomic problems where the impacts or benefits can be linked to flow conditions. It will be applied to several such needs in the MRRP in support of the HC evaluations.

HEC-EFM is an open-source software. It has been certified for use in the Corps as a planning model. The certification involved review and assessment of the technical soundness of the model, its computational accuracy and conformance with Corps' policies. The certification does not address a critical component of any HEC-EFM model – the user-defined relationships that constitute the basis for the calculations and model outputs. The technical soundness of the relationships are typically addressed through normal review processes (e.g., independent technical review, agency technical review, etc.).

Application to Effects Analysis

Typical applications of EFM for the EA and Management Plan involve analyzing synthetic stage and flow hydrographs produced by HEC-RAS to determine if and when HEC-EFM Ecosystem Function Relationship (EFR) conditions were met. These conditions, defined by the user, include seasonality, duration, rate of change, and/or return frequency as a function of stage and flow.

Data and Input Needs

Model inputs generally include the different flow regimes of interest, ecological values and their relationships to flow conditions, and any relevant spatial data.

Output is in the form of statistics, hydraulics, and spatial results. The statistical results can be input to a GIS or to the H&H models to develop water surface profiles, depth and velocity grids, inundation boundary maps, shear stresses, etc. Future condition flow data is frequently imported to EFM from HEC-RAS analyses, but EFM can work with hydrograph and rating curves (or other sources) if HEC-RAS is not available. Additional details on required inputs follows:

- *"Flow Regime" data:* HEC-EFM flow regimes consist of two concurrent daily time series that reflect conditions at a single location of interest, which is repeated at many locations to represent the study area. Typically, these data are daily mean flow and stage representing river hydrology or reservoir conditions and can be obtained from the HEC-RAS and HEC-ResSim output (though any source can be used).
- *"Relationships":* Statistical representations of the links between ecological or human considerations and the flow regimes are the key to HEC-EFM modeling. These statistics can include season, duration, rate of change, and percent exceedance. They are typically determined through the expert knowledge of the team. For the EA, they will evolve from the CEMs.
- *Spatial data:* Water surface profiles and spatial layers of water depth, velocity, and inundation areas can be used in HEC-GeoEFM. These can be derived from the HEC-RAS output and GIS modeling.
- In addition, EFM modeling on the Missouri River will need to include channel configuration alternatives. These equate to alternative channel-geometry data for HEC-RAS runs; the geometry data will need to be generated to represent alternative implementations of channel configurations intended to increase emergent sandbar habitat (ESH) and channel top-width and complexity of channel-margin habitats, conventionally described as shallow-water habitat (SWH).

Information Management Tools

The U.S. Army Corps of Engineers' Hydrologic Engineering Center has developed tools to support data management for their modeling systems. Two tools, in particular, will likely be employed to support analyses under the EA. The HEC Data Storage System (HEC-DSS) is integral to several of the models and will certainly be employed for editing and viewing data for some, if not all, of the HEC line of software. In addition, the use of HEC's Watershed Analysis Tool (WAT) to help manage all of the anticipated models and analyses is under consideration and will likely be used to manage alternative input and outputs.

HEC-DSS

HEC's Data Storage System, or HEC-DSS, is a database system designed to efficiently store and retrieve sequential data used by their models. Included are time series data, curve data, spatial-oriented gridded data, and other similar data input to or output from HEC-ResSim, HEC-RAS and HEC-EFC and most of HEC's major application programs. The system was designed to facilitate retrieval and storage of data by the application programs and editing by users.

Data in HEC-DSS database files can be graphed, tabulated, edited and manipulated with HEC-DSSVue, a Java-based visual utilities program. HEC-DSS Utility programs also provide "batch" type data entry capabilities from a variety of formats, report generation with HEC-DSS data, as well as legacy applications whose functionality has been superseded by HEC-DSSVue.

HEC-WAT

The Hydrologic Engineering Center developed an interface called the Watershed Analysis Tool (HEC-WAT or the WAT) to streamline and integrate multi-disciplinary water resource studies involving the application of their other software. The WAT incorporates individual software (HEC-ResSim, HEC-RAS, HEC-EFM, etc.) using a "plug-in" concept and allows them to work together in a coordinated fashion and from the same interface. Additional software can be incorporated into the WAT by developing new plug-ins.

HEC-WAT permits individual models to use a shared schematic (representation of the physical system), which assures that the naming convention and project identification and location for the study is consistent throughout the modeling efforts. It provides the visualization tools to create models, edit models, and compare alternatives. The WAT shares data across models through the DSS file, inundation maps, and depth grids. The modeling files from the individual pieces of software are stored in the WAT architecture so that the project files are located in a common site for easy retrieval and documentation. Output and alternative analysis comparisons from the models can be accessed directly from the WAT making the results and reporting from all the models much more accessible.

ADH and TUFLOW

Working groups have been exploring the need for multi-dimensional hydrodynamic, water quality and sediment modeling to be used to supplement the one-dimensional modeling framework established by ResSim and HEC-

RAS. The group has concluded that some supplemental multi-dimensional modeling will be required to address a subset of hypotheses for each species and to provide insight into some processes to improve the parameterization of the 1D model results or assist with their interpretation. Appendix D lists a set of existing models that could be used for these purposes. Although additional efforts may be undertaken in the near- and long-term, there is considerable interest in pursuing the use of a few of these models; specifically, a TUFLOW model of the Lisbon-Jameson reach and ADH models at Deer Island and below Gavins Point Dam within the non-navigation portion of the Missouri River managed by the Corps and National Park Service as the Recreational River.

Descriptions

TUFLOW (Two dimensional Unsteady FLOW) was developed in the 1990's by the University of Queensland, Australia for a project requiring a two-dimensional hydrodynamic model that linked dynamically with 1D hydraulic models. TUFLOW employs a finite difference, alternating direction implicit scheme that solves the full 2D free surface shallow water flow equations over a regular grid. The model has evolved toward addressing coastal systems and flooding in urban environments, but has a number of capabilities and features useful to analysis of SWH and floodplain features on the Missouri River. The model produces the normal outputs expected of comparable tools including map, time-series and text based outputs of over 20 different data types including stage, velocity, depths, unit flow, energy, etc. and permits customized categories that could include categories of habitat types. The map and time-series output can be combined and viewable via GIS. Unlike other models used for the EA and Management Plan, TUFLOW is a commercial product (WBM Oceanics). Several sub-modules and versions with different capabilities are available from the vendor.

ADH (ADaptive Hydraulics) is an open-source modeling platform developed by the ERDC Coastal and Hydraulics Laboratory. ADH draws its name from its use of adaptive numerical meshes that can be employed to improve model accuracy without sacrificing efficiency. This also allows for the rapid convergence of flows to steady state solutions. ADH is capable of simulating both saturated and unsaturated groundwater, overland flow, three-dimensional Navier-Stokes flow, and two- or three-dimensional shallow water problems. The 2-D shallow-water equations are a result of the vertical integration of the equations of mass and momentum conservation for incompressible flow under the hydrostatic pressure assumption (Berger and Lee 2004). It contains other useful features

such as wetting and drying, completely coupled sediment transport, and wind effects. A series of modularized libraries make it possible for ADH to include vessel movement, friction descriptions, as well as a host of other crucial features such that it can be applied to address most concerns for the EA and Management Plan. ADH can run in parallel or on a single processor and runs on both Windows systems and UNIX based systems.

Application to Effects Analysis

The potential use of TUFLOW for the EA extends from the US Geological Survey (USGS) having applied the model to the Lisbon-Jameson reach of the river for the purpose of evaluating passive larval sturgeon drift on the lower river (Erwin and Jacobson, in Pub). That model provides a basis for extending the analysis to consideration of active drift (including behavior) and perhaps a more accurate distribution of larvae within the water column. This analysis helps address critical hypotheses regarding the extent to which reconfigured channel morphology can alter rate of downstream advection or hydraulic dispersion of free-embryo larvae. Sensitivity analyses with the model can also inform the extent to which flow management combined with habitat modification can decrease channel velocities and/or increase the probability that larvae will be transported into and retained in channel margin habitats.

The same circumstance can be evaluated at other locations on the system where conditions differ from the Lisbon-Jameson reach. An existing ADH model of a four-mile reach near Deer Island appears to offer utility in assessing the above problem for a different SWH configuration. The ADH model of the Deer Island reach also includes sediment transport, and was recently used to assess ESH development and erosion, among other issues (Buesing 2010). That model can be used for further studies related to a key hypothesis for terns and plovers; that flow pulses act to create, recondition, and otherwise alter ESH in reaches where sediment supply is sufficient for ESH development. Testing this hypothesis will require assessments of magnitude, duration, and frequency of pulses as well as the erosion, transport and deposition of sediments in representative reaches where ESH development is possible and relevant to bird nesting. There may be utility in using a MD SWMS model of the reach developed by the USGS (Jacobson et al 2009) for purposes of comparing conditions at two time periods.

Quality Control Reviews

A Quality Management Plan (QMP) was developed in accordance with EC 1165-2-214 (USACE 2014) to ensure the ResSim and HEC-RAS models meet the Corps' standards for the intended application. A QMP will also be prepared for the remaining models once their use has been confirmed and the applications are settled. Reviews conducted for the remaining models may include certification for use as a planning model on Corps' formulation studies.

District Quality Control (DQC) is an internal review process of basic science and engineering work products focused on fulfilling the project quality requirements defined in the Project Management Plan (PMP). DQC will include peer and supervisory reviews, interdisciplinary reviews, and formal independent technical reviews.

The term "peer review" in this document is synonymous to the "quality checks and reviews" defined in Chapter 3 of ER 1110-1-12 (USACE 2006). Peer reviews involve colleagues with subject matter expertise reviewing the technical accuracy of the work. Peer reviews include evaluation of correctness of basic data, correctness of calculations, accuracy of documentation, and compliance with current guidance, criteria, and standards. Peer reviews shall be performed and documented throughout the design process to the extent required to avoid impacts to others relying on the quality of the work.

The term "interdisciplinary review" for this document is synonymous to the internal portion of the "PDT Review" defined in Chapter 3 of ER 1110-1-12. The team's interdisciplinary check ensures the work developed by one discipline does not conflict or interfere with the work of another discipline. Each member will check other disciplines work for coordination with their work and comment on work by other team members that does not appear to satisfy criteria or client requirements. Informal Interdisciplinary Reviews are performed throughout the report process via coordination of disciplines. Initial tests of how the model may work with various programs including (e.g.,how HEC-RAS works with EFM or WAT) are also conducted.

Formal DQC reviews consistent with Independent Technical Review (ITR) requirements will be performed following completion of major components or milestones in the model development. After reviews are completed, the model/data developers will address all comments to the satisfaction of the reviewer and make modifications to the products and documentation as

necessary. Also as part of the DQC process Northwestern Division Missouri River Basin Water Management will review the reservoir operations components of models to ensure reasonableness and consistency with past experience in the basin.

After completion of the final models and reports, the PDT shall certify in writing on the PDT Certification form that their products are in general compliance with established policy, criteria, and engineering practice. Internal peer review and interdisciplinary reviews have taken place for the ResSim and HEC-RAS models and all significant conflicts and comments have been resolved.

The ITR Team / formal DQC team will certify in writing on the ITR Certification form that the product is in general compliance with established policy, criteria and engineering practice, and utilizes justifiable and valid assumptions. This included review of: assumptions; methods, procedures, and material used in analyses; alternatives evaluated; the appropriateness of data used and level obtained; and reasonableness of the result, including whether the product meets the customer's needs consistent with law and existing Corps policy. All comments resulting from ITR have been resolved for the ResSim and HEC-RAS models.

Agency Technical Reviews (ATRs) have been undertaken in accordance with EC 1165-2-214 (USACE 2014) to ensure the quality and credibility of documentation and products. ATRs for the ResSim and HEC-RAS modeling has been managed through the National Ecosystem Planning Center of Expertise (ECO-PCX). Overall review strategy is covered by the MPEIS review plan. An Independent External Peer Review (IEPR) is expected for the overall MPEIS and will result in another level of review for all the models used for the study.

A complete review process for the EFM, sediment, water quality, and multi-dimensional models developed to support the EA will be implemented and will occur at several stages of the study and incorporate several levels of reviews. In addition, an ATR of the overall effort will also be conducted. The nature of the review will be similar to that already be applied to the ResSim and HEC-RAS models, though the compressed schedule may require accelerated reviews and some adjustments to the plan.

The Technical Lead will be responsible for maintaining review certifications, written comments, marked up documents, and any other quality control related documents until the final product has been approved. All review certification

sheets and formal written comments will be retained in the permanent project file maintained by the Technical Lead. The applicable forms from the list below will be completed during the Quality Control process.

- DQCP Review and Approval Certification
- Peer Review/Design Check Certification
- ATR Review/Design Check Certification

Documentation

Need and approach

Documentation is critical for presenting a transparent and logical decision-making process and a defensible recommendation. The decision documents must tie together the CEM and its linkage to the objectives, evaluation metrics, model selection, model application, alternative benefits and impacts, alternative selection, remaining uncertainties, and how uncertainties will be addressed through adaptive management. Credible documentation that demonstrates the rationale for decisions made during the process is particularly important for projects like the MRRP where plan selection is not strictly dictated by economic evaluation.

The EA habitat team will develop a documentation protocol that extends beyond the QA/QC process described above and includes descriptions of all model development issues, data employed in each model, analyses performed with each model, and other relevant information. The Technical Lead will be responsible for maintain this documentation.

5 Supporting Data, Literature, and Models

Scope and Classification

The geographic scope of the habitat analysis for the EA includes the Missouri River from Ft. Peck (River Mile 1771) to its confluence with the Mississippi River (River Mile 0), as well as those tributaries and portions of the Mississippi River that directly or indirectly contribute to habitat affecting population dynamics of the interior least tern, piping plover and pallid sturgeon. While the bird and sturgeon teams are necessarily interested in habitat utilization in other areas, the data needs for habitat modeling are generally focused within those geographic boundaries described above.

The scope of relevant literature from which to draw information related to the habitat analyses need not be constrained to the Missouri River basin. Similar studies or modeling efforts on other systems can provide valuable insights into important processes, study techniques, etc. For that reason, the literature review includes some studies outside the Missouri River basin. However, the focus of compilation efforts has been on studies of that system, particularly studies that offer insights into geomorphic conditions or processes affecting habitat.

A classification system was developed to help identify the relevance of any particular model application, data set, study, paper or other information source. The classification is summarized in Table 2. It organizes the material into information categories and further divides that into specific types of information. Keys are used to indicate which specific information types are addressed and the associated format of the material (data sets, reports, models, or other)[2]. A particular reference can have multiple keys. The keys facilitate literature searches and identification of critical information gaps.

[2] Note: As of the current draft, not all resources have been have been tagged with the relevant keys

Table 2. Classification keys for data, reports, models and other information related to habitat modeling.

Information Category	Types of Information	Key			
		Datasets	Reports	Models	Other
Climate	Historic data - ave and extreme for temp, precip, wind, etc.	CD1	CR1	CM1	CO1
	Long-term climate change studies/forecasts	CD2	CR2	CM2	CO2
	Other	CDO	CRO	CMO	COO
Reservoir Operations	Daily pool elev, releases, storage, etc.	RD1	RR1	RM1	RO1
	Pool-volume/pool-shoreline relations	RD2	RR2	RM2	RO2
	Abstractions	RD3	RR3	RM3	RO3
	Reservoir sedimentation rates	RD4	RR4	RM4	RO4
	Other	RDO	RRO	RMO	ROO
Hydrology/ Hydraulics	Daily discharge data for Missouri River Mainstem gages	HD1	HR1	HM1	HO1
	Daily discharge for furthest downstream gage on any tributary	HD2	HR2	HM2	HO2
	Stage/discharge (i.e. rating curves) for any river location	HD3	HR3	HM3	HO3
	High water marks or other calibration data	HD4	HR4	HM4	HO4
	Velocity distribution data for any study reaches	HD5	HR5	HM5	HO5
	Hydraulic geometry relations	HD6	HR6	HM6	HO6
	Other	HDO	HRO	HMO	HOO
Channel Bathymetry and Floodplain Topography	Hydrographic surveys for any river reaches (multi-year data)	MD1	MR1	MM1	MO1
	Lidar or surveys for river banks, floodplains and levees	MD2	MR2	MM2	MO2
	Navigation maps or (preferably) spatial datasets showing locations of navigation training structures and revetments	MD3	MR3	MM3	MO3
	Aquatic habitat mapping	MD4	MR4	MM4	MO4
	Other	MDO	MRO	MMO	MOO
Channel Dynamics	Historical aerial photography, satellite imagery, or spatial data permitting the identification of islands or emergent sandbars	DD1	DR1	DM1	DO1
	Sandbar growth, decay, movement	DD2	DR2	DM2	DO2
	Channel degradation trend studies	DD3	DR3	DM3	DO3
	Rating shift analyses for any gage/Specific gage analyses	DD4	DR4	DM4	DO4
	Bed form surveys or studies	DD5	DR5	DM5	DO5
	Bank erosion locations, rates, or mechanisms	DD6	DR6	DM6	DO6
	Other	DDO	DRO	DMO	DOO
Water Quality and Sediments	Water quality (average and extremes at various resolutions for DO, Temperature and Turbidity at any point in system)	QD1	QR1	QM1	QO1
	Bed, bed material and/or suspended sediment concentration, or load on the mainstem or major tribs for which the data is available	QD2	QR2	QM2	QO2
	Bed material sediment gradations at any locations available	QD3	QR3	QM3	QO3
	Other	QDO	QRO	QMO	QOO
Floodplain/ Riparian	Levee locations, ownership and conditions	FD1	FR1	FM1	FO1
	Riparian vegetation/habitat mapping	FD2	FR2	FM2	FO2
	Other	FDO	FRO	FMO	FOO
Other	Other	ODO	ORO	OMO	OOO

Assessment

The EA process outlined by Murphy and Wieland (2011) includes steps to ensure that the analysis is based on the best science. As it relates to the habitat modeling activities, this largely involves following current standards of practice in the hydrologic and hydraulic modeling including an assessment of all data sources used to develop and parameterize the models. This has already occurred for the HEC-RAS and ResSim models and those models have gone through extended review to assure those standards have been met. All review comments and responses for each of the models have been maintained for quality assurance.

Similar must be employed when revising those models to reflect alternatives and when developing new models for the EA. In many instances, the same data used for the HEC-RAS and ResSim models will be used for new model development. The EA Habitat Team must also critically review any existing data or study conclusions that are used as lines of evidence in support of the habitat assessment. That effort has begun, but will necessarily continue for the duration of the EA.

Datasets

Overview

This section of the report summarizes important datasets that have, or could be used to support model development, testing, calibration, or verification as part of the habitat modeling efforts for the EA. It includes those information types identified in Table 2, and is organized according to those categories. Data integrity and reliability assessments have been conducted or confirmed for only a portion of the datasets; evaluations are ongoing as of the current report draft and the final report will reflect the status of that review and its findings.

Habitat and Assessment Monitoring Project (HD5, HD0, MD1, MD2, MD3, MD4, DD5, DD6, QD3, FD1, FD2)

The Habitat Assessment and Monitoring Project (HAMP) is an interagency collaboration of state, Federal and academia initiated in 2004 to evaluate habitat modifications aimed at increasing and improving shallow water habitat (SWH). The HAMP assesses the physical and biological responses to habitat modification in the Missouri River downstream of Ponca, NE (~RM 750) for pallid sturgeon and other targeted fish species. The project area

includes 44 river bends; 24 in the Kansas City District and 20 in Omaha District. Physical habitat assessments consisting of before/after and impact/control have been carried out in both districts to characterize the effects of chutes, revetment chutes, and bank, dike and revetment notching. Corresponding datasets of bathymetry, topography, sediments, velocity fields and habitat utilization have been compiled and are managed by the Hydrology and Hydraulics (H&H) Branches for the respective Districts. Survey data has also been collected within constructed chutes, backwaters, and revetment lowering projects. This data is available for multiple years for all constructed off-channel habitats within Omaha District (over 30 projects). Survey collection times vary by site.

USGS Sandbar Imagery (DD1, DD2)

The USGS Northern Prairie Wildlife Research Center in cooperation with the U.S. Army Corps of Engineers is investigating least tern and piping plover habitats in terms of the dynamics of land cover and emergent sandbars on the Garrison, Fort Randall, Lewis and Clark Lake, and Gavins Point segments of the Missouri River. Remotely sensed, sub-meter resolution images from sensors including WorldView-2 and GeoEye, and 6-m resolution RapidEye images are acquired multiple times each year. Land cover and emergent sandbars are mapped using a prototype knowledge- and object-based image analysis model developed for the Missouri River. Investigations include the dynamics of plant succession on sandbars, fluvial erosion of sandbars, sandbar area variability related to discharge, and spatial and temporal distribution of sandbars. Information about habitat dynamics is used in an adaptive management program and investigations of least tern and piping plover population dynamics.

Missouri River Side Channel Chute Monitoring (MD1, MD4, DD6)

These are data collected in or adjacent to constructed and natural chutes on the Missouri River. Data are composed of cross-sectional surveys including surface topography and chute bathymetry, ADCP discharge transects at a range of flows, and longitudinal channel profiles (Jacobson and others, 2004; Jacobson, 2006). Chutes with monitoring data include the Cranberry, Lisbon, Jameson Island, Overton Bottoms, and Tate Island Chutes in central Missouri.

Pallid Sturgeon Population Assessment Database (MD1, MD4,)

The Pallid Sturgeon Population Assessment Database (PSPAD) was developed by the Pallid Sturgeon Population Assessment Team (PSPA

Team). The PSPA Team is comprised of representatives of State and Federal Agencies and academia with knowledge and expertise of the Missouri River, pallid sturgeon and native Missouri River fishes. They developed standard operating procedures (SOP) for sampling and data collection on the Missouri River, and maintain strict QA/QC procedures for data placed in the PSPAD. Although the focus of the PSPAD is biological, it includes habitat data collected through several projects. For example, the Chute Study-Mitigation Project has collected extensive physical habitat information to be able to describe temporal changes in the availability and composition of chute habitat. (Note: Habitat Team needs to further assess the data in the system)

Spring Rise Data (HD6, MD1, MD3, MD4, DD5)

Elliott and others (2009) monitored the effects of experimental pulsed Spring Rise flows at four 6 kilometer long reaches located downstream from Gavins Point Dam. Reach-scale bathymetric and velocity maps were generated for hydrodynamic modeling (see Jacobson et al 2009) near Yankton, SD, Kenslers Bend, NE, Little Sioux, IA, and Miami, MO. Transects were surveyed multiple times over a wide range of discharges. Hydroacoustic mapping and ADCP measurements were used to evaluate velocity and bed-sediment erosion and deposition. The datasets from the monitoring and the modeling results provide useful data to the EA with respect to flow-induced habitat variation and morphological adjustments.

Garrison Reservoir Climate Change Pilot Study (CD2)

While not technically a database, this study (USACE 2012) considers the potential impact of climate-induced hydrologic changes to the Missouri River at the Garrison Dam and the data contained in the report are particularly useful in evaluating climate change for the EA and Management Plan. Five different climate scenarios were developed by the US Bureau of Reclamation (USBR) from one hundred twelve downscaled climate projections. Each climate scenario contained two different periods: 2010-2039 (Near Future) and 2040-2069 (Distant Future). The USBR used the data from the projected climate scenarios as input for a Variable Infiltration Capacity (VIC) model and derived values for runoff, infiltration, and contributions to groundwater from precipitation. New elevation-storage relationships and reservoir inflows for each climate scenario were developed and incorporated into Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) and the Daily Routing Model (DRM) in order to model changes in stream flow and amount of sediment transported to the Garrison

Reservoir, Lake Sakakawea. The modeling results showed an increase in pool elevations and releases at Sakakawea for all climate scenarios with respect to the historical pool elevations and releases; a 10-fold increase in duration of pool level exceeding spillway height. A majority of the affect was attributed to the increased inflows and not the increased sediment loads. When assessed using the DRM, impacts were far less due to operation of the other reservoirs.

Historical Streamflow Data – USGS NWIS (HD1, HD2, HD3, QD1, QD2, QR1)

Web-accessible data for each USGS gage and for user-selected time period at http://waterdata.usgs.gov/nwis/sw

Evaporation or Depletions Database (CD0)

The Bureau of Reclamation provides depletions for use with the Daily Routing Model (DRM) and the HEC-ResSim models for the Missouri River Mainstem reservoirs. Two types of depletions are provided, historic depletions and present level depletions. The historic flows used to create the incremental flows include historic depletions. To update the depletions in the reservoir models, the present level depletions are subtracted from the historic depletions and the difference is used as the depletion input. Reclamation provides monthly data by reach, so the flows are broken down into daily values and inserted into the model input files. Depletions are computed by Reclamation periodically and depletion data generally lags the census data.

High Plains Regional Climate Center (CD1)

Provides many types of useful real-time and historical climate data including maps, data sets, reports, and models. (http://www.hprcc.unl.edu/),

National Climatic Data Center (CD1)

Provides many type of useful climate date, including Radar, ground-based, and satellite data. Real-time and historical data for temperature, dew point, relative humidity, precipitation, wind speed and direction, visibility, atmospheric pressure, and types of weather occurrences. Includes Access to near-real-time, high-volume numerical weather prediction and global climate models and data. Looking into the past, present, and future to assist in the analysis of multidisciplinary datasets and promote interoperable data analysis. (http://www.ncdc.noaa.gov/data-access)

Streamflow Projections for the Western United States (CD2)
This site presents streamflow projections to 2099 for locations identified by the US Bureau of Reclamation.
http://gis.usbr.gov/Streamflow_Projections/)

Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections (CD2)
Note: This site was down during much of the review period and the Habitat Team will assess information from this source further as it considers options for hydrologic assessments under the EA (http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/)

Technical Memorandum No. 86-68210-2011-01, West-Wide Climate Risk Assessments: Bias-Corrected and Spatially Downscaled Surface Water Projections (CR2)
The USBOR summarizes climate change effects on major rivers in Western U.S. (http://www.usbr.gov/WaterSMART/docs/west-wide-climate-risk-assessments.pdf),

LIDAR Datasets (MD2)
LIDAR is available along entire river corridor and is generally sufficient for a 2 ft. contour. This data is 2006 or newer. The data is currently maintained at the USACE Districts, and will eventually be available as part of NED. Some variation in specifications for the various data sets has been noted, but the implications in terms of product are not yet clear. Refined data for specific areas of interest may be necessary for the Effects Analysis. LIDAR upstream of Kansas City is available for 2001 and 2012. Downstream of Kansas City, the LIDAR coverage is with a variety of survey from 2010-2012. (Corp contacts - C. Sellmeyer and C. Bitner). Data has been hydroflattened. USFWS WR has much of the LIDAR data in its possession as well (Pers. Com. J. Eash).

SSURGO Soil Data (DD0)
The USAG (Robb Jacobson) has soil data layers generated 1.5 yrs ago, but the digital data will soon be served seamlessly on the web. This data is updated continually, so the EA Team must make sure that any soil layers are dated for future reference because once they are downloaded they become 'static'. Soil Web Survey is updated every Sept. More than 50 counties in Missouri are mapped, with some discontinuities at county boundaries. Mark Abney (NRCS) indicated that a soil join re-correlation is in process to create a seamless soil layer for Missouri. Updated data should be online at the end of September for

Phase 1 (2000-2006). Generally, soils were updated subsequent to 93' in scour and deposition areas, from "the pinch" down. Other states are following suit along different timelines. (pers. comm. R. Jacobson, M. Abney)

USGS rating curves (HD3)

Updated rating curves can be obtained on-line through the portal (URL below). The tables provided are shift corrected, incorporating the mathematical adjustments for ease of use by the user. The shift adjustments are applied to the individual ratings as measured data becomes available, resulting in an adjusted rating. Some ratings may change as often as weekly, others may not change for months or years. (http://ky.water.usgs.gov/hyd_data/rating_depot.htm),

USGS Map Store (DD1, MD2)

Provides access to a wide array of current and historical digital and paper maps.
http://store.usgs.gov/b2c_usgs/usgs/maplocator/(ctype=areaDetails&xcm=r3standardpitrex_prd&carea=%24ROOT&layout=6_1_61_48&uiarea=2)/.do

USACE Districts Reservoir Surveys (RD2, RD4, RR2, RR4)

Reservoir sedimentation volumes are available from various survey dates; the most recent are in the 2006 to 2012 range. Previous surveys in the late 80's and as far back as the 1950's provide insights into sedimentation rates. Data are maintained in the Omaha District H&H Branch.

USACE Districts High Water Marks (HD4, HR4)

High water marks were established for the 2011 flood profile; normal flow profile elevations are collected once or twice per year in the Navigation channel, less frequently in other reaches. Data are maintained in H&H Branch.

USACE Districts GIS Database (MD2, MD3, Md4, MD5, DD1, DD2, FD1, FD2, FD3)

District GIS sections maintain a wide array of digital data as well as historical maps and reports.

Omaha Districts H&H Bed Survey Data (DD5, QD3)

Bed surveys available from multiple time periods, most recent is in 2007 to 2012 period in the Fort Randall Dam to Rulo reach of the Missouri River. Additional data collection efforts are planned for the Ft Peck, Garrison, and Sioux City to Rulo reach of the Missouri River in 2014.

Omaha District H&H Bank Erosion Data (DD6, DR6, DM6)
The Gavins Point Degradation study, navagation channel bank recession report (2013), and Randall, Garrsion, and Gavins Point bankline mapping reports (2013) provide some data on bankline recession. Some bank erosion rates are reported in degradation studies. ARC GIS files of the Section 32/33 bank stabilization efforts are maintained by District GIS. Older RMA2 models of Shallow Water Habitat chutes and a few sandbars below Gavins Point have been surveyed. JET testing of bank material below Gavins Point in 2012 and SedFlume testing of sandbars in Lewis and Clark Lake (2012) provide additional data on bank erosion.

Omaha District H&H Bed Material and Sediment Data (QD3, QD4)
Gavins to Rulo bed surveys, other multiple degradation reports with historic data, CEIS. Sediment Strategies Report 2001.

Water Quality Data (QD1, QD2, QR1, QR2)
Long-term data collection, mainly at USGS gages but also in other locations. Data coverage is highly variable. Data is available at District Water Control Sections and downloadable from USGS NWIS (http://waterdata.usgs.gov/nwis/sw) for select gages. Water quality data is also available from EPA at (http://cfpub.epa.gov/surf/locate/index.cfm)

Historical Mapping and Reports (DD1)
40's and 50's-broad scale drainage analysis. J.M. Holbrook and Scott C. Lundstrom (USGS) MRC-mapped basin (2, 1800s). Various geologic mapping efforts can be found on Scott's website: http://esp.cr.usgs.gov/info/platte/missouri.html Data from some of the earlier geologic mapping efforts were digitized and are available through USACE (referenced by Chuck Sellmeyer - USACE). Suter reports to Congress in the 1890's following his mapping efforts of the Missouri River. These maps can be previewed at: http://www.historicmapworks.com/Atlas/US/16790/Missouri+River+Charts+1877+Major+Charles+R++Suter+Surveys/ Articles that reference Sutter, e.g.: http://www.sciencedirect.com/science/article/pii/S0022169404003282 http://www.tandfonline.com/doi/abs/10.1577/1548-8446(1987)012%3C0002%3ATTWMRW%3E2.0.CO%3B2 History MRC with Suter: http://www.mvd.usace.army.mil/mrc/history/index.php (Chuck Sellmeyer - USACE stated that the Corp has the digital maps, reports and imagery)

Floodplain Sediment Data Post-Flood (FD2, FD0, FR2)
Study after 1993 flood identified several new soil layers associated with flood event. An issue to note: soils in depositional areas should relate to topography, therefore elevation and soil survey dates should match to prevent misrepresentation of either changes in elevation or soil type. Tim Neigh (formerly of MDC) was contracted by NRCS to identify probable vegetation types based on soils. These were labeled as the 'reference state'.

Reports and Other Literature

Overview
This section of the report summarizes important reports and other literature used to support the habitat modeling and assessment for the EA. The Habitat Team is compiling relevant literature using Mendeley®, a free reference manager, PDF organizer and academic network software. In addition to the citations, Mendeley maintains source documents and extracts abstracts and keywords from each document. It also permits the assignment of the Tags the Team is using to categorize content.

The EA team has agreed to compile all report citations in an Endnote® database. This database will serve as an archival of literature used to support the EA, and will be made available in some, as-yet-undefined manner. References stored in the Mendeley database and cited in EA reports will be exported to an Endnote format for integration into the citation database.

The following section provides a summary of literature reporting on relevant modeling efforts identified by the Habitat Team's efforts to date. Abstracts of model studies are presented in alphabetical order according to author and are cited in the bibliography. Other relevant literature not otherwise cited in this report is listed in Appendix F. New references will be added over the course of the EA study.

Models and Model Studies

Overview
Many of the existing models have been discussed in previous sections of the report, so this section focuses on model studies or models that could be used to support the Effects Analysis but which have not previously been discussed in earlier sections of this report.

Numerical modeling of sediment flushing from Lewis and Clark Lake (Ahn, Yang, Boyd, Pridal, & Remus, 2013)

GSTARS4 was calibrated by simulating the historic record of management of the reservoir operation from 1975 through 1995. The measured bed profile from 1975 was used as the initial boundary condition for the simulation. Fifty-seven cross-sections surveyed in 1975, 1995 and 2007, respectively, along the 110 km of the study reach between Fort Randall and Gavins Point dam were available for this study. Using measured cross-section in 1975 as the initial channel boundary, GSTARS4 was run with the hydraulic and sediment data for 20 years of record in an attempt to match the 1995 measurements. The development of reservoir delta moves gradually toward the reservoir regime. However, scouring occurred due to the operation of Fort Randall dam in the upper river regime. At about 40 – 65 km upstream of Gavins Point dam, the thalweg bed profile changed faster than that in other parts due to sediment supply from the three tributaries, primarily from the Niobrara River. Water discharge from Fort Randall dam and water surface elevation on Lewis and Clark Lake at Gavins Point dam were used as upstream and downstream boundary conditions, respectively. Water surface elevation varied between 367 m and 369 m. Although the unsteady effect may not be significant, both steady and unsteady flow routings were conducted for comparison. An additional phase in ongoing with the study to migrate the model to HEC-RAS and further evaluate additional alternatives with an estimated completion date in FY 14.

Feasibility Investigation Hydrogeomorphic Modeling and Analyses Upper Mississippi River System Floodplain (Alton & Heitmeyer, 2007)

This report assesses the feasibility of conducting a Hydrogeomorphic Method (HGM) evaluation of ecosystem restoration and management options for the Upper Mississippi River System (UMRS). Objectives of the report are to: 1) identify the availability of historic data for use in developing HGM matrix models for the historic UMRS ecosystem, 2) identify the availability of current data for understanding changes to the UMRS ecosystem from historic condition, 3) identify current technology and expertise needed to develop HGM models and maps, and 4) assess the feasibility of developing HGM evaluations for the entire UMRS.

Measuring and predicting abundance and dynamics of habitat for piping plovers on a large reservoir (Anteau, Wiltermuth, Sherfy, & Shaffer, 2014)

Measuring habitat and understanding habitat dynamics have become increasingly important for wildlife conservation. Using remotely-sensed data, procedures were developed to measure breeding habitat abundance for the federally listed piping plover (Charadrius melodus) at Lake Sakakawea, North Dakota, USA. A model to predict habitat abundance based on past and projected water levels, vegetation colonization rates, and topography was also developed. Previous studies define plover habitat as flat areas (<10% slope) with ≤30% obstruction of bare substrate. Compared to ground-based data, remotely-sensed habitat classifications (≤30/>30% bare-substrate obstruction) were 76% correct and omission and commission errors were equal. Due to water level fluctuations, habitat abundance varied markedly among years (1986–2009) ranging from 9 to 5195 ha. The proportion of bare substrate declined with the number of years since a contour was inundated until 5 years ($\beta = -0.65$, SE = 0.05), then it stabilized near zero, and the decline varied by shoreline segment (5, 50, and 95 percentile were $\beta = -0.19$, SE = 0.05, $\beta = -0.63$, SE = 0.05, and $\beta = -0.91$, SE = 0.05, respectively). Years since inundated predicted habitat abundance well at shoreline segments (R2 = 0.77), but it predicted better for the whole lake (R2 = 0.86). The vastness and dynamics of plover habitat on Lake Sakakawea suggest that this is a key area for conservation of this species. Model-based habitat predictions can benefit resource conservation because they can (1) form the basis for a sampling stratification, (2) help allocate monitoring efforts among areas, and (3) help inform management through simulations or what-if scenarios.

Invited Paper: On the Use of Demographic Models of Population in Endangered Species Management (Beissinger et al., 2013)

Why demographic models should be used cautiously in Population Viability Analysis (PVA) with endangered species was examined. The structure, data requirements, and outputs of analytical, deterministic single-population, stochastic single-population, metapopulation, and spatially explicit models were reviewed. Predictions from quantitative models for endangered species are believed to be unreliable due to poor quality of demographic data used in most applications, difficulties in estimating variance in demographic rates, and lack of information on dispersal (distances, ages, mortality, and movement patterns). Unreliable estimates also arise because stochastic models are difficult to validate, environmental trends and periodic

fluctuations are rarely considered, the form of density dependence is frequently unknown but greatly affects model outcomes, and alternative model structures can result in very different predicted effects of management regimes. It is suggested that PVA (1) evaluate relative rather than absolute rates of extinction, (2) emphasize short-time periods for making projections, (3) start with simple models and choose an approach that data can support, (4) use models cautiously to diagnose causes of decline and examine potential routes to recovery, (5) evaluate cumulative ending functions and alternative reference points rather than extinction rates, (6) examine all feasible scenarios, and (7) mix genetic and demographic currencies sparingly. Links between recovery options and PVA models should be established by conducting field tests of model assumptions and field validation of secondary model predictions.

Discrete choice modeling of shovelnose sturgeon habitat selection in the Lower Missouri River (Bonnot et al., 2011)

Substantive changes to physical habitat in the Lower Missouri River, resulting from intensive management, have been implicated in the decline of pallid (Scaphirhynchus albus) and shovelnose (S. platorynchus) sturgeon. To aid in habitat rehabilitation efforts, we evaluated habitat selection of gravid, female shovelnose sturgeon during the spawning season in two sections (lower and upper) of the Lower Missouri River in 2005 and in the upper section in 2007. Discrete choice models were fitted within an information theoretic framework to identify selection of means and variability in three components of physical habitat. Characterizing habitat within divisions around fish better explained selection than habitat values at the fish locations. In general, female shovelnose sturgeon were negatively associated with mean velocity between them and the bank and positively associated with variability in surrounding depths. For example, in the upper section in 2005, a 0.5 m s^{-1} decrease in velocity within 10 m in the bank direction increased the relative probability of selection 70%. In the upper section fish also selected sites with surrounding structure in depth (e.g., change in relief). Differences in models between sections and years, which are reinforced by validation rates, suggest that changes in habitat due to geomorphology, hydrology, and their interactions over time need to be addressed when evaluating habitat selection. Because of the importance of variability in surrounding depths, these results support an emphasis on restoring channel complexity as an objective of habitat restoration for shovelnose sturgeon in the Lower Missouri River.

Two-Dimensional Modeling to Evaluate Shallow Water Habitat On the Missouri River (Boyd, 2011)

Two-dimensional hydraulic flow models were developed using the SMS/RMA2 modeling package to support dike modifications made to comply with recommendations made in the 2003 revised Biological Opinion issued by the USFWS. Extensive surveys were collected to accurately model existing conditions and new modifications that include dike notching, dike sills, and chevrons. Models were built for control bends and those with new modifications. The flow solutions indicate the extent of change in the flow regime and can be used as an indicator of future performance of similar structures. Sensitivity testing of the Hamburg Bend model resulted in a set of control parameters that effectively represent the flow dynamics on the Missouri River. These parameters can be used as a baseline when evaluating changes on the river due to structure modifications.

An experimental test and models of drift and dispersal processes of pallid sturgeon (Scaphirhynchus albus) free embryos in the Missouri River (Braaten et al., 2011)

Free embryos of wild pallid sturgeon Scaphirhynchus albus were released in the Missouri River and captured at downstream sites through a 180-km reach of the river to examine ontogenetic drift and dispersal processes. Free embryos drifted primarily in the fastest portion of the river channel, and initial drift velocities for all age groups (mean=0.66–0.70 ms–1) were only slightly slower than mean water column velocity (0.72 ms–1). During the multi-day long- distance drift period, drift velocities of all age groups declined an average of 9.7% day–1. Younger free embryos remained in the drift upon termination of the study; whereas, older age groups transitioned from drifting to settling during the study. Models based on growth of free embryos, drift behavior, size-related variations in drift rates, and channel hydraulic characteristics were developed to estimate cumulative distance drifted during ontogenetic development through a range of simulated water temperatures and velocity conditions. Those models indicated that the average free embryo would be expected to drift several hundred km during ontogenetic development. Empirical data and model results highlight the long-duration, long-distance drift and dispersal processes for pallid sturgeon early life stages. In addition, results provide a likely mechanism for lack of pallid sturgeon recruitment in fragmented river reaches where dams and reservoirs reduce the length of free-flowing river available for pallid sturgeon free embryos during ontogenetic development.

Modelling the Effects of River Flow on Population Dynamics of Piping Plovers (Charadrius Melodus) and Least Terns (Sternula Antillarum) Nesting on the Missouri River (Buenau, Hiller, & Tyre, 2013)

Reservoir management on the Missouri River has changed the flow regime that once created dynamic emergent sandbar habitat (ESH) for the interior least tern (Sternula antillarum) and piping plover (Charadrius melodus). High flows that create large amounts of ESH are now rare, but the remaining inter-annual variability in river stage has strong effects on the amount of ESH available for nesting shorebirds. The scarcity of habitat has led the United States Army Corps of Engineers to develop an adaptive management plan for the restoration of ESH to support nesting terns and plovers. We describe the stochastic simulation models of ESH, plover populations and tern populations used in the adaptive management process, and examine the effects of river flow on projected outcomes of habitat restoration. The population models are most sensitive to uncertainty in adult survival rates. Model validation against historical amounts of ESH and population sizes suggests the model is a reasonable predictor of future dynamics. Flow variability contributes as much uncertainty as parameter estimation error to plover model projections but negligible uncertainty to the tern model. Autocorrelation in flow between years has stronger effects on population outcomes than the intensity of habitat restoration effort does. We compared population outcomes after a habitat-creating flow with population outcomes following habitat restoration and found that large pulses of habitat creation produced similar or better outcomes in the short term than consistent but low habitat restoration. However, bird populations fared better in the long term with low levels of restoration when habitat-forming flows were rare.

Sediment Transport Modeling Of A Missouri River Bend With ADH (Buesing, 2010)

In an effort to determine how best to create shallow water habitat for pallid sturgeon on the Missouri River, the Lower Little Sioux bend has been modeled using Adaptive Hydraulics Modeling (ADH) software. Modified dike field and channel widening alternatives have been investigated. Hydrodynamic model runs without sediment transport were performed first to narrow down the list of alternatives to be modeled using the sediment transport capabilities of ADH. The relative differences in the results of the sediment transport modeling were used to estimate the amount of shallow water habitat that would be created (in the case of the modified dike field alternatives) or would be sustained after flood events (in the case of the

channel widening alternatives). In addition to the results of the Missouri River investigation, a number of ADH sediment transport lessons learned will be discussed during this presentation.

Channel Morphodynamics in Four Reaches of the Lower Missouri River , 2006 – 07 (Elliott, C.M., Reuter, J.M., and Jacobson, 2009)

Channel morphodynamics in response to flow modifications from Gavins Point Dam are examined in four reaches of the Lower Missouri River. Measures include changes in channel morphology and indicators of sediment transport in four 6 kilometer long reaches located downstream from Gavins Point Dam, near Yankton, South Dakota, Kenslers Bend, Nebraska, Little Sioux, Iowa, and Miami, Missouri. Each of the four reaches was divided into 300 transects with a 20-meter spacing and surveyed during the summer in 2006 and 2007. A subset of 30 transects was randomly selected and surveyed 7–10 times in 2006–07 over a wide range of discharges including managed and natural flow events. Hydroacoustic mapping used a survey-grade echosounder and a Real Time Kinematic Global Positioning System to evaluate channel change. Acoustic Doppler current profiler measurements were used to evaluate bed-sediment velocity. Results indicate varying amounts of deposition, erosion, net change, and sediment transport in the four Lower Missouri River reaches. The Yankton reach was the most stable over monthly and annual time-frames. The Kenslers Bend and Little Sioux reaches exhibited substantial amounts of deposition and erosion, although net change was generally low in both reaches. Total, or gross geomorphic change was greatest in the Kenslers Bend reach. The Miami reach exhibited varying rates of deposition and erosion, and low net change. The Yankton, Kenslers Bend, and Miami reaches experienced net erosion during the time period that bracketed the managed May 2006 spring rise event from Gavins Point Dam.

Precision of Population Viability Analysis (Ellner, Fieberg, Ludwig, & Wilcox, 2002)

Although population viability analysis (PVA) is widely used in setting conservation policy, there is disagreement about the usefulness of this method. Objections have been raised concerning the precision of predictions in view of the short time series of data available and the sensitivity of estimates of extinction risk to estimated parameters (Hamilton & Moller 1995; Taylor 1995; Groom and Pascual 1998; Ludwig 1999). Beissinger and Westphal (1998) reviewed the use of demographic models for endangered-

species management. They pointed out that poor data cause difficulties in parameter estimation, which in turn lead to unreliable estimates of extinction risk. There are additional problems with model validation, especially if all available data have been used to estimate parameters. Beissinger and Westphal (1998) recommend that PVA be used to evaluate relative rather than absolute extinction risk, that projections be made only over short time periods, and that simple models be used rather than complicated ones. Fieberg and Ellner (2000) showed that values of the quasiextinction probability—the probability of decline to a lower population threshold—for a simple model range between 80% and 5% as the value of the intrinsic growth Rate *r* varies between 0.03 and 0.02. Such a range in estimates of *r* is common for data sets of moderate size. They also show that a precise estimate of extinction probability over a horizon of *t* years requires between 5 *t* and 10 *t* years of data, and that similar results hold for agestructured models. In a recent article, Brook et al. (2000) used field data on declining species to test the accuracy and bias of PVA models for predicting extinction risk and concluded that "PVA is a valid and sufficiently accurate tool for categorizing and managing endangered species." The reasons for these differing assessments of the value of PVA were examined.

The Application of Conceptual Models to Ecosystem Restoration
(C. Fischenich, 2008)
Conceptual models are descriptions of the general functional relationships among essential com- ponents of an ecosystem. They tell the story of "how the system works" and, in the case of eco- system restoration, how restoration actions aim to alter those processes or attributes for the betterment of the system. As such, conceptual models can provide the Ecosystem Restoration Team with: a synthesis of the current understanding of how a system works, help in understanding and diagnosing the underlying problem, a basis for isolating cause and effect and simplifying complex systems, a common framework or "mental picture" from which to develop alternatives, a tool for making qualitative predictions of ecosystem response, a way to flag potential thresholds, from which system responses may accelerate or follow potentially unexpected or divergent paths, a means by which to outline further restoration, R&D, and computational efforts, a supplement to numerical models for assessing project benefits and impacts, a means of identifying appropriate monitoring indicators and metrics, and a basis for implementing adaptive management strategies
Most professionals rely heavily upon conceptual models, but few explicitly formulate and express the models such that they provide broad utility for

ecosystem restoration. Model building consists of determining system parts, choosing the relationships that link these parts, specifying the mechanisms by which the parts interact, identifying missing information, and exploring the model behavior (Heemskerk et al. 2003). The model building process can be as enlightening as the model itself, because it reveals what is known and what is unknown about the connections and causalities in the systems under study.

Regulated river modeling for climate change impact assessment : the Missouri River (Hotchkiss, Jorgensen, Stone, & Fontaine, 2000)

The Great Plains of the United States, drained primarily by the Missouri River, are very sensitive to shifts in climate. The six main stem dams on the Missouri River control more than one-half of the nearly 1.5 million square kilometer basin and can store three times the annual inflow from upstream. The dams are operated by the U.S. Army Corps of Engineers using a Master Manual that describes system priorities and benefits. The complex operational rules were incorporated into the Soil and Water Assessment Tool computer model (SWAT). SWAT is a distributed parameter rainfall-runoff model capable of simulating the transpiration suppression effects of CO2 enrichment. The new reservoir algorithms were calibrated using a 25-year long historic record of basin climate and discharge records. Results demonstrate that it is possible to incorporate the operation of a highly regulated river system into a complex rainfall-runoff model. The algorithms were then tested using extreme climate scenarios indicative of a prolonged drought, a short drought, and a ten percent increase in basin-wide precipitation. It is apparent that the rules for operating the reservoirs will likely require modification if, for example, upper-basin precipitation were to increase only ten percent under changed climate conditions.

Conceptualizing and Communicating Ecological River Restoration (R.B. Jacobson & Berkley, 2011)

A general conceptual model for communicating aspects of river restoration and management is presented. The model is generic and adaptable to most riverine settings, independent of size. The model has separate categories of natural and social-economic drivers, and management actions are envisioned as modifiers of naturally dynamic systems. The model includes a decision-making structure in which managers, stakeholders, and scientists interact to define management objectives and performance evaluation. The model depicts a stress to the riverine ecosystem as either (1) deviation in the

regimes (flow, sediment, temperature, light, biogeochemical, and genetic) by altering the frequency, magnitude, duration, timing, or rate of change of the fluxes or (2) imposition of a hard structural constraint on channel form. Restoration is depicted as naturalization of those regimes or removal of the constraint. The model recognizes the importance of river history in conditioning future responses. Three hierarchical tiers of essential ecosystem characteristics (EECs) illustrate how management actions typically propagate through physical/chemical processes to habitat to biotic responses. Uncertainty and expense in modeling or measuring responses increase in moving from tiers 1 to 3. Social-economic characteristics are shown in a parallel structure that emphasizes the need to quantify trade-offs between ecological and social-economic systems. Performance measures for EECs are also hierarchical, showing that selection of measures depend on participants' willingness to accept uncertainty. The general form is of an adaptive management loop in which the performance measures are compared to reference conditions or success criteria and the information is fed back into the decision-making process.

Hydrodynamic Simulations of Physical Aquatic Habitat Availability for Pallid Sturgeon in the Lower Missouri River, at Yankton, South Dakota, Kenslers Bend, Nebraska, Little Sioux, Iowa, and Miami, Missouri, 2006–07 (Jacobson, R., Johnson, H., and Dietsch, 2009)

The objective of this study was to assess the sensitivity of habitat availability in the Lower Missouri River to discharge variation, with emphasis on habitats that might support spawning of the endangered pallid sturgeon. We constructed computational hydrodynamic models for four reaches that were selected because of evidence that sturgeon have spawned in them. The reaches are located at Miami, Missouri (river mile 259.6–263.5), Little Sioux, Iowa (river mile 669.6– 673.5), Kenslers Bend, Nebraska (river mile 743.9–748.1), and Yankton, South Dakota reach (river mile 804.8–808.4). The models were calibrated for a range of measured flow conditions, and run for a range of discharges that might be affected by flow modifications from Gavins Point Dam. Model performance was assessed by comparing modeled and measured water velocities. A selection of derived habitat units was assessed for sensitivity to hydraulic input parameters (drag coefficient and lateral eddy viscosity). Overall, model results were minimally sensitive to varying eddy viscosity; varying lateral eddy viscosity by 20 percent resulted in maximum change in habitat units of 5.4 percent. Shallow-water habitat units were most sensitive to variation in drag coefficient with 42 percent change in unit area

resulting from 20 percent change in the parameter value; however, no habitat unit value changed more than 10 percent for a 10 percent variation in drag coefficient. Sensitivity analysis provides guidance for selecting habitat metrics that maximize information content while minimizing model uncertainties. To assess model sensitivities arising from topographic variation from sediment transport on an annual time scale, we constructed separate models from two complete independent surveys in 2006 and 2007. The net topographic change was minimal at each site; the ratio of net topographic change to water volume in the reaches at 95 percent exceedance flow was less than 5 percent, indicating that on a reach-average basis, annual topographic change contributed little to habitat area variation. Net erosion occurred at Yankton (the upstream reach) and because erosion was distributed uniformly, there was little affect on many habitat metrics.

Topographic change was spatially nonuniform at Little Sioux and Kenslers Bend reaches. Shallow water habitat units and some reach-scale patch statistics (edge density, patch density, and Simpson's Diversity Index) were affected by these changes. Erosion dominated at the downstream reach but habitat metrics did not vary substantially from 2006 to 2007. Among habitat metrics that were explored, zones of convergent flow were identified as areas that most closely correspond to spawning habitats of other sturgeon species, as identified in the scientific literature, and that are consistent with sparse data on pallid sturgeon spawning locations in the Lower Missouri River. Areas of convergent zone habitat varied little with discharges that would be associated with spring pulsed flows, and relations with discharge changed negligibly between 2006 and 2007.

Other habitat measures show how physical habitat varies with discharge and among the four reaches. Wake habitats defined by velocity gradients seem to correspond with migration pathways of adult pallid sturgeon. Habitats with low Froude-number correspond to low energy areas that may accumulate passively transporting particles, organic matter, and larval fish. Among the modeled reaches, Yankton had substantially longer water residence time for equivalent flow exceedances than the other three modeled reaches. Longer residence times result from greater flow resistance in the relatively wide, shallow channel and may be associated with longer residence times of passively transported particulate materials.

Impacts of climate change on streamflow in the Upper Mississippi River Basin: A regional climate model perspective (Jha, Pan, Takle, and Gu 2004)

Impact of climate change on streamflow in the Upper Mississippi River Basin is evaluated by use of a regional climate model (RCM) coupled with a hydrologic model, Soil and Water Assessment Tool (SWAT). The RCM we used resolves, at least partially, some fine-scale dynamical processes that are important contributors to precipitation in this region and that are not well simulated by global models. The SWAT model was calibrated and validated against measured streamflow data using observed weather data and inputs from the U.S. Environmental Protection Agency Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) geographic information systems/database system. Combined performance of SWAT and RCM was examined using observed weather data as lateral boundary conditions in the RCM. The SWAT and RCM performed well, especially on an annual basis. Potential impacts of climate change on water yield and other hydrologic budget components were then quantified by driving SWAT with current and future scenario climates. Twenty-one percent increase in future precipitation simulated by the RCM produced 18% increase in snowfall, 51% increase in surface runoff, and 43% increase in groundwater recharge, resulting in 50% net increase in total water yield in the Upper Mississippi River Basin on an annual basis. Uncertainty analysis showed that the simulated change in streamflow substantially exceeded model biases of the combined modeling system (with largest bias of 18%). While this does not necessarily give us high confidence in the actual climate change that will occur, it does demonstrate that the climate change "signal" stands out from the climate modeling (global plus regional) and impact assessment modeling (SWAT) "noise."

Hydroecological modeling of the Lower Missouri River (Johnson, Jacobson, and DeLonay, 2006)

Spatially Referenced Regression On Watershed attributes (SPARROW) models were developed to provide spatially explicit information on local and regional total nitrogen and total phosphorus sources and transport in the Missouri River Basin. Model results provide estimates of the relative contributions from various nutrient sources and delivery factors. The models also describe instream decay and reservoir and lake attenuation of nutrients. Results aid in the prioritization of nutrient-reduction strategies by identifying major sources and delivery factors contributing to instream nutrient loads and stream reaches carrying the largest nutrient loads.

Implications Of Alternative Missouri River Flows For Power Plants (Kruse & Womack, 2004)

The purpose of this paper is to discuss the potential impacts of low Missouri River flows on the power plants operating along the Missouri River and using the Missouri River for cooling water. There are nine power companies that operate the eighteen power plants using water from the Missouri River for cooling purposes. Of these nine companies, seven agreed to participate in this study including plants in Missouri, Kansas and Nebraska. Mid American Energy, who operates the three power plants in Iowa that use the Missouri River for cooling water, and Nebraska Public Power Diistrict declined to participate in the study. The results discussed in this paper apply only to the seven participating companies.

Integrated environmental modeling: A vision and roadmap for the future (Laniak et al., 2013)

Integrated environmental modeling (IEM) is inspired by modern environmental problems, decisions, and policies and enabled by transdisciplinary science and computer capabilities that allow the environment to be considered in a holistic way. The problems are characterized by the extent of the environmental system involved, dynamic and interdependent nature of stressors and their impacts, diversity of stakeholders, and integration of social, economic, and environmental considerations. IEM provides a science-based structure to develop and organize relevant knowledge and information and apply it to explain, explore, and predict the behavior of environmental systems in response to human and natural sources of stress. During the past several years a number of workshops were held that brought IEM practitioners together to share experiences and discuss future needs and directions. In this paper we organize and present the results of these discussions. IEM is presented as a landscape containing four interdependent elements: applications, science, technology, and community. The elements are described from the perspective of their role in the landscape, current practices, and challenges that must be addressed. Workshop participants envision a global scale IEM community that leverages modern technologies to streamline the movement of science-based knowledge from its sources in research, through its organization into databases and models, to its integration and application for problem solving purposes. Achieving this vision will require that the global community of IEM stakeholders transcend social, and organizational boundaries and pursue greater levels of collaboration. Among the highest

priorities for community action are the development of standards for publishing IEM data and models in forms suitable for automated discovery, access, and integration; education of the next generation of environmental stakeholders, with a focus on transdisciplinary research, development, and decision making; and providing a web-based platform for community interactions (e.g., continuous virtual workshops).

Potential Effects of Long-Lead Hydrologic Predictability on Missouri River Main-Stem Reservoirs (Maurer & Lettenmaier, 2004)

Understanding the links between remote conditions, such as tropical sea surface temperatures, and regional climate has the potential to improve streamflow predictions, with associated economic benefits for reservoir operation. Better definition of land surface moisture states (soil moisture and snow water storage) at the beginning of the forecast period provides an additional source of streamflow predictability. The value of long-lead predictive skill added by climate forecast information and land surface moisture states in the Missouri River basin is examined. Forecasted flows were generated that represent predictability achievable through knowledge of climate, snow, and soil moisture states. For the current main-stem reservoirs (90 × 109 m3 storage volume) only a 1.8% improvement in hydropower benefits could be achieved with perfect forecasts for lead times up to one year. This low value of prediction skill is due to the system's large storage capacity relative to annual inflow. To evaluate the effects of hydrologic predictability on a smaller system, a hypothetical system was specified with a reduced storage volume of 36 × 109 m3. This smaller system showed a 7.1% difference in annual hydropower benefits for perfect forecasts, representing $25.7 million. Using realistic streamflow predictability, $6.8 million of the $25.7 million are realizable. The climate indices provide the greatest portion of the $6.8 million, and initial soil moisture information provides the largest increment above climate knowledge. The results demonstrate that use of climate forecast information along with better definition of the basin moisture states can improve runoff predictions with modest economic value that, in general, will increase as the size of the reservoir system decreases.

Evaluation Of The Missouri River Shallow Water Habitat Using a 2d-Hydrodynamic Model (Papanicolaou, Dermisis, & Young, 2011)

Many of the Upper Missouri River dikes have been notched to create additional shallow water habitat (SWH, operationally defined as areas in the stream with depth<1.5 m, and velocity<0.75ms^{-1}) for fish populations. The goal of this study was to quantify the additional SWH gained from notching these dikes and to evaluate their performance under different flow conditions. A coupled field and numerical study was performed on a reach of the Missouri River, near Nebraska City, NE, which contains a number of dikes notched in 2004. The numerical simulations showed that the SWH criterion for depth was more difficult to satisfy in the study reach than the SWH criterion for velocity. Notching the dikes resulted in a slight shift of the bankline due to local erosion in the vicinity of the dikes and the formation of scour holes downstream of the notches. Results from the study suggested that notching the dikes had limited impact on the SWH because the area gained from the bankline shift was offset by the area lost from the scour holes formation. The performance of the notched dikes in sustaining the minimum habitat suitability conditions for the Missouri River ecosystem was also investigated. These conditions corresponded to discharges<709m^{3} s^{-1} for the period from mid-July to mid-August, or equivalently SWH areas>5225m^{2} dike^{-1} during the same period. Analysis of the Missouri River annual discharge records at the study site showed that the dikes can provide the minimum required SWH for mean annual discharges<667m$^{3/}$s. For mean annual discharges> 667m^{3} /s, new alternative structures or restoration facilities were needed, in addition to the existing dikes, to sustain the minimum required SWH. The dikes were not effective in providing any SWH for mean annual discharges>2000cms.

Two-Dimensional Modeling Applications for use with Missouri River Restoration (Pridal, Remus, & Boyd, 2007)

The Missouri River Biological Opinion (2000) and the Amended Biological Opinion (2003) set forth the requirements for the creation of Missouri River shallow water habitat. A significant physical monitoring and modeling effort has been undertaken in conjunction with habitat creation. Numerous bend length two-dimensional models have been constructed with successful reproduction of hydraulics at the structure level. This paper describes the application of two-dimensional analysis at several sites along the Missouri River in support of the shallow water habitat program. The merits of two-dimensional models, model selection, ability to replicate observed

hydraulics, classification of shallow water habitat with the model, design and analysis of habitat construction methods are presented.

Retro-modeling the Middle Mississippi River (Remo & Pinter, 2007)

A one-dimensional (1-D) unsteady-flow ‘‘retro-model’’ was developed using historic (c. 1900) hydrologic and geospatial data and implemented using HEC-RAS. The objective of this investigation was to create a 1-D unsteady-flow model for the Middle Mississippi River for the beginning of the 20th century in order to assess the magnitude and types of changes in flood stages associated with 20th century river engineering. The retro-model was constructed from survey data dating to 1888–1889 and hydrologic data from 1900 to 1904. The late 19th century survey data was supplemented by a modern high-resolution DEM used to fill gaps in the historic data. Land-cover data recorded during this historic survey was used to establish floodplain roughness values based on published Manning’s n for the various land-cover types, and these roughness values were then adjusted to calibrate the model. Comparison of the retro-model results with the 2004 Upper Mississippi River System Flow Frequency Study (UMRSFFS) flood stages showed increases in flood stages of 2.3–4.7 m for large events (>50-year recurrence interval). These results confirm previous research results showing large-scale reductions in flood conveyance on the Middle Mississippi during the 20th century. Increased roughness of the floodway coupled with reduction in channel and floodplain area due to wing dike and levee construction are the likely explanation for the observed increases in flood stages. Between 1889 and 1998, channel widths through the study reach decreased $40%, and floodplain area for the 100-year flood decreased by $60%. In addition, Manning’s n values in the retro-model were lower than the values used in the UMRSFSS, suggesting that (1) the modern floodway is rougher than the historic floodway, (2) this increased roughness is not a result of explicit changes in land cover, but rather (3) the increase is a result of implicit roughness changes such as wing dike construction. The retro-model developed in this investigation provides a framework for modeling hydrodynamic and ecological responses to altered hydrologic regimes during more than a hundred years of channel modification.

The use of retro- and scenario-modeling to assess effects of 100+ years river of engineering and land-cover change on Middle and Lower Mississippi River flood stages (Remo, Pinter, & Heine, 2009)

Since the 19th century, the Middle and Lower Mississippi River (MMR and LMR) have been intensively modified for flood protection and commercial navigation. In order to quantify the effects of levee expansion, channel modification, and land-cover change upon flood stages, we have developed 1-D unsteady- flow models of multiple historical reference conditions (‘‘retro-models”) for three large study reaches (225–315 km each): one along the MMR and two reaches along the LMR. For each reference condition, four 1-D unsteady-flow models were developed. These models include a calibrated model of actual conditions and three ‘‘scenario” models: (1) a model with levees of the next time step, (2) a model with the channel geometry of the next time step, and (3) a model with floodplain roughness (i.e., land cover) of the next time step. Comparison of the model for actual conditions and the scenario models provide a quantitative assessment of levee expansion, channel modification, and land-cover change on stage. Scenario modeling suggests that the majority (38–70%) of the changes in flood stage on the LMR and MMR study reaches can be attributed to changes in channel geometry and hydraulic roughness. Levees were the next largest contributor to changes in flood stage. For time steps with significant levee expansion, these structures increase stage up to 1.0 m. Observed changes in floodplain land cover were associated with little (or none) of the increase in flood stage. These result show changes in channel geometry and roughness related to river engineering tools employed for improving navigation and flood protection are the principal drivers of historic changes in flood stages along these investigated reaches.

Incorporating Bank-Toe Erosion by Hydraulic Shear into the ARS Bank-Stability Model: Missouri River, Eastern Montana (Simon, Collison, and Layzell, 2003)

Bank-stability concerns along the Missouri River, eastern Montana are heightened by a proposed change in flow releases from Ft Peck dam to improve habitat conditions for Pallid Sturgeon. The effects of the proposed flow releases on streambank pore-pressures and bank-toe erosion needs to be evaluated to properly model bank-stability. The ARS Bank-Stability Model incorporates pore-water pressure distributions, layering, confining pressures, reinforcement effects of riparian vegetation and complex bank geometries to solve for the factor of safety (F_s). To increase the applicability

and accuracy of the model for use in predicting critical conditions the hydraulic effects of bank-toe erosion have been added. Upper-bank stability is often a function of the degree of fluvial undercutting that occurs during rises in stage when the bank toe becomes submerged and steepened. This erosion, which is a function of the erodibility of previously failed materials and *in situ* sediments at the toe has been difficult to measure or estimate in the field. Recent field research on erosion of *in situ* cohesive streambeds and bank toes with a submerged jet-test device provides a means of calculating bank-toe erosion. Results of almost 200 tests at stream sites across the United States provide the following general relation: $k = 0.1\ \tau_c^{\ -0.5}$; where k = erodibility coefficient in cm^3/N-s and τ_c = critical shear stress in Pa. Critical shear stresses are obtained *in situ* with the jet-test device (92 tests) for bank-toe materials along the Missouri River, Montana to obtain k and to calculate an erosion rate based on an excess shear-stress relation: $\varepsilon = k\ (\tau - \tau_c)$; where ε = erosion rate in m/s and τ = average boundary shear stress in Pa. Inputs for the bank-toe erosion routine are: (1) a rectangular-shaped hydrograph of specified height and duration, (2) bed or water-surface slope, (3) flow depth, (4) bank geometry, and (5) τ_c for all bank layers and failed debris. Erosion is simulated normal to the submerged bank surface and the resulting bank geometry serves as input into the bank-stability part of the model.

Impacts of climate change on Missouri River Basin water yield (Stone et al., 2001)

Water from the Missouri River Basin is used for multi- ple purposes. The climatic change of doubling the atmospheric car- bon dioxide may produce dramatic water yield changes across the basin. Estimated changes in basin water yield from doubled CO2 climate were simulated using a Regional Climate Model (RegCM) and a physically based rainfall-runoff model. RegCM output from a five-year, equilibrium climate simulation at twice present CO2 levels was compared to a similar present-day climate run to extract monthly changes in meteorologic variables needed by the hydrologic model. These changes, simulated on a 50-km grid, were matched at a commensurate scale to the 310 subbasins in the rainfall-runoff model climate change impact analysis. The Soil and Water Assessment Tool (SWAT) rainfall-runoff model was used in this study. The climate changes were applied to the 1965 to 1989 historic peri- od. Overall water yield at the mouth of the Basin decreased by 10 to 20 percent during spring and summer months, but increased during fall and winter. Yields generally decreased in the southern portions of the basin but increased in the northern reaches. Northern sub-basin yields increased up to 80 percent: equivalent to 1.3 cm

of runoff on an annual basis. For example, crops and agricultural production cover approximately 46 percent of the Missouri River Basin, of which 5 percent is irrigated (Srinivasan et al., 1994). These and other water resource needs make the Missouri River Basin extremely vulnerable to any hydrologic impacts of climate change. A complete method has been developed for analyzing the impacts of climate change on water resources using a continuous daily time step model that numerically routes the water yield through the Missouri River Basin. The Soil and Water Assessment Tool (SWAT) has been modified to incorporate data from a Regional Climate Model (RegCM). The objectives of this paper are to describe a reproducible method for evaluating climate change impacts on the Missouri River Basin and to analyze climate change impacts on basin water yields.

Water yield responses to high and low spatial resolution climate change scenarios in the Missouri River Basin (Stone, Hotchkiss, and Mearns)

Water yield responses to two climate change scenarios of different spatial scales were compared for the Missouri River Basin. A coarse-resolution climate change scenario was created from runs of the Commonwealth Scientific and Industrial Research Organization General Circulation Model (CSIRO GCM). The high-resolution climate change scenario was developed using runs of the Regional Climate Model RegCM, for which the GCM provided the initial and lateral boundary conditions. Water yield responses to the high- and low-resolution climate change scenarios were investigated using the Soil and Water Assessment Tool (SWAT). Basinwide water yield increased for both GCM and RegCM scenarios but with an overall greater increase for the RegCM scenario. Significant differences in water yields were found between the GCM and RegCM climate scenarios.

Extending a prototype knowledge- and object-based image analysis model to coarser spatial resolution imagery : an example from the Missouri River (Strong, 2012)

A prototype knowledge- and object-based image analysis model was developed to inventory and map least tern and piping plover habitat on the Missouri River, USA. The model has been used to inventory the state of sandbars annually for 4 segments of the Missouri River since 2006 using QuickBird imagery. Interpretation of the state of sandbars is difficult when images for the segment are acquired at different river stages and different states of vegetation phenology and canopy cover. Concurrent QuickBird and RapidEye images were classified using the model and the spatial

correspondence of classes in the land cover and sandbar maps were analysed for the spatial extent of the images and at nest locations for both bird species. Omission and commission errors were low for unvegetated land cover classes used for nesting by both bird species and for land cover types with continuous vegetation cover and water. Errors were larger for land cover classes characterized by a mixture of sand and vegetation. Sandbar classification decisions are made using information on land cover class proportions and disagreement between sandbar classes was resolved using fuzzy membership possibilities. Regression analysis of area for a paired sample of 47 sandbars indicated an average positive bias, 1.15 ha, for RapidEye that did not vary with sandbar size. RapidEye has potential to reduce temporal uncertainty about least tern and piping plover habitat but would not be suitable for mapping sandbar erosion, and characterization of sandbar shapes or vegetation patches at fine spatial resolution.

Ecological Modeling Guide for Ecosystem Restoration and Management (Swannack et al., 2012)

Ecological models are important tools for planning ecosystem restoration and management activities. Models help to organize thinking, conceptualize understanding of complex systems, and forecast environmental benefits that may result from proposed restoration and management actions. This report provides information to guide environmental planers in selection, development, evaluation, and documentation of ecological models. A number of critical issues are addressed, including specifying objectives and formulating a sound conceptual model, choosing among types of models, deciding when to develop a new model, systematically evaluating the quantitative model, addressing parameter and model uncertainty, developing sections of the model through iteration, analyzing alternatives, and documenting results. Quantitative modeling is shown to be a dynamic process that is best served using an iterative approach. In practice, individual parts of a conceptual model are quantified and evaluated in a stepwise fashion until the entire model is captured quantitatively. This iterative approach creates transparency in model development, which can remove the “black-box” stigma that has been associated with the use of models in the environmental sciences.

Daily Routing Model (DRM) (USACE Omaha District, No Date)

The DRM is a daily hydrologic model of the Missouri River system currently used by NWD Water Management. It is used simulate and evaluate alternative Mainstem operations for all authorized purposes under a widely

varying long-term hydrologic record. The DRM currently uses historic period of record from 1898 to 2012 (2011 is difficult to model), consists of 20 node locations, including the six System dams and 14 gaging stations on the Missouri River. The DRM uses two sets of input data and a number of smaller data files. The first data set consists of historic reach inflows and streamflow depletions. There is also an option to include forecasted monthly runoff. The second data set contains various constants and variable parameters that define regulation decisions and operational limits for a particular simulation. These include downstream flow targets, reservoir characteristics, regulation levels, regulation guide curves, power generation criteria, navigation guide criteria, and fish and wildlife criteria, including endangered and threatened species.

Missouri River from Gavins Point Dam to Ponca (RM 811 to 752) Evaluation of Flow Obstructions to Create Sandbar Habitat (West Consultants, 2012)

The U.S. Army Corps of Engineers (USACE) Omaha District implements an Emergent Sandbar Habitat (ESH) construction program to create nesting habitat for the interior least tern (Sternula antillarum) and piping plover (Charadius melodus) bird populations. ESH refers to exposed, inter-channel sandbars. In contrast to islands, ESH complexes are temporary formations and comparatively dynamic in nature. In the present study, USACE tasked WEST Consultants to evaluate alternative structures and materials for obstructing flow and thereby creating ESH as nesting habitat for the two shorebird species. The project area lies within part of a reach designated as "critical habitat" for the interior least tern and piping plover. The Federal government is required by the Endangered Species Act (ESA) to provide critical habitat for any species listed under the ESA. Both birds were listed in the mid 1980's as either Federally Endangered (interior least tern) or Threatened (piping plover). Since that time, USACE and the U.S. Fish and Wildlife Service (USFWS) began consultation on how to improve operations on the Missouri River to benefit the species. The current study is focused on improving nesting habitat along the critical habitat reach from Gavins Point Dam to Ponca (River Mile 811 to 752).

Identifying structural elements needed for development of a predictive life-history model for pallid and shovelnose sturgeons (Wildhaber, DeLonay, et al., 2011)

Intensive management of the Missouri and Mississippi Rivers has resulted in dramatic changes to the river systems and their biota. These changes have

been implicated in the decline of the pallid sturgeon (Scaphirhynchus albus), a United States federal endangered species. The sympatric shovelnose sturgeon (S. platorynchus) is more common and widespread but has also been in decline. The decline of pallid sturgeon is considered symptomatic of poor reproductive success and low or no recruitment. In order to organize information about these species and provide a basis for future development of a predictive model to help guide recovery efforts, we present an expert-vetted, conceptual life-history framework that incorporates the factors that affect reproduction, growth, and survival of shovelnose and pallid sturgeons.

Sediment Management Study (LCLSMS) Lewis and Clark Lake Sediment Management Study : Sediment Transport and Flow Analysis with GSTARS4 (Yang, 2013)

Drawdown flushing will be applied to the Lewis and Clark Lake sedimentation studies. The Generalized Sediment Transport model for Alluvial River Simulation (GSTARS) can be used to evaluate the efficiency of a sediment management plan by drawdown flushing. GSTARS3, the latest official version of GSTARS model, has been tested by many independent researchers and shown to predict channel geomorphic changes, for common cases, successfully. However, GSTARS3 is based on simplified modeling of very complex flow conditions, as well as sediment entrainment, transport, and deposition processes. In general, these simplified assumptions are valid, but GSTARS3 cannot be applied to unsteady flow conditions, because it is not a truly unsteady model. A new model, GSTARS4, was developed for drawdown flushing simulations, based on GSTARS3 model. A major improvement of GSTARS4 model is that the model can simulate truly unsteady flow.

Lewis and Clark Lake Sediment Management Study (LCLSMS); Part I: Summary Report on Evaluating Hydraulic Transport of Missouri River Delta Sediments (USACE Omaha District, 2013)

Two sediment transport numerical models were developed to predict the movement of sediment through and below Gavins Point Dam. The Lewis and Clark Lake Model used the GSTARS4 code to predict sediment transport through the Missouri River delta and past the spillway at Gavins Point Dam. The model extends from Fort Randall Dam (RM 880) to Gavins Point Dam (RM 811). The Gavins Point Dam to Sioux City, IA model used the HEC-RAS model to route the lake model flow and sediment output through the recreational river reach below the dam and deliver to the downstream navigation channel. This downstream model extends from Gavins Point Dam (RM 811) to Sioux City, IA (RM 730).

Lewis and Clark Lake Sediment Management Study (LCLSMS) Part III: HEC-RAS Sediment Modeling from Gavins Point Dam to Sioux City, IA (USACE Omaha District, 2013)
This report discusses the mobile bed hydraulic and sediment models developed between Gavins Point Dam and Sioux City, IA on the Missouri River. The goal is to evaluate impacts to the river channel and floodplain that may be caused by the scenarios modeled in the GSTARS4 Lewis and Clark Lake model.

Other Information Supporting Habitat Analysis for the EA

The EA Habitat team has compiled a large number of literature references not cited in this report but that, nonetheless, may prove useful in executing the modeling tasks. Additionally, we are aware of resources (references, imagery, databases, tools, etc.) not reported in this draft. We will continue to review and evaluate those materials and include the information in our studies and this summary as warranted.

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Appendix A –Effects Analysis Task 2 and Task 3 Descriptions

Task 2 - Compile and assess existing data and modeling resources that can be applied to the Analysis.

To ensure the Analysis relies on the best available scientific data, it will be necessary to acquire and critically evaluate relevant existing data sets, including accompanying analyses and findings to determine their reliability for use in guiding model development or parameterizing models. It will also be necessary to consider the utility of existing models or tools for use in the Analysis, and identify critical gaps that require new models be developed or existing models revised. This step should also identify any necessary boundary conditions for the models.

a. Gather and assess the utility of existing information for use in the analysis. This will include review of relevant data, results from pertinent analyses and findings from research and monitoring data specific to the listed species and the Missouri River system; data from these species and other locations; and other species in other locations. Critically assess the reliability of individual data sets and the robustness of the overall data for the purposes of conducting the Analysis. The utility of each data source will be explained.

b. Identify existing models (or models under development) that could reasonably be applied to the Analysis. Conduct a gap assessment to determine the need for model adaptation/development to fill areas where existing models cannot reasonably be used. Ensure that selected models will be capable of integration (to a reasonable degree) and that they can be applied at the temporal and spatial scales of interest. Candidate models (existing and needed) will be further evaluated as part of Step 5. Analyze available information on river operations. Organize and synthesize information on hydrodynamics of the river system, including dam operation rules, to determine the best method for scenario evaluation. Incorporate the necessary operations rule sets into the ResSim models, and ensure that the model behavior is consistent with expectations. Determine a range of reasonable operation rules for the models when considering simulations outside the range covered by the current Master Manual.

c. Identify critical modeling or data gaps that may not be resolved within the established timeframe for the Analysis. Determine what steps might be taken to remedy the problem over the long-term (including lines-of-evidence and causal criteria approaches), and establish the impact to the near-term implementation of the Effects Analysis.

Task 3 - Development of predictive, quantitative versions of the conceptual models to explore the relationships and responses of system, actions and species.

These models will essentially operationalize the CEMs and permit quantitative assessments of species responses to management actions, accounting for the importance of specific relationships and the uncertainty identified in the conceptual models. These models will be developed by the experts within the analysis team with support from the MRRP staff and regional expertise. The end product will be a suite of models to conduct the needed assessments. The basic framework for the model suite will be species demographic models connected to habitat and flow models that account for both management actions and stressors, with focus on stressors directly influenced by dam operations and recovery actions. The model suite must reasonably reflect the spatial and temporal distribution and variability of flows, habitats and species.

a. The primary quantitative model for species will be a Population Viability Analysis (PVA) model. These models will include species responses to habitat alterations as well as direct management interventions. The models will include uncertainty, including estimation error and environmental variability, as random variables in order to provide estimates of the resulting uncertainty in model predictions and allow for statistical validation and potentially for comparison of management alternatives.

i. Gather best available data and existing models as applicable
ii. Determine structure of each individual species model
iii. Estimate parameters and associated uncertainty
iv. Build model and test general model response
v. Perform sensitivity analysis and identify key parameters

b. Hydrology and hydraulics of the Missouri River system are thought to be fundamental transmitters of stress, connecting management actions to habitats and species' responses. Hence, these models carry considerable importance in understanding driver-stressor-effects relations. The primary

models for hydrology and hydraulics are anticipated to be a suite of HEC models (ResSim, HEC-RAS, HEC-EFM, etc.) that account for system operation and management actions in terms relevant to the PVA models. The models will be built and operated at an appropriate spatial and temporal resolution to reasonably gauge shifts in habitat conditions and associated ecological responses for the listed species, as dictated by the needs of the species models.

c. Calibration and validation (where possible) of the models to confirm that results are consistent with observed responses or best current understanding.

Appendix B – Conceptual Ecological Models[3]

<Insert Models In Final Document Draft>

[3] Note: Models presented in this appendix are those submitted for review by the ISAP in January, 2014. These models do not reflect subsequent revision based upon comments from the ISAP.

Appendix C – Human Considerations Objectives and Metrics

Table C1. List of human consideration objectives and metrics (March 14, 2014 Draft list)

ID	Objective	Metrics
EQ1	Changes in native Fish and Wildlife species and habitats	Percent similarity of select aquatic habitat variables and floodplain habitat type distribution for each alternative relative to a best attainable condition
EQ2	Effect to the preservation of cultural resources, particularly protection against unmitigated losses	Description (probably qualitative or using a constructed scale) of protection of and losses to cultural resources (distinguishing between losses that can and cannot be mitigated)
NED1	Agriculture-related impacts to national economic development (NED)	1. Percentage of time for which an interior drainage structure is inundated (and a flap gate closed, for example) as an indicator of risk for interior flooding
		2. Net income to farmers measured through a farm budget analysis
		3. Expected annual damages to non-crop agricultural resources (barns, fences, equipment, land forming/leveling, farm supplies, and farm roads, etc.) based on typical non-crop damages per flooded acre multiplied by average number of crop acres impacted
NED2	Commercial Sand Dredging-related impacts to NED	
	1. Changes in transportation savings	Transportation rate savings measured by commodity group and dollars per ton [categories of transportation rate savings include cost of using the waterway, shift of mode, shift of origin destination, and new movement]
	2. Changes in non-routine repair, replacement, and rehabilitation (RR&R) costs to maintain authorized channel	Non-routine RR&R costs (dollars/year)
NED3	Changes in Flood Risk Management effects on NED	
	1. Effects of changes in flood risk to property and infrastructure	Estimated change in flood damages to property (including equipment and inventories such as crops) and infrastructure, as well as clean-up, emergency and related costs (measured in dollars/year)
	2. Effects of changes in flood risk on non-routine OMRR&R (operation, maintenance, repair, replacement and rehabilitation) costs	Estimated change in non-routine OMRR&R costs (measured in dollars/year) for levees, channel, etc.
NED4	Hydropower-related impacts to NED	
	1. Changes in energy value of existing hydropower facilities	Replacement Energy benefits are computed as the product of the energy loss in megawatt-hours and an energy unit value price (dollars/MWh)
	2. Changes in capacity value of existing hydropower facilities	The dependable capacity of a hydropower project is a measure of the amount of capacity that the project can

		reliably contribute towards meeting system peak power demands. This is computed as the product of a capacity value (MW) and a capacity unit value (dollars/MW) representing the value of the most likely thermal alternative
NED5	Irrigation-related impacts to NED	
	1. Changes in farm net income from irrigated acreage	Estimated changes in net farm income in dollars per year based on changes in irrigation operations; either in terms of increased or decreased costs of using intakes or from loss or gain of irrigated acreage once operating has become cost prohibitive
	2.Changes in non-routine RR&R costs	Non-routine RR&R costs for intakes (dollars/year)
NED6	Navigation-related impacts to NED	
	1. Changes in transportation savings	Transportation rate savings measured by commodity group and dollars per ton [categories of transportation rate savings include cost of using the waterway, shift of mode, shift of origin destination, and new movement]
	2. Changes in non-routine RR&R costs to maintain the authorized channel	Non-routine RR&R costs (dollars/year)
	3. Middle Mississippi River (St. Louis to mouth of Ohio River near Cairo, IL) navigation impacts	TBD, possibly qualitative assessment using a constructed scale
NED7	Impacts to NED from Recreation benefits	
	1. Changes in recreation visitation	Visitors per year [includes accounting for the percent of time boat ramps are not functional, percent of time floodplain facilities are not accessible, and quality of aquatic and floodplain habitat]
	2. Changes in values of recreation enjoyment per day per visitor	Unit Day Values (dollars per day per visitor) [includes (1) the variety and quality of the recreational activities, (2) availability of similar sites nearby, (3) accessibility to and within the site, (4) adequacy of facilities, and (5) esthetics/other environmental factors]
	3. Changes in non-routine RR&R costs	Non-routine RR&R costs (dollars/year) [includes ramp extensions, new access roads/parking, and RR&R of damaged facilities due to changes in water levels]
NED8	Thermal Power-related impacts to NED	
	1. Changes in operational costs (including the need to purchase additional power from the grid) due to changes in thermal power operating conditions	Estimated changes in operating costs in dollars per year for thermal power production
	2. Non-routine repair, replacement, or modification (capital costs)	Non-routine repair, replacement, or modification costs including any costs over and above actual construction costs, such as permitting costs (dollars/year)
NED9	Changes in non-routine OMRR&R from Wastewater-related impacts to national economic development (NED)	Non-routine OMRR&R costs (dollars/year) [includes changes in permit requirements, discharge extensions, and RR&R of damaged facilities due to changes in water levels]
NED10	Water Supply-related impacts to NED	

	1. Changes in operational costs (including water treatment) due to changes in water supply operating conditions	Estimated changes in operating costs in dollars per year for water supply
	2. Non-routine repair, replacement, or modification (capital costs) costs	Non-routine repair, replacement, or modification costs including any costs over and above actual construction costs, such as permitting costs (dollars/year)
OSE1	Agriculture-related impacts to OSE	
	1. Sustainability of Century farms, family farms, and traditional ways of life	This metric may be described qualitatively or use a constructed scale to facilitate comparison with other types of OSE
	2. Environmental justice considerations	This metric may be described qualitatively or use a constructed scale to facilitate comparison with other types of OSE
OSE2	Changes in community well-being and related impacts resulting from an alternate source of dredging, if applicable	This metric may be described qualitatively or use a constructed scale to facilitate comparison with other types of OSE on the other social, cultural, and economic resources
OSE3	Changes to Cultural Resources sites that affect community cohesion, sense of place, and opportunities for discovery and learning	Description (qualitative or using constructed scales) of the impact of lost cultural resources on community cohesion, sense of place, and opportunities for discovery and learning and how these losses might vary across alternatives
OSE4	Environmental Conservation of changes to the carbon sequestered resulting from alternatives	This metric may be described qualitatively or use a constructed scale to facilitate comparison with other types of OSE
OSE5	Environmental Conservation passive use values resulting from changes in passive uses and services including existence, option, altruistic, and bequest values	This metric may be described qualitatively or use a constructed scale to facilitate comparison with other types of OSE
OSE6	Other social effects of changes in Flood Risk Management	
	1. Consider impacts on public safety and health, including disease	Changes in population at risk exposure (measured by population data from the U.S. Census Bureau and/or local and regional planning agencies); vulnerable population exposure such as number of daycare and assisted living facilities, schools, and hospitals impacted; changes in factors that affect danger, including overbank stages, flooding frequency, warning time, and evacuation capability
	2. Consider impacts on environmental justice	Changes in incidence of flood damage and other flooding impacts on disproportionately minority or poor communities (Census data on socioeconomic characteristics of population, in conjunction with national/regional economic metrics for impacts of flooding)
	3. Consider impacts on key cultural values such as community cohesion and stability and sacred Tribal sites	Impacts to sites considered sacred by Tribes and to long- established riverside communities. Metric to be determined; may be described qualitatively or use a constructed scale
OSE7	Hydropower-related impacts	
	1. Changes in system reliability	Hydropower Analysis Center is in the process of

	resulting from changes in flexibility to provide ancillary services	developing methodology for this metric. This may also include transmission availability. This metric may be described qualitatively or use a constructed scale
	2. Changes in air emissions resulting from changes in increased or decreased reliance on thermal generating resources	Emissions (e.g., SOx, NOx, CO2, etc.) for alternative thermal generating resources (lbs/Mwh). This generally will come from the EPA's Egrid database
OSE8	Irrigation-related impacts to OSE	
	1. Individual and community well-being, traditional ways of life, and economic vitality	These affects are likely to be described qualitatively. If possible, a constructed scale could be developed reflecting these changes and how the magnitude of the change would affect each of these topic areas
	2. Potential for invasive species, if formerly locally produced crops needed to be imported to the area	This metric may be described qualitatively or through use of a constructed scale to facilitate comparison with other types of OSE

Appendix D – List of Existing Multi-Dimensional Models

Type	Location	Model (s)	Purpose	Reach(RM)	Source	Reference
2D Hydro	Wolf Creek	ADH	Flood Analysis		NWK	Anthony Hall (CENWK)
" "	Benedictine Bottoms Chutes			424-429	NWK/HDR	
" "	Rocheport Bend	RMA2		183	USGS	
" "	KC Metro	RMA2	93 Flood Analysis	350-380	NWK/HDR	
" "	Portland Bend	CCHE2D				
" "	Miami, Missouri	MD_SWMS	Sturgeon Habitat Analysis	259.6–263.5	USGS	Jacobson, R.B., Johnson, H.E., III, and Dietsch, B.J., 2009, Hydrodynamic simulations of physical aquatic habitat availability for pallid sturgeon in the Lower Missouri River, at Yankton, South Dakota, Kenslers Bend, Nebraska, Little Sioux, Iowa, and Miami, Missouri, 2006-07: U.S. Geological Survey Scientific Investigations Report 2009-5058, 67 p. http://pubs.usgs.gov/sir/2009/5058/
" "	Deer Island, Little Sioux, IA	MD_SWMS	Sturgeon Habitat Analysis	669.6–673.5	USGS	" "
" "	Kenslers Bend, Nebraska	MD_SWMS	Sturgeon Habitat Analysis	743.9–748.1	USGS	" "
" "	Yankton, SD	MD_SWMS	Sturgeon Habitat Analysis	804.8–808.4	USGS	" "
" "	Multiple (8) LMR Locations	River 2D	Sturgeon Shallow Water Habitat	200-205	USGS	Jacobson, R.B., and Galat, D.L., 2006, Flow and form in rehabilitation of large-river ecosystems: An example from the Lower Missouri River: Geomorphology, v. 77, no. 3-4, p. 249-269.
" "	Booneville, MO	River 2D	Sturgeon Spawning & SWH	200-206	USGS	Johnson, H.E., Jacobson, R.B., and Delonay, A.J., 2006, Hydroecological modeling of the Lower Missouri River, in Proceedings of the Third Federal Interagency Hydrologic Modeling Conference, Reno, Nevada, April 2-6, 2006: Subcommittee on Hydrology of the Interagency Advisory Committee on Water Information, p. 1-8.

" "	Boyer, Desoto, Lower Dectaur, Lower Little Sioux, Peterson, Tyson	SMS/RMA2/SED2D	SWH Assessment for HAMP	686, 671, 658, 652, 642, 634	CENWO	D. B. Pridal, J. I. Remus, and P. M. Boyd, (2007) Two-Dimensional Modeling Applications for use with Missouri River Restoration, World Environmental and Water Resources Congress 2007: Restoring Our Natural Habitat
" "	Nebraska City, NE	FESWMS	Dike Notching for SWH		IIHR	A. N. (Thanos) Papanicolaou, Md. Elhakeem, D. Dermisis And N. Young, 2011. Evaluation Of The Missouri River Shallow Water Habitat Using A 2d-Hydrodynamic Model. River Res. Applic. 27: 157–167 (2011)
" "	Vermillion, SD (Rec River)	River 2D	Habitat Evaluation	769-772	USFWS	Smith, Kenner, Stancill, Wheeler, Two Dimensional Hydraulic Model of the Missouri River, Characterizing Pallid Sturgeon Habitat Below Gavins Point Dam
" "	Blair, Neb City, Omaha, Rocheport, Vermillion, Waverly	RMA-2	Master Manual Habitat Characterization, data from 1995		CENWO	Master Manual - Doug Latka
" "	Chamois, MO	RMA-2	2002 Study for stability	114-116	CENWK	
" "	Hamburg Bend	ADH	2012 study of Upper and Lower Hamburg Bend Chute Repairs		ERDC	Abraham, Clifton
" "	Ft Peck to Garrison	RMA-2	2D Larval Drift. Only partially completed, funding was stopped. Included dye test and preliminary 2D modeling	1630-1633, 1664 -1666, 1708-1711	ERDC	Ronnie Heath
" "	RM 795	ADH	ESH Flow Obstruction Study	795-796	CENWO	USACE, Missouri River from Gavins Point Dam to Ponca (RM 811 to 752) Evaluation of Flow Obstructions to Create Sandbar Habitat, Jan 2012
" "	Plowboy Bend	SMS/TuFlow	Floodplain Connectivity Assessment	160.5 - 173.5	USGS	Jacobson, R.B., Lindner, G., and Bitner, C.J., in press, The role of floodplain restoration in mitigating flood risk, Lower Missouri River, USA, in Hudson, P.F., and Middlekoop, H., eds., Geomorphology and Management of Lowland Floodplains: North American and European Fluvial Systems in an Era of Global Environmental Change: New York, NY, Springer.

" "	Glasgow, MO - Booneville, MO	SMS/TuFlow	Free-embryo advection/disperson drift dynamics related to chutes, shallow-water habitat, and floodplain connectivity	210-219	USGS	Robb Jacobson
2D Sed	Randall to Gavins Point	GSTARS4	Sediment Flushing Lewis&Clark	811-880	CENWO	Lewis and Clark Lake Sediment Management Study: Sediment Transport and Flow Analysis with GSTARS4 (Yang and Ahn, 2010)
" "	Hamburg Bend, Nebraska City, NE	SMS/RMA2/SED2D	SWH Evluation	550 to 557	CENWO	Boyd, P. 2011. Two-dimensional modeling to evaluate shallow water habitat on the missouri river
" "	Deer Island	ADH	Project Design	669.6–673.5	CENWO	Deer Island PIR
" "	Intake, MT (Yellowstone)	ADH	Project Design, ongoing	6 RM	CENWO	Svendsen
" "	Boyer Bend	ADH	Evaluate 2009 Flood Deposition	636 - 634	ERDC	Abraham, Numerical Study of Missouri River Backwater Habitat Sedimentation at Boyer Bend, ERDC \ CHL Letter Report, Jan 2012
1D Sed	Gavins Pt - Sioux City	RAS	Sediment Transport/Flushing	730-811	CENWO	USACE. 2013. Part III - Lewis and Clark Lake Sediment Management Study (LCLSMS): HEC-RAS with Sediment Modeling from Gavins Point Dam to Sioux City, IA. U.S. Army Corps of Engineers, Omaha, NE
" "	Randall to Gavins	RAS	Sediment Transport/Flushing	811-880	CENWO	USACE. 2013. Part III - Lewis and Clark Lake Sediment Management Study (LCLSMS): HEC-RAS with Sediment Modeling from Gavins Point Dam to Sioux City, IA. U.S. Army Corps of Engineers, Omaha, NE
" "	Kansas City, MO	RAS	Bed Degradation	350-380	CENWK	John Shelley

Appendix E – Summary of available HAMP data.

Table E1. HAMP related data available from USACE NWK (as of February 2014)

	Dataset Name	Date Collected	Content/ Description
Main Channel	2013 Hydrosurvey	summer/fall 2013	10511 cross sections at 250ft internvals at Corps designated XS's from Rulo to mouth, water's edge points collected
	2012 Hydrosurvey	summer/fall 2012	1310 cross sections at 2000 ft internvals at Corps designated XS's from Rulo to mouth, water's edge points collected
	2011 (June) Flood Hydrosurvey St. Joe to Waverly	2011 June	half mile to one mile interval cross sections
		2011 August	half mile to one mile interval cross sections
		2011 November	half mile to one mile interval cross sections
	2011 Flood Hydrosurvey KC Reach	June 9, 2011	250' interval cross sections
		June 13, 2011	250' interval cross sections
		June 28, 2011	250' interval cross sections
		July 7, 2011	250' interval cross sections
		July 14, 2011	250' interval cross sections
		August 9, 2011	250' interval cross sections
		August 31, 2011	250' interval cross sections
		September 22, 2011	250' interval cross sections
		November 9, 2011	250' interval cross sections
	2009 Hydrosurvey	summer/fall 2009	10551 cross sections at 250' intervals
	2008 Hydrosurvey	summer/fall 2008	7300 cross sections at XX' intervals
	2007 Hydrosurvey	summer/fall 2007	11798 cross sections at 250' intervals
	2007 HAMP Bend Hydrosurvey	summer/fall 2007	87' interval cross section at HAMP Bends includes
	Baltimore	2006 August	~100' interval cross section
	Boyer	2006	~50' interval cross section
	Camden	2006	~100' interval cross section
	Creve Coeur	2006	~100' interval cross section
	Dallas	2006 September	~100' interval cross section
	Doziers Bend	2006 September	~100' interval cross section
	Fishing River	2006	~100' interval cross section
	Malta	2006	~100' interval cross section
	Marion	2006	~50' interval cross section
	Nemaha	2006 September	~100' interval cross section
	Pickney	2006 September	~100' interval cross section
	Rocheport	2006	~50' interval cross section
	Searcy	2005	~50' interval cross section
	Sni	2006 August	~100' interval cross section
	Tarkio	2006	~100' interval cross section
	Washington	2006	~100' interval cross section
Chutes			
Littles Island	2013 Littles Hydrosurvey	summer/fall 2013	200' XS internval- complete survey
	2010 Flood Littles Hydrosurvey	summer 2010	
Pelican Island	2013 Aug Peclian Hydrosurvey	2013-Aug	200' XS internval- 30% complete

	2013 Pelican Hydrosurvey	summer/fall 2013	200' XS internval- 43% complete
	2013 May Peclican Hydrosurvey	2013 May	200' XS internval-25% complete
	2010 Flood Pelican Hydrosurvey	summer 2010	
Byran Island	2013 Bryan Hydrosurvey	summer/fall 2013	200' XS internval-25% complete
	2010 Flood Bryan Hydrosurvey	summer 2010	
Johnson Island	2013 July Johnson Hydrosurvey	2013- July	200' XS internval & longitudinals - complete survey
	2013 Johnson Hydrosurvey	summer/fall 2013	200' XS internval- complete survey
	2012 October Johnson Hydrosurvey	2012-October	longitudinals & serpintine coverage - complete survey
	2010 Flood Johnson Hydrosurvey	summer 2010	
Howell	2013 Howell Hydrosurvey	summer/fall 2013	200' XS internval- 11% complete
Lunch Island	2013 Lunch Island	summer/fall 2013	200' XS internval- complete survey
	2010 Flood Lunch Hydrosurvey	summer 2010	
Tadpole Island	2013 Tadpole Island Hydrosurvey	summer/fall 2013	200' XS internval- complete survey
	2012 Tadpole Island Control Structure	2012 September	coverage around upstream control structure
	2012 Tadpole Island Feb Complete Survey	2012 Febrary	100' XS internal, center line, high bank - complete survey
	2008 Tadpole Island Multibeam Survey	2008 October	full coverage <10' point spacing, elevation based on gage readings
Overton North	2013 Overton North Hydrosurvey	summer/fall 2013	200' XS internval- complete survey
	2012 Overton North Survey	2012 July	200' XS internval & longitudinals- complete survey
	2010 Flood Overton North Hydrosurvey	summer 2010	
	2008 Overton North Multibeam Survey	2008 October	full coverage <10' point spacing, elevation based on gage readings
	**USGS data received from 2004, 2005,2007, 2009		
Franklin Island	2013 Franklin Island	summer/fall 2013	200' XS internval- complete survey
	2010 Flood Franklin Hydrosurvey	summer 2010	
Jameson Island	2013 Jameson Island Hydrosurvey	summer/fall 2013	200' XS internval- complete survey
	2013 July Jameson Island	2013 July	200' XS & 2 longitudenals- complete survey
	2012 Feb Jameson Island Survey	2012 February	100' XS interval & high bank- complete survey
	2012 July Jameson Island Survey	2012 July	500' XS interval, 5 longitudenals & high bank- complete survey

	2011 July Jameson Island Hydrosurvey		200' XS interval- complete survey
	2011 June Jameson Island Hydrosurvey	2011 June	300' XS internval & longitudentals -complete survey
	2010 Flood Jameson Hydrosurvey	summer 2010	
	2009 January Jameson Survey	2009 January	land survey (spotty data points, no metadata)
	2007 September Jameson Survey	2007 Septemeber	land survey of cleared alignment
	2006 February Jameson Survey	2006 February	land survey of 3 point cross section of proposed aligment
Lisbon	2013 Lisbon Chute	summer/fall 2013	200' XS internval- 58% complete
	2010 Flood Lisbon Hydrosurvey	summer 2010	
Cranberry	2013 Cranberry	summer/fall 2013	200' XS internval- complete survey
	2010 Flood Cranberry Hydrosurvey	summer 2010	
	2013 Small Baltimore	summer/fall 2013	200' XS internval- 41% complete
	2010 Flood Small Baltimore Hydrosurvey	summer 2010	
Hodge	2013 Hodge	summer/fall 2013	200' XS internval- 42% complete
	2010 Flood Hodge Hydrosurvey	summer 2010	
Worthwine	2013 Worthwine Hydrosurvey	summer/fall 2013	200' XS internval- complete survey
	2012 Worthwine Survey	2012 February	100' XS interval + some high bank- complete survey
	2011 Flood Worthwine Hydrosurvey	2011 August	200' XS interval- complete survey
	2010 Flood Worthwine Hydrosurvey	summer 2010	
Dalbey	2013 Dalbey Bottoms	2013 June	200' XS interval- complete survey on all three Dalbey Chutes (A, B & C)
2-D Modeling Efforts			
Roacheport Bend	Roacheport_Bend_data hydrosurvey	August 17-19, 2005	50' XS interval
	Roacheport Bend ADCP	August 23, 2005	200' XS interval
Chamois Bend	Chamois hydrosurvey	June 10-12, 2002	150' XS interval
	Chamois ADCP	June 10-12, 2002	150' XS interval
Marion Bend	Marion Bottoms hydrosurvey	2005 July	150' XS interval
	Marion Bottoms ADCP	2005 July	200 m XS interval
Jameson Bend	Jameson Bend hydrosurvey		250 m XS interval
Slaughterhouse Bend	Slaughterhouse Bend hydrosurvey	2006	longitudinal

Wilhoite Bend	Wilhoite Bend hydrosurvey	2006	banklines/longitudinal
	Wilhoite Bend Multibeam survey	2006	longitudinal sweeps
Washington Bend	Washington Bend hydrosurvey	2006	100' XS intervals

Table E2. Missouri River hydrographic survey data available from USACE NWO HAMP (as of Feb. 2014)

Location	Type	RM		HAMP Survey Data*								
		DS	US	2005	2006	2007	2008	2009	2010	2011	2012	2013
Upper Glovers Point Bend	River Bend	712	714.3		B	BAS	BMS	BMS	No Funding			BMA
Lower Decatur Bend	River Bend	686	687.4		BA	BS	BM					BMA
Upper Louisville Bend	River Bend	683.4	686		BA	BAS	BM					BMA
Upper Little Sioux Bend	River Bend	674.8	676.3		B	BAS	BM					BMA
Lower Little Sioux Bend	River Bend	670.5	672.8	B	BA	BAS	BM	BM				BMA
Peterson Cut-off	River Bend	657.8	659.2	B	B	BAS	BM	BM				BA
Tysons Bend	River Bend	651.6	655	B	B	BAS	B					BA
Desoto Cut-off	River Bend	641.8	644.8	B	BA	BS	BM	BM				BA
Lower Calhoun Bend	River Bend	637.3	638.5		BA	BA	B	B				BA
Boyer Bend	River Bend	634.1	636	BA	B	BA	BA	B				BA
Tobacco Bend	River Bend	586.3	589.4		BMAS	BA	MA					BMA
Pin Hook	River Bend	576.8	579.2		BMAS	BA	MA					BMA
Van Horns	River Bend	574.8	576.8		BMAS	BA	MA					BMA
Upper Civil Bend	River Bend	572.8	574.8		BMAS	BA	MA					BMA
Lower Civil Bend	River Bend	571.5	572.8		BMAS	BA	MA					BMA
Lower Copeland	River Bend	562.9	565.1		BMAS	BAS	MA					BMA
Nebraska	River Bend	560.4	562.9		BMAS	BA	MA	MA				BMA
Otoe	River Bend	555.5	556.7		BAS	BS	MA	MA				BMA
Upper Hamburg Bend	River Bend	552.9	555.9		BAS	BAS	MA					BMA
Glovers Point Chute	Chute	711.2	713.4							BA		
Middle Decatur Chute	Chute	687.4	688.2							BA		B
Lower Decatur Chute	Chute	684.9	687.3							B		
Fawn Island Chute	Chute	673.3	674.1							BA	B	B
Sandy Point Chute	Chute	655	657.8									BA
California Bend, IA, Chute	Chute	649.5	650.1							BA	B	B
California Bend, NE, Chute	Chute	648.5	650.1							BA		
Lower Calhoun Chute	Chute	637.1	637.6							B		
Boyer Chute	Chute	633.7	637.8							BA	BA	BA
Council Bend Chute	Chute	616.8	617.8							BA	BA	BA
Plattsmouth Chute	Chute	592.1	594.5							BA	BA	BA
Tobacco Island Chute	Chute	586.3	588.4							BA	BA	BA
Upper Hamburg Chute	Chute	552.2	555.9							BA	BA	BA
Lower Hamburg Chute	Chute	550.6	553.4							BA	BA	BA
Kansas Bend Chute	Chute	544.5	546.4							BA	BA	BA
Nishnabotna Chute	Chute	542.4	543.3							BA	BA	B
Deroin Bend Chute	Chute	516.4	520.5							BA	BA	BA
Rush Bottoms Chute	Chute	499	502							BA	BA	B
Ponca State Park Backwater	Backwater	753								B	B	B

Glovers Pt Backwater	Backwater	711.5								B	B	B
Hole In the Rock Backwater	Backwater	706								B	B	B
Soldier Bend Backwater	Backwater	660.4								B	B	B
Tyson Backwater	Backwater	653.2								B	B	B
California Bend (IA) Backwater	Backwater	649.5								B	B	B
Boyer Backwater	Backwater	634.2								B	B	B
Plattsmouth Backwater	Backwater	592.3								B	B	B
Langdon Bend Backwater	Backwater	529								B	B	B

*B= single Beam Bathymetry, M= Multibeam, S=Sediment Samples, A= ADCP data

Appendix F – Summary of literature used by Habitat Modeling Team

A Brief History and Summary of the Effects of River Engineering and Dams on the Mississippi River System and Delta (Alexander, Wilson, & Green, 2012)

The U.S. Geological Survey Forecast Mekong project is providing technical assistance and information to aid management decisions and build science capacity of institutions in the Mekong River Basin. A component of this effort is to produce a synthesis of the effects of dams and other engineering structures on large-river hydrology, sediment transport, geomorphology, ecology, water quality, and deltaic systems. The Mississippi River Basin (MRB) of the United States was used as the backdrop and context for this synthesis because it is a continental scale river system with a total annual water discharge proportional to the Mekong River, has been highly engineered over the past two centuries, and the effects of engineering have been widely studied and documented by scientists and engineers.

The MRB is controlled and regulated by dams and river engineering structures. These modifications have resulted in multiple benefits including navigation, flood control, hydropower, bank stabilization, and recreation. Dams and other river-engineering structures in the MRB have afforded substantial socioeconomic benefits; however, they also have transformed the hydrologic, sediment transport, geomorphic, water-quality, and ecologic characteristics of the river. Large dams on the Missouri River have substantially reduced the magnitude of peak floods, increased base discharges, and reduced the overall variability of intra-annual discharges. The extensive system of levees and wing dikes throughout the MRB, although providing protection from intermediate magnitude floods, have reduced overall channel capacity and increased flood stage by up to 4 meters for higher magnitude floods. Prior to major river engineering, the estimated average annual sediment yield of the Mississippi River Basin was approximately 400 million metric tons. The construction of large main-channel reservoirs on the Missouri and Arkansas Rivers, sedimentation in dike fields, and protection of channel banks by revetments throughout the basin, have reduced the overall sediment yield of the MRB by more than 60 percent. The primary alterations to channel morphology by dams and other engineering projects have been (1) channel simplification and reduced dynamism; (2) lowering of channel-bed elevation; and (3) disconnection of the river channel from the flood plain, except during extreme flood events.

Freshwater discharge from the Mississippi River and its associated sediment and nutrient loads strongly influence the physical and biological components in the northern Gulf of Mexico. Ninety percent of the nitrogen load reaching the Gulf of Mexico is from nonpoint sources with about 60 percent coming from fertilizer and mineralized soil nitrogen. Much of the phosphorus is from animal manure from pasture and rangelands followed by fertilizer applied to corn and soybeans. Increased nutrient enrichment in the northern Gulf of Mexico has resulted in the degradation of water quality as more phytoplankton grow, which increases turbidity and depletes oxygen in the lower depths creating what is known as the dead zone. In 2002, the dead zone was 22,000 square kilometers (km2), an area similar to the size of the State of Massachusetts.

Changes in the flow regime from engineered structures have had direct and indirect effects on the fish communities. The navigation pools in the upper Mississippi River have aged, and these overwintering habitats, which were created when the pools filled, have declined as sedimentation reduces water depth. Reproduction of paddlefish may have been adversely affected by dams, which impede access to suitable spawning habitats. Fishes that inhabit swift-current habitats in the unimpounded lower Mississippi River have not declined as much as in the upper Mississippi River. The decline of the pallid sturgeon may be attributable to channelization of the Missouri River above St. Louis, Missouri. The Missouri River supports a rich fish community, but the widespread and long history of human intervention in river discharge has contributed to the declines of about 25 percent of the species.

The Mississippi River Delta Plain is built from six delta complexes composed of a massive area of coastal wetlands that support the largest commercial fishery in the conterminous United States. Since the early 20th century, approximately 4,900 km2 of coastal lands have been lost in Louisiana. One of the primary mechanisms of wetland loss on the Plaquemines- Balize complex is believed to be the disconnection of the river distributary network from the delta plain by the massive system of levees on the delta top, which prevent overbank flooding and replenishment of the delta top by sediment and nutrient deliveries. Efforts by Federal and State agencies to conserve and restore the Mississippi River Delta Plain began over three decades ago and have accelerated over the past decade. Regardless of these efforts, however, land losses are expected to continue because the reduced upstream sediment supplies are not sufficient to keep up with the projected depositional space being created by the combined forces of delta plain subsidence and global sea-level rise.

A velocimetric survey of the Lower Missouri River from river mile 492.38 to 290.20, July–October 2011 and July 2012 (Armstrong, Wilkison, and Norman, 2014)

Velocimetric surveys were made by the U.S. Geological Survey in 2011 and 2012 to provide data for the U.S. Army Corps of Engineers' ongoing study of bed degradation in the Lower Missouri River. Using Acoustic Doppler Current Profile technology, velocity data were collected at 87 river miles along the Lower Missouri River from Rulo, Nebraska to Waverly, Missouri, from July to October 2011 and in July 2012, for a total of 118 velocimetric surveys. Multiple-repeat velocimetric surveys were done eight times at three river miles from July to October 2011. Synoptic velocimetric surveys spanning 2–4 days were done twice at ten river miles, once in July 2011 and once in October 2011. Additional synoptic velocimetric surveys were done at proximal river miles in October 2011 and July 2012. Main-channel, near-bed, near-bank, and whole-river velocities were extracted from the Acoustic Doppler Current Profile data using AdMap and compiled as an average of reciprocal pairs for each survey. In addition, the mean velocity computed by the Winriver II software for each survey was integrated with the extracted data.

Population viability analysis of Lower Missouri River shovelnose sturgeon with initial application to the pallid sturgeon (Bajer & Wildhaber, 2007)

Demographic models for the shovelnose (Scaphirhynchus platorynchus) and pallid (S. albus) sturgeons in the Lower Missouri River were developed to conduct sensitivity analyses for both populations. Potential effects of increased fishing mortality on the shovelnose sturgeon were also evaluated. Populations of shovelnose and pallid sturgeon were most sensitive to age-0 mortality rates as well as mortality rates of juveniles and young adults. Overall, fecundity was a less sensitive parameter. However, increased fecundity effectively balanced higher mortality among sensitive age classes in both populations. Management that increases population -level fecundity and improves survival of age-0, juveniles, and young adults should most effectively benefit both populations. Evaluation of reproductive values indicated that populations of pallid sturgeon dominated by ages >= 35 could rapidly lose their potential for growth, particularly if recruitment remains low. Under the initial parameter values portraying current conditions the population of shovelnose sturgeon was predicted to decline by 1.65% annually, causing the commercial yield to also decline. Modeling indicated that the commercial yield could increase substantially if exploitation of females in ages <= 12 was highly restricted

Bates,P.D., Horritt,M.S., Smith, C.N. And Mason, D. 1997. Integrating remote sensing observations of flood hydrology and hydraulic modeling. Hydrological Processes, VOL. 11, 1777±1795 (1997)

The further development of two-dimensional finite element models of river flood flow is currently constrained by a lack of data for rigorous parameterization and validation. Remote sensing techniques have the potential to overcome a number of these constraints thereby allowing a research design for model development. This is illustrated with reference to a case study of a two-dimensional finite element model applied to the Missouri River, Nebraska and compared with a synchronous Landsat TM image of flood inundation extent. The case study allows research needs for the integration of hydraulic modeling and remote sensing to be defined.

Implications of Flood Pulse Restoration for Populus Regeneration on the Upper Missouri River (Bovee & Scott, 2002)

Flood magnitude has been reduced from 40 to 50% which leads to establishment of seedlings above the zone of frequent ice-driven disturbance.

Boyd, P. M. 2012. Regional Sediment Management (RSM) principles in flood recovery. Coastal and Hydraulics Engineering Technical Note ERDC/CHL CHETN-XIV-29. Vicksburg, MS: US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory

This Coastal and Hydraulics Engineering Technical Note (CHETN) summarizes actions undertaken during 2011 and 2012 to incorporate US Army Corps of Engineers (USACE) Regional Sediment Management (RSM) principles into a wide variety of projects as part of flood recovery and reconstruction on the Missouri River. Significant damage was caused by the 2011 Missouri River flood, and mitigation of sediment impacts and repair of infrastructure were given a high priority in an effort to return the flood protection system to acceptable flood protection levels. Flood recovery activities on the Missouri River occurred at a rapid pace for about 12 months during the latter part of calendar year 2011 and into 2012. From October 2011 (when the water receded) until the start of the 2012 navigation season (when the navigation channel became operational), work proceeded at a very rapid pace. Roads and bridges were repaired within weeks to a few months, and levees were repaired by early 2012. There was little time for brainstorming and creative thinking. The primary goal was always to re-establish full service of all authorized project purposes as quickly as possible. In the process of meeting that goal, all available

opportunities were taken to integrate RSM principles into many of the flood recovery projects. RSM was not integrated into every flood recovery project. Some projects were not the type for which RSM concepts could be capitalized, and some projects had very restrictive design criteria. Other projects, however, were good candidates for developing RSM designs that benefitted other regional projects as well as the intended local project.

Moving beyond static species distribution models in support of conservation biogeography (Franklin, 2010)

Aim is to demonstrate that multi-modelling methods have effectively been used to combine static species distribution models (SDM), predicting the geographical pattern of suitable habitat, with dynamic landscape and population models to forecast the impacts of environmental change on species' status, an important goal of conservation biogeography. Three approaches were considered: (1) incorporating models of species migration to understand the ability of a species to occupy suitable habitat in new locations; (2) linking models of landscape disturbance and succession to models of habitat suitability; and (3) fully linking models of habitat suitability, habitat dynamics and spatially explicit population dynamics. Linking species–environment relationships, landscape dynamics and population dynamics in a multi-modelling framework allows the combined impacts of climate change (affecting species distribution and vital rates) and land cover dynamics (land use change, altered disturbance regimes) on species to be predicted. This approach is only feasible if the life history parameters and habitat requirements of the species are well understood. Forecasts of the impacts of global change on species may be improved by considering multiple causes. A range of methods are available to address the interactions of changing habitat suitability, habitat dynamics and population response that vary in their complexity, realism and data requirements.

Spatiotemporal patterns and changes in Missouri River Fishes (Galat et al., 2005)

The longest river in North America, the Missouri, trends southeast from Montana across the mid-continent of the United States, 3,768 km to its confluence with the Mississippi River near St. Louis, Missouri. Frequent flooding, a shifting, braided channel, and high turbidity characterized the precontrol "Big Muddy." Major alterations occurred over the past century primarily for flood protection, navigation, irrigation, and power production. Today, the middle one-third of its length is impounded into the largest volume reservoir complex in the United States and the lower one-third is channelized, leveed, and its banks stabilized.Spatial and temporal patterns of Missouri River

fishes are reviewed for the main channel, floodplain, and major reservoirs. Twenty-five families, containing 136 species, compose its ichthyofauna. Seven families represent 76% of total species richness, with Cyprinidae (47 species), Catostomidae (13), Centrarchidae (12), and Salmonidae (10), the five most specious. Native fishes compose 79% of the river's ichthyofauna with representatives of four archaic families extant: Acipenseridae, Polyodontidae, Lepisosteidae, and Hiodontidae. Fifty-four percent of Missouri River fishes are classified as "big river" species, residing primarily in the main channel, and 93% of these are fluvial dependent or fluvial specialists. Significant floodplain use occurs for 60 species. Many of its big river fishes are well adapted for life in turbid, swift waters with unstable sand-silt bottoms.Populations of 17 species are increasing and 53% of these are introduced, primarily salmonids, forage fishes, and Asian carps. Ninety-six percent of the 24 species whose populations are decreasing are native. Fishes listed as globally critically imperiled and federally endangered (G1) or globally vulnerable (G3) include pallid sturgeon Scaphirhynchus albus (G1), lake sturgeon Acipenser fulvescens, Alabama shad Alosa alabamae, sturgeon chub Macrhybopsis gelida, and sicklefin chub M. meeki (G3). Eleven fishes are listed by two of more of the seven main-stem states as imperiled; all are big river species. Richness increases going downriver from 64 species in Montana to 110 species in Missouri with 36% of widely distributed taxa absent below one or more reservoir. Longterm fish collections from several states show declines in sauger Sander canadensis throughout the river and decreases in the lower river of several big river fishes (e.g., sturgeons, chubs, Hybognathus spp.). Spatiotemporal changes in Missouri River fishes reflect interactions between natural (climate, physiography, hydrology, and zoogeography) and anthropogenic (impoundment, geomorphic, flow, and temperature alterations, and introduced species) factors. Recurrent droughts and floods and persistent stakeholder conflicts over beneficial uses have recently directed national attention to Missouri River issues. Acquisition of floodplain lands and channel and floodplain rehabilitation programs are underway to improve habitat in the lower river. Unfortunately, many are site specific and few have included explicit ecological objectives and performance evaluations. Several proposals for flow normalization are being considered, but remain controversial.

Relationships between Larval Fish Drift and Abiotic Factors in the Missouri River (Hay, Franti, Marx, Peters, & Hesse, 2008b)

We estimated the relative importance of key abiotic variables to predict the drift of larval fishes in the Missouri River. A multi-year database of spring drift sampling was used to examine relationships between larval freshwater drum

(Aplodinotus grunniens) and catostomid drift and variables representing discharge, temperature. and turbidity in the Missouri River from Fort Randall Dam in South Dakota to Rulo. Nebraska. Two statistical modeling approaches were used to estimate the relative importance of the predictor variables. Temperature-related variables were consistently the most important predictors of the presence and density of larval freshwater drum and three species of catostomids.

Macroinvertebrate drift density in relation to abiotic factors in the Missouri River (Hay, Franti, Marx, Peters, & Hesse, 2008a)
Changes in flow management to restore ecosystem health have been proposed as part of many restoration projects for regulated rivers. However, uncertainty exists about how the biota will respond to flow management changes. The objectives of this study were to estimate the relative importance of key abiotic predictor variables to aquatic macroinvertebrate drift densities in the Missouri River and to compare these results among reaches of the river. A multi-year, multi-location database of spring macroinvertebrate drift net sampling was used to develop relations between drift density and variables representing discharge, temperature, and turbidity in the Missouri River from Fort Randall Dam, South Dakota to the mouth of the Little Nemaha River, Nebraska. Multimodel inference using generalized linear mixed models and an information theoretic approach were used to estimate the relative importance of the predictor variables and the parameters. The results varied by reach. Discharge-related factors were more important at the upstream end of the study area, and turbidity was more important at the downstream end of the study area. Water temperature or degree days were also important predictors in the upstream reaches. The results below Gavins Point Dam suggest that increased macroinvertebrate drift densities are a response to reduced habitat and food availability. The results identify important variables for drift density that could be used in future experimental studies of flow manipulation for the Missouri or other large, regulated rivers.

The Missouri River Hydrosystem (Hesse & Sheets, 1993)
Recent political initiatives, expanding knowledge regarding river science, and degraded conditions of fisheries and shellfisheries in the Mississippi River Basin have provided the stimuli to begin restoration of rivers in the basin. The Missouri River is a case in point; lost functions included separation of the floodplain from the channel, loss of the natural hydrograph, curtailment of sediment and organic matter transport, altered temperature regimes and removal of instream cover. We have approached restoration from the

perspective that it is essential to recover part of all lost functions rather than to pursue a new direction, acknowledging the profound changes in morphology, because it is our opinion that the native community will be served best by such an approach. It is important to recognize the conditions of fish and wildlife habitat from the pre-dam and pre-channelization period if we are to be effective at restoring these conditions. Early hydrographic surveys were available to achieve this objective. Hydraulic reconnection of channel features, cut off by channelization and degradation, and recovery of the natural hydrograph are paramount.

Sediment regime constraints on river restoration--An example from the Lower Missouri River (Jacobson, Blevins, and Bitner, 2009)

Dammed rivers are subject to changes in their flow, water-quality, and sediment regimes. Each of these changes may contribute to diminished aquatic habitat quality and quantity. Of the three factors, an altered sediment regime is a particularly unyielding challenge on many dammed rivers. The magnitude of the challenge is illustrated on the Lower Missouri River, where the largest water storage system in North America has decreased the downriver suspended-sediment load to 0.2%-17% of pre-dam loads. In response to the altered sediment regime, the Lower Missouri River channel has incised as much as 3.5 m just downstream of Gavins Point Dam, although the bed has been stable to slightly aggrading at other locations farther downstream. Effects of channel engineering and commercial dredging are superimposed on the broad-scale adjustments to the altered sediment regime.

Assessment of shallow-water habitat availability in modified dike structures, Lower Missouri River, 2004 (Jacobson, Elliott, and Johnson, 2004)

This study documented the effects of wing-dike notching on the availability of shallow water habitat in the Lower Missouri River. Five wing dikes were surveyed in late May 2004 after they were notched in early May as part of shallow-water habitat (SWH) rehabilitation activities undertaken by the U.S. Army Corps of Engineers. Surveys included high-resolution hydroacoustic depth, velocity, and substrate mapping. Relations of bottom elevations within the wing dike fields to index discharges and water-surface elevations indicate that little habitat meeting the SWH definition was created immediately following notching. This result is not unexpected, as significant geomorphic adjustment may require large flow events. Depth, velocity, and substrate measurements in the post-rehabilitation time period provide baseline data for monitoring ongoing changes. Differences in elevation and substrate were noted at all sites. Most dike fields showed substantial aggradation and replacement of

mud substrate with sandier sediment, although the changes did not result in increased availability of SWH at the index discharge. It is not known how much of the elevation and substrate changes can be attributed directly to notching and how much would result from normal sediment transport variation.

Flow and form in rehabilitation of large-river ecosystems: An example from the Lower Missouri River (Robert B. Jacobson & Galat, 2006)

On large, intensively engineered rivers like the Lower Missouri, the template of the physical habitat is determined by the nearly independent interaction of channel form and flow regime. We evaluated the interaction between flow and form by modeling four combinations of modern and historical channel form and modern and historical flow regimes. The analysis used shallow, slow water (shallow-water habitat, SWH, defined as depths between 0 and 1.5 m, and current velocities between 0 and 0.75 m/s) as an indicator of habitat that has been lost on many intensively engineered rivers and one that is thought to be especially important in rearing of young fishes. Two-dimensional hydrodynamic models for modern and historical channels of the Lower Missouri River at Hermann, Missouri, indicate substantial differences between the two channels in total availability and spatial characteristics of SWH. In the modern channel, SWH is maximized at extremely low flows and in overbank flows, whereas the historical channel had substantially more SWH at all discharges and SWH increased with increasing discharge. The historical channel form produced 3–7 times the SWH area of the modern channel regardless of flow regime. The effect of flow regime is evident in increased within- year SWH variability with the natural flow regime, including significant seasonal peaks of SWH associated with spring flooding. Comparison with other reaches along the Lower Missouri River indicates that a) channel form is the dominant control of the availability of habitat even in reaches where the hydrograph is more intensively altered, and b) rehabilitation projects that move toward the historical condition can be successful in increasing topographic diversity and thereby decreasing sensitivity of the availability of habitat to flow regime. The relative efficacy of managing flow and form in creating SWH is useful information toward achieving socially acceptable rehabilitation of the ecosystem in large river systems.

Hydrologic and geomorphic considerations in restoration of river-floodplain connectivity in a highly altered river system, Lower Missouri River, USA (Jacobson, Janke, & Skold, 2011)

Planning for restoration of river-floodplain systems requires understanding how often and how much of a floodplain may be inundated, and how likely the

floodplain is to retain the water once flooded. These factors depend fundamentally on hydrology and geomorphology of the channel and floodplain. We discuss application of an index of river-floodplain connectivity, the Land Capability Potential Index (LCPI), to regional-scale restoration planning along 600 km of the Lower Missouri River. The LCPI integrates modeled water-surface elevations, floodplain topography, and soils to index relative wetness of floodplain patches. Geomorphic adjustment of the Lower Missouri River to impoundment and channel engineering has altered the natural relations among hydrology, geomorphology, and floodplain soils, and has resulted in a regional upstream to downstream gradient in connectivity potential. As a result, flow-regime management is limited in its capacity to restore floodplain ecosystems. The LCPI provides a tool for identifying and mapping floodplain restoration potential, accounting for the geomorphic adjustment. Using simple criteria, we illustrate the utility of LCPI-like approaches in regional planning for restoration of plains cottonwood (Populus deltoides) communities, hydrologically connected floodplain wetlands, and seasonal floodplain wetlands.

Physical habitat dynamics in four side-channel chutes, Lower Missouri River (Jacobson, Johnson, Laustrup, D'Urso, and Reuter, 2004)

Construction of the side-channel chutes has become a popular means to rehabilitate habitate of the Lower Missouri River. We studied various aspects of hydrology, hydraulics, and geomorphology of four side-channel chutes to document a range of existing conditions in the Lower Missouri River. The Cranberry Bend side-channel chute has existed for at least 40 years and is an example of a persistent, minimally engineered chute. The Lisbon Bottom side-channel chute is a young chute, created by extreme floods during 1993-1996, and allowed to evolve with minimum engineering of inlet and outlet structures. The Hamburg Bend and North Overton Bottom side-channel chutes were constructed in 1996 and 2000, respectively, as part of the Missouri River Bank Stabilization and navigation Fish and Wildlife Mitigation Project. These side-channel chutes provide increased areas of sandbars and shallow, slow water - habitats thought to be substantially diminished in the modern Missouri River. Depths and velocities measured in side-channel chutes are also present in the main channel, but the chutes provide more areas of slow, shallow water and they increase the range of discharges over which shallow, slow water is present. The 3.6 km long Lisbon Bottom chute provides as much as 50% of the entire shallow water habitat that exists in the encompassing 15 km reach of the river. At Cranberry Bend and Lisbon Bottom, the side-channel chutes provided 10-40% of the availabile sandbar area in the reach, depending on discharge. Each

of the side-channel chutes shows evidence of continuing erosion and deposition. The longevity and the Cranberry Bend chute attests to dynamic stability -- that is, a chute that maintains form and processes while shifting in position. The Hamburg chute similarly shows evidence of lateral movement and construction of flood plain to compensate for erosion. The Lisbon Bottom chute -- the most intensively studied chute -- appears to have achieved an equilibrium width and continues to migrate slowly; however, evidence of aggradation indicates that the chute has not reached an ultimate form, and may be continuing to adjust to altered hydrology and sediment availability. The North Overton Bottoms chute is the newest in the study. In its originally constructed form, the North Overton Bottoms pilot chute was extremely stable, even while being subjected to two floods in excess of 2-year recurrence interval and after accumulating large, potentially destabilizing large woody debris jams. Ongoing adaptive re-engineering of the North Overton Bottoms chute has prevented assessment of how the chute might have adjusted its form in the absence of intervention.

3-D flow and scour near a submerged wing dike: ADCP measurements on the Missouri River (Jamieson, Rennie, Jacobson, & Townsend, 2011)

Detailed mapping of bathymetry and three-dimensional water velocities using a boat-mounted single-beam sonar and acoustic Doppler current profiler (ADCP) was carried out in the vicinity of two submerged wing dikes located in the Lower Missouri River near Columbia, Missouri. During high spring flows the wing dikes become submerged, creating a unique combination of vertical flow separation and overtopping (plunging) flow conditions, causing large-scale three-dimensional turbulent flow structures to form. On three different days and for a range of discharges, sampling transects at 5 and 20 m spacing were completed, covering the area adjacent to and upstream and downstream from two different wing dikes. The objectives of this research are to evaluate whether an ADCP can identify and measure large-scale flow features such as vortex shedding and recirculating flow that develop in the vicinity of a submerged wing dike ; and whether or not moving-boat (single-transect) data are sufficient for resolving complex three-dimensional flow fields. Results indicate that spatial averaging from multiple nearby single transects may be more representative of an inherently complex (temporally and spatially variable) three-dimensional flow field than repeated single transects. Results also indicate a correspondence between the location of calculated vortex cores (resolved from the interpolated three-dimensional flow field) and the nearby scour holes, providing new insight into the connections between vertically oriented coherent structures and local scour, with the unique perspective of flow and morphology in a large river.

A Practical Handbook for Population Viability Analysis (Morris et al., 1999)

<Need Abstract or Summary>

A longitudinal assessment of the aquatic macroinvertebrate community in the channelized lower Missouri River (Poulton et al., 2003)

The authors conducted an aquatic macroinvertebrate assessment in the channelized reach of the lower Missouri River, and used statistical analysis of individual metrics and multimetric scores to identify community response patterns and evaluate relative biological condition. Longitudinal site differences that are potentially associated with water quality related factors originating from the Kansas City metropolitan area were observed using data from coarse rock substrate in flowing water habitats (outside river bends), and depositional mud substrate in slack water habitats (dike fields). Three sites above river mile (RM) 369 in Kansas City (Nebraska City, RM = 560; St. Joseph, RM = 530; Parkville, RM = 377) and three below (Lexington, RM = 319; Glasgow, RM = 228; Hermann, RM = 94) were sampled with rock basket artificial substrates, a qualitative kicknet method, and the Petite Ponar. A total of 132 aquatic macroinvertebrate taxa were collected from the lower Missouri River; one third of these taxa belonged to the sensitive EPOT insect orders (Ephemeroptera, Plecoptera, Odonata, and Trichoptera). Rock baskets had the highest mean efficiency (34.1%) of the methods, and the largest number of taxa was collected by Ponar (n = 69) and kicknet (n = 69) methods. Seven of the 15 metrics calculated from rock basket data, and five of the nine metrics calculated from Ponar data showed highly significant differences (ANOVA, $P < 0.001$) at one or more sites below Kansas City. A substantial reduction in net-spinning Trichoptera was observed in rock habitats below Kansas City (Lexington), an increase in relative dominance of Oligochaeta in depositional habitats at the next site downstream (Glasgow), and lower relative condition scores in rock habitat at Lexington and depositional habitat at Glasgow. Collectively, these data indicate that some urban-related impacts on the aquatic macroinvertebrate community are occurring. Results suggest that the methods and assessment framework used in this study could be successfully applied on a larger scale with concurrent water and sediment chemistry to validate metrics, establish impairment levels, and develop a specific macroinvertebrate community index for the lower Missouri River. This could be accomplished this with longitudinal multi-habitat sampling at a larger number of sites related to all potential impairment sources, including tributaries, urban areas, and point sources.

Selection of nest-site habitat by interior least terns in relation to sandbar construction (Sherfy, Stucker, & Buhl, 2011)

Federally endangered interior least terns (Sternula antillarum) nest on bare or sparsely vegetated sandbars on midcontinent river systems. Loss of nesting habitat has been implicated as a cause of population declines, and managing these habitats is a major initiative in population recovery. One such initiative involves construction of mid-channel sandbars on the Missouri River, where natural sandbar habitat has declined in quantity and quality since the late 1990s. We evaluated nest-site habitat selection by least terns on constructed and natural sandbars by comparing vegetation, substrate, and debris variables at nest sites (na =a 798) and random points (na =a 1,113) in bare or sparsely vegetated habitats. Our logistic regression models revealed that a broader suite of habitat features was important in nest-site selection on constructed than on natural sandbars. Odds ratios for habitat variables indicated that avoidance of habitat features was the dominant nest-site selection process on both sandbar types, with nesting terns being attracted to nest-site habitat features (gravel and debris) and avoiding vegetation only on constructed sandbars, and avoiding silt and leaf litter on both sandbar types. Despite the seemingly uniform nature of these habitats, our results suggest that a complex suite of habitat features influences nest-site choice by least terns. However, nest-site selection in this social, colonially nesting species may be influenced by other factors, including spatial arrangement of bare sand habitat, proximity to other least terns, and prior habitat occupancy by piping plovers (Charadrius melodus). We found that nest-site selection was sensitive to subtle variation in habitat features, suggesting that rigor in maintaining habitat condition will be necessary in managing sandbars for the benefit of least terns. Further, management strategies that reduce habitat features that are avoided by least terns may be the most beneficial to nesting least terns.

(Wildhaber, Holan, et al., 2011)

Approaches using telemetry, precise reproductive assessments, and surgically implanted data storage tags (DSTs) were used in combination with novel applications of analytical techniques for fish movement studies to describe patterns in migratory behavior and predict spawning success of gravid shovelnose sturgeon. From 2004 to 2007, over 300 gravid female shovelnose sturgeon(Scaphirhynchus platorynchus) from the Lower Missouri River, that were expected to spawn in the year they were collected, were surgically implanted with transmitters and archival DSTs. Functional cluster modeling of telemetry data from the spawning season suggested two common migration patterns of gravid female shovelnose sturgeon. Fish implanted from 958 to 1181

river kilometer (rkm) from the mouth of the Missouri River (or northern portion of the Lower Missouri River within 354 rkm of the lowest Missouri River dam at rkm 1305) had one migration pattern. Of fish implanted from 209 to 402 rkm from the mouth of the Missouri River (or southern portion of the Lower Missouri River), half demonstrated a movement pattern similar to the northern fish while the other half demonstrated a migration pattern that covered more of the river. There was no apparent difference in migration patterns between successful and unsuccessful spawners. Multiple hypotheses exist to explain differences in migratory patterns among fish from different river reaches. Additional work is required to determine if observed differences are due to multiple adapted strategies, environmental alteration, and/or initial tagging date. Hierarchical Bayesian modeling of DST data indicated that variation in depth usage patterns was consistently different between successful and unsuccessful spawners, as indicated by differences in likelihood of switching between high and low variability states. Analyses of DST data, and data collected at capture, were sufficient to predict 8 of 10 non-spawners/ incomplete spawners and all 30 spawners in the absence of telemetry location data. Together, the results of these two separate analyses suggest that caution is necessary in extrapolating spawning success from broad-scale movement data alone. More direct measures of spawning success may be necessary to precisely determine spawning success and to evaluate the effects of management actions.

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