Fort Peck Adaptive Management Framework

For Upper Missouri River Pallid Sturgeon

Missouri River Recovery Program

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U.S. Army Corps of Engineers
Omaha District
Kansas City District

&

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This Fort Peck Adaptive Management Framework is a Missouri River Recovery Program product as part of its effort to develop a suite of management actions to meet USACE responsibilities under the Endangered Species Act requirements. This document is based largely on efforts and analysis of the MRRP Technical Team.

Technical Team members who contributed to this Framework are: Dr. Craig Fischenich, Dr. Robb Jacobson, Dr. Graham Long, Dave Marmorek; and other contributors : Pat Braaten, Aaron Delonay, Steve Krentz, Wayne Nelson-Stastny, Clayton Ridenour, Zach Shattuck, and Kirk Steffensen.

Abstract

This report outlines a potential approach that was developed by the Missouri River Recovery Program Technical Team to formulate and evaluate test flow releases from Fort Peck Dam for pallid sturgeon and describes an adaptive management framework for their implementation based on the best available scientific information about the species and current knowledge of potential management actions. In developing this approach, information from the Effects Analysis (conducted between 2013-2016 for the MRRP) was reviewed and new information evaluated to reconsider Level 1 and Level 2 actions in the Upper Basin of the Missouri River to reflect increased priority of evaluating test flow releases from Fort Peck Dam to complement the Yellowstone River Fish Passage Project near Intake, Montana. Two conceptual hydrographs are presented, along with a set of studies gleaned from a review of existing information and an expert elicitation process. Actions in the proposed framework are a starting point for consideration and discussion. Some proposed actions may require further analysis and adjustment to this proposed framework in the future.

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Unit Conversion Factors

Multiply	By	To Obtain
Acres	4,046.873	square meters
acre-feet	1,233.5	cubic meters
cubic feet	0.02831685	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
Feet	0.3048	Meters
Hectares	1.0 E+04	square meters
Inches	0.0254	Meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters

1 Introduction

1.1 Context and rationale

In the January 19, 2018 amendment to the October 30, 2017 Biological Assessment (BA) for the Operation of the Missouri River Mainstem Reservoir System, the Operation and Maintenance of the Bank Stabilization and Navigation Project, the Operation of Kansas River Reservoir System, and the Implementation of the Missouri River Recovery Management Plan (MRRMP), the USACE proposed, among other things, to work with the US Fish and Wildlife Service (USFWS) and the Missouri River Recovery Implementation Committee (MRRIC) "to review previous information and information generated since the Effects Analysis to formulate test flow releases from Fort Peck Dam and an adaptive management (AM) framework for their implementation." This commitment was relied on by USFWS in its 2018 Biological Opinion (BiOp) finding that the USACE's Proposed Action is 'not likely to jeopardize' pallid sturgeon.

This document was developed as part of the Corps' commitment for such an AM framework. It was informed by the efforts of the Missouri River Recovery Program (MRRP)'s AM Technical Team between December 2017 and November 2018, with some interaction with the USFWS, MRRIC's Working Groups and making use of additional technical perspectives from pallid sturgeon experts. This Fort Peck AM Framework can be included as a new component of the MRRP Science and Adaptive Management Plan for the Missouiri River Basin (SAMP; Fischenich et al. 2018), providing a structured process through which substantive decisions regarding the appropriate role of Fort Peck Dam operations and other management actions to support Upper Missouri River pallid sturgeon can be made and would be adjusted over time as new information is obtained. More in-depth engagements with MRRIC's Working Groups are anticipated and may result in adjustments to the Fort Peck AM Framework in the future.

During the development of this framework, legal constraints on the implementation of a fish passage structure on the Yellowstone River near Intake, Montana, were lifted. This framework assumes that the fish passage structure will be constructed and commissioned in short order, and so no special considerations have been incorporated to address decisions regarding operations of Fort Peck Dam due to uncertainty about the existence of a passage structure on the Yellowstone River near Intake, Montana. However, the Fort Peck AM Framework presented in this report was developed to assess critical uncertainties regarding recruitment of pallid sturgeon on the upper Missouri River while maintaining opportunities for recruitment on the Yellowstone River.

1.2 Purpose of the framework and relationship to the SAMP

Recognizing the potential need for management of flows from Fort Peck Dam in order to address pallid sturgeon objectives for the upper river, the amended BA called for the development of a framework to guide the implementation of any flow management actions under adaptive management. This is necessary given the significant uncertainty regarding the causes for recruitment failure in the Missouri River.

This framework establishes a logical and systematic series of scientific investigations and experiments that may ultimately lead to the long-term implementation of activities needed to meet species objectives in the Upper Basin. It also conceptually describes how criteria and mechanisms gained from studies and experimentation could guide decisions about what implementation activities (if any) are warranted, and how they should be structured. Actions contemplated in this AM framework may require additional NEPA analysis prior to implementation.

This document outlines two main areas of work to develop a framework. The first concerns the immediate management focus that have been identified in work dating back at least to the Effects Analysis (Jacobson et al. 2016), which appear in various iterations of the SAMP and, most recently, in the 2018 BiOp. The BiOp notes that effects of the USACE's System Operations in the Upper Missouri River are potentially negatively impacting the pallid sturgeon's ability to recruit due to 1) altered water temperatures, 2) altered flow regime, and 3) altered sediment regime and turbidity as a result of the construction of the water management System and its ongoing operational hydrograph (USFWS 2018). Effective management actions to address these issues could result from modifying the System operational hydrograph in the Upper River to better replicate aspects of the historical hydrograph. To this end, this framework builds on foundational work to provide logical, parallel pathways of simultaneous Level 1* studies and Level 2 hydrograph modification experiments and actions that together could potentially pave the way to future Level 3 and Level 4 actions if the evidence shows these actions may be warranted. Thus this framework has, as its primary focus, information designed to help:

- Identify / prioritize Level 1 science studies to address key unknowns, focusing on the issues of flow, temperature and turbidity of the Missouri River downstream from Fort Peck Dam.

- Clarify key decisions and sequencing of actions related to implementing Level 2 flow actions to address these issues.

- Describe approaches for implementing a test flow action (e.g., components of the hydrograph to test different hypotheses).

- Summarize monitoring and assessment activities that may be needed to evaluate effectiveness once a test flow action has been implemented and, potentially, to assess effects on human considerations.

The second area of work takes a broader and potentially longer-term perspective of the wider set of factors that might be limiting pallid sturgeon recruitment. This work emphasizes that there are many potential factors that, alone or in combination, could be limiting Upper River pallid sturgeon. Those discussed above are currently considered by an expert panel (see acknowledgements for a list of panelists) to be the leading candidates or are the primary causes of effects that occur along complex effects pathways. In this view, altering the hydrograph to address the underlying issues is only one of several means of achieving certain identified physical or biological ends; further, it is possible that hydrograph alterations may not be effective. Opportunities to address Upper River pallid sturgeon requirements through avenues other than hydrograph alterations for flow, temperature or turbidity, might also lead to preferable solutions for pallid sturgeon and/or for other interests (e.g., endangered birds, human considerations).

* Level 1 through Level 4 activities in this report are in reference to the Pallid Sturgeon Framework described in Section 4.2.1.1 and Table 39 of the SAMP.

This study was not an effort to fully reevaluate the far more comprehensive efforts of the Effects Analysis, but rather, to reconsider relevant issues addressed in the Effects Analysis in the light of updated information and given the need to ensure complimentary actions between the upper Missouri and Yellowstone Rivers in the context of the MRRP objectives for the upper Missouri and Yellowstone Rivers pallid sturgeon demographic unit. In doing so, the Technical Team used a complementary organization of information, through the development of Effects Pathway diagrams (Beanlands and Duinker 1983). At the same time, care was taken to maintain continuity with previous organization of issues (i.e. Big Questions and Hypotheses) and the adaptive management framework reflected in the SAMP.

1.3 Guiding principles

Section 4.2.5. of the MRRP's SAMP states some important principles regarding the implementation of an AM framework. In developing this framework for Fort Peck, the Technical Team adopted those principles already in the SAMP and also sought to:

- Build on the established foundation of historical work, including the Effects Analysis and the SAMP.
- Develop tools and approaches that will facilitate smoother integration of new information into the established knowledge framework via the SAMP.
- Build an approach that will integrate technical aspects of human considerations seamlessly when and if this becomes necessary.
- Meet near-term needs (i.e. the need for 'a framework' to be delivered in November 2018), but build for the longer term of that framework through the SAMP.
- Keep a broad scope - a framework should facilitate consideration of flow and non-flow actions to benefit the Upper River pallid population, accounting for conditions on both the Yellowstone and Missouri Rivers and pursue objectives while considering the entire Upper River pallid sturgeon demographic unit.

- Focus on science and technical issues, but design for transparency and ongoing engagement, recognizing that the implementation of a framework will require a series of value judgments to be made at various points in the Adaptive Management cycle. Although this framework outlines management activities for evaluation, none of these activities will be implemented until the appropriate processes are followed to disclose anticipated impacts on Tribes, stakeholders, and endangered birds.

1.4 Nature and timing of agency and MRRIC involvement

In developing this framework, the Technical Team had some engagement with agencies and the MRRIC Working Groups (e.g., a 3-hour meeting with the Fish and HC Work Groups on May 21, 2018 to present some exploratory analyses; summaries of the Fort Peck AM framework at the May 22-24 2018 MRRIC meeting; update presentation to a joint web meeting of the Fish and HC Work Groups on September 4, 2018; an update on progress at the October 30, 2018 Fall Science Meeting), and the example hydrographs were presented in the 2017 AM Report. This document is a starting point for further engagement between the agencies, MRRIC, Tribes and stakeholders, and no final management decisions have been made at this time.

The Technical Team input informing this document has been focused on the species needs and potential management actions to achieve those needs, recognizing further engagement will be needed about framework components or criteria that may involve significant value judgments, particularly as they might pertain to impacts on Human Considerations (HCs). The development of specific alternatives in potential subsequent NEPA analyses will afford opportunities to consider relevant trade-offs, refine action descriptions and develop appropriate decision criteria.

1.5 Approach

The Technical Team was tasked to formulate test flow releases from Fort Peck Dam for pallid sturgeon and an adaptive management framework for their implementation. It was also asked to review information generated since the Effects Analysis and reprioritize Level 1 and Level 2 actions in the Upper Basin as needed to reflect increased priority for a test flow release from Fort Peck Dam. The Technical Team undertook five primary activities related to this charge, as follows:

Table 1. Summary of Activities undertaken in the development of this framework.

Activity	Rationale and Deliverable
1. Design and preliminary analysis of two conceptual hydrographs	• Learn more about hydrologic possibilities and their implications for frequency of occurrence, geophysical differences, potential for HC impacts • Summary in Section 2 below.
2. Design and population of Effects Pathway Diagrams.	• Organize what is known and what is uncertain about cause-effect relationships in a way that helps clarify key uncertainties for technical and communications purposes.
3. Expert survey to review technical priorities and opportunities for studies and actions.	• Survey what a broader array of experts consider, on the weight of current evidence, to be the state of knowledge on limiting factors and biological needs; seek diverse opinions on and ideas for studies. • Summary findings are discussed in Section 3 below. • A description is provided in the Appendix
4. Consolidation of expert views and proposed modifications of Level 1 and Level 2 studies.	• Aggregate the above learning into a revised initial proposed set of studies • A discussion of outcomes is provided in Section 3. • Proposed study tables are in the Appendix
5. Design of a proposed adaptive management implementation framework for Level 1 and Level 2 studies.	• Consider a smart implementation method for the studies that is sensitive to policy considerations and system conditions • A discussion of outcomes is provided in Section 3.

1.5.1 Activity 1: Design and preliminary analysis of two conceptual hydrographs

The Technical Team formulated two flow regimes (conceptual hydrographs) to illustrate how hydrograph development might proceed when formulating alternative hydrographs for evaluation in compliance with the 2018 BiOP. Some preliminary analyses of these hydrographs were conducted using HEC ResSim and HEC RAS modeling similar to how alternatives were evaluated in the MRRMP-EIS (USACE 2018). Results of these exploratory analyses were presented to the agencies and the MRRIC Fish and HC Work Groups on May 21, 2018.

The general approach to developing example conceptual hydrographs was to define hypothesized biological functions of the parts of the conceptual hydrographs that would drive flow-release strategies. The functions anticipated for the hydrograph, related to reproductive ecology of the pallid sturgeon, are: 1) attractant flow to motivate pallid sturgeon movement as far upstream as possible to maximize drift (larval dispersal) distance, 2) flows that will retain the fish in the upstream reaches, 3) an additional flow pulse to aggregate fish and create a spawning cue, and 4) and low flows on the receding limb of the hydrograph to minimize velocities, and therefore, to maximize drift time. Figure 1 shows the reproductive functions relative to the historical regulated and unregulated flows at Fort Peck Dam.

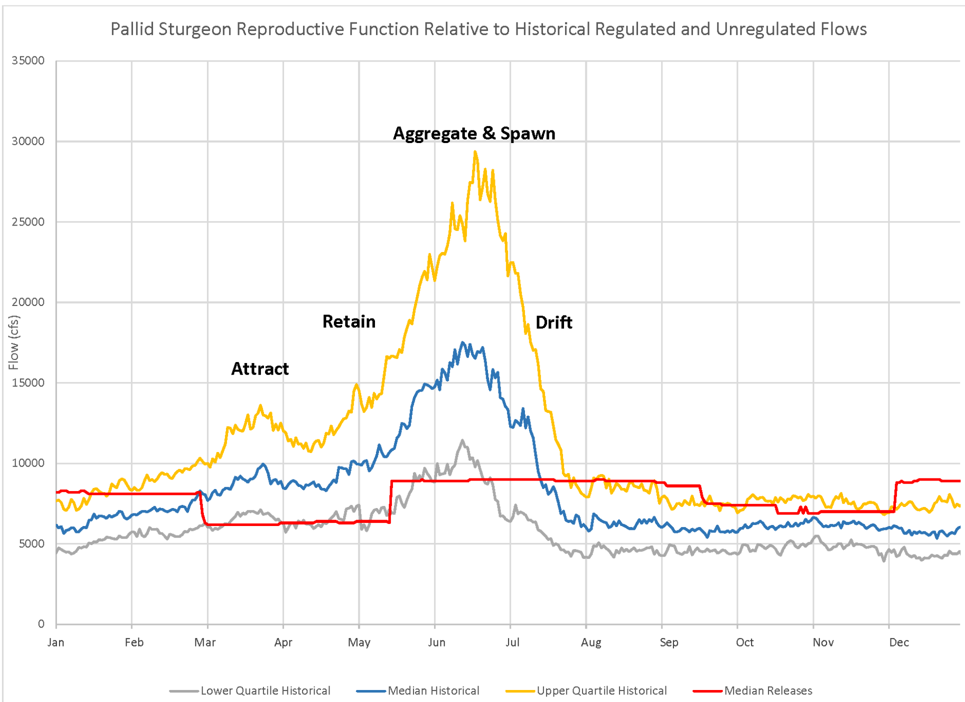

Figure 1. Pallid sturgeon reproductive functions relative to historical regulated and unregulated flows at Fort Peck Dam.

The examples presented are based on the objectives for the pieces of the hydrograph that are hypothesized to support reproductive functions for the pallid sturgeon, and serve as proof of concept.

1.5.2 Activity 2: Design and population of Effects Pathway Diagrams

The Technical Team, supported by a broader group of agency and technical experts (see acknowledgements at the front of the report for a list), created four draft Effects Pathway Diagrams to help organize discussions of what is currently hypothesized as links between system operations and impacts to pallid sturgeon. There is one diagram per hydrograph component: A) Attraction and holding (in the Missouri River); B) Spawning; C) Drift; D) Post-Drift. These diagrams will be shared once further technical review has occurred.

Figure 2: Illustrative screenshot of one of four Effects Pathway Diagrams

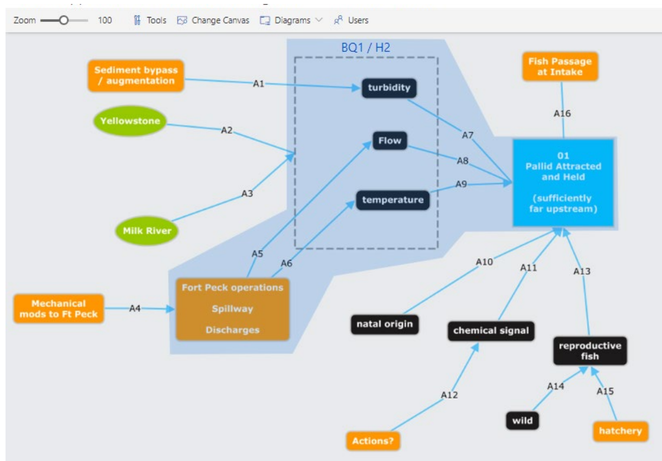

Figure 2 shows one example, for hydrograph component A. It shows the main links of influence between factors that could limit the ability to attract and hold pallid sturgeon in the Upper Missouri River when desired, and possible management actions that could theoretically address them. These diagrams are simpler forms of the more comprehensive conceptual ecological models (CEMs) developed for the Effects Analysis. Overlaps with Big Questions and Hypotheses in the Effects Analysis will ultimately be illustrated on the diagrams. The diagrams are not intended to be comprehensive; rather, they focus on the main linkages that the Technical Team viewed to be of most significant interest given the state of science at the time of development. They also do not provide a conclusion or direction for action; they are a simply a visual representation of what scientists currently believe may be potential linkages. As the science about each of these hypotheses continues to develop it may confirm or disprove linkages, ultimately informing discussions on management actions that could be taken for the species, in a logical transparent process.

Each numbered linkage in the diagrams corresponds to a separate summary of what is known about the link and what is uncertain. The information has been collated from existing documents, distinguishing information known before and after the Effects Analysis in order to make clear the evolving understanding, and to highlight new information which emerged subsequent to the Effects Analysis. Review of the documents characterizing the linkages developed by the Technical Team is ongoing, and additional review is still required and will occur according to internal agency processes. Disposition of the final reports and supporting documents and their possible future use has yet to be determined.

1.5.3 Activity 3: Expert survey to review technical priorities and opportunities for studies and actions.

Concurrent with developing the influence diagrams and discussion documents, and structured in a way that mirrors the diagrams, an Expert Survey was undertaken to probe the views of a broader range of experts for their opinions on the current state of the weight of evidence for various questions. The experts represented a range of institutional, technical and geographical perspectives*. Experts were chosen based on their experience with past research completed on the Upper Missouri River.

The expert survey was organized to mirror the structure of the SAMP table 41 (reproduced as Table 8 in the Appendix) and asked, for each potential limiting pathway of the four Effects Pathway Diagrams (see Appendix for more details), the following questions:

- What is your degree of confidence, based on the balance of evidence known today, that [pathway X] contains some element that could be considered to be limiting pallid sturgeon?*†

- What is your degree of confidence, based on the balance of evidence known today, there is sufficient understanding to correctly specify the physical or biological requirements for a management response?

- What is your degree of confidence, based on the balance of evidence known today, that there could be a Level 3 or Level 4 solution that could, if needed be available to remove the issue as a limiting factor?

In each case, experts were asked to explain their responses and to provide suggestions of studies that might be implemented to reduce the uncertainty surrounding these questions.

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* Shown in the acknowledgements section, anonymous summaries presented in the Appendix.

† Limiting is defined here as being or containing a system variable for which the current state does not meet a minimum value or threshold required to enable recruitment to age 1 to occur to a sufficient extent to sustain a minimum viable population, and therefore for which some change from the current condition would be essential for recruitment to age 1 to happen. It may function as such independently or as a co-limiting factor (i.e. when coupled with another variable).

1.5.4 Activity 4: Consolidation of expert views and proposed modification of Level 1 and Level 2 studies

Following the survey, a series of activity assessment matrices were developed. These matrices were used to organize specific potential Level 1 and Level 2 activities that could be implemented to reduce the various uncertainties that are discussed in the diagrams and discussion documents. Several hundred ideas for potential avenues of investigation were initially gathered. They were filtered and aggregated by the Technical Team over several rounds (by, for example, removing duplicates and items already in the SAMP) to reduce the ideas into specific Level 1 and Level 2 activities that could integrate with and build upon those already in the SAMP. More detail on this process is provided in the Appendix. Some high-level findings of this process are presented in Section 3.

1.5.5 Activity 5: Design of a proposed adaptive management implementation framework for Level 1 and Level 2 studies.

As initial information from the above activities became available, the Technical Team engaged agency staff and leadership in discussions about what constituted an appropriate framework. It was determined that mechanisms utilized in the SAMP served as an adequate basis for the presentation of the framework for Fort Peck. Accordingly, the same basic structure as was used in the SAMP has been employed herein. For example, the Pallid Sturgeon Framework described in section 4.2.1 of the SAMP, which refers to research (Level 1); in-river testing/experimentation (Level 2); scaled implementation (Level 3); and implementation at the ultimate scale required (Level 4), is retained and underpins the Fort Peck AM Framework.

The Framework is expected to accelerate the identification of recruitment bottlenecks, resulting in a more strategic and focused process for identifying potential management actions for implementation. It also promotes learning that may result in the refinement of Level 2 or 3 actions. This approach has the added benefit of minimizing impacts to stakeholders and avoiding unnecessary implementation costs. At any time during the Framework's implementation, it may become apparent that: 1) a particular action is not needed, 2) a proposed action requires modification to be effective, or 3) that some new action not previously evaluated is required.

1.6 Framework scope

The Fort Peck AM Framework presented in this report was developed by the Technical Team so as to assess critical uncertainties regarding recruitment of pallid sturgeon on the upper Missouri River while maintaining opportunities for recruitment on the Yellowstone River.. It relies heavily upon the MRRP AM processes described in the SAMP as a basis for its implementation. These processes would apply additional factors to the prioritization of potential Level 1 and Level 2 studies and help refine the related decision criteria. Additional analyses of some proposed Level 2 experiments may be required to more fully assess effects, and these analyses may result in some refinement of the actions and related framework parameters. The framework does contain:

- A generalized proposed approach to identifying and tracking high priority hypotheses for now and in future AM cycles;

- Building on the SAMP, a refined list of suggested Level 1 and Level 2 pallid sturgeon studies to be considered for implementation; these pertain to issues for which there is a relatively broad scientific consensus that there is a limiting factor or where opportunities exist for low-cost studies to reduce uncertainties in situations where existing evidence is thin;

- Two example conceptual hydrographs and brief discussion of their origin and significance for future planning;

- Descriptions of situations in which system conditions may favor actions to help meet MRRP objectives.

The framework does not contain:

- Specific test flow hydrographs that are ready to implement.

    - Rationale: The Technical Team did not evaluate the effects of the example hydrographs on authorized purposes.

- Fully-specified Level 1 and Level 2 studies

  - Rationale: The study tables presented in this document characterize the studies, but full study designs have not been prepared. Further work is required to design / specify them to a sufficient level for detailed cost estimates and for implementation.

- Proposals on HC monitoring needs.

  - Rationale: HC monitoring may ultimately be an important factor, but specific needs for HC monitoring cannot be predicted without first specifying the precise nature of the actions to be examined.

Possible next steps for addressing these needs are discussed in Section 4.

2 Description of Fort Peck Hydrographs for Pallid Sturgeon Recruitment

2.1 Overview

In helping inform this study, the Technical Team was tasked with developing a hydrograph for testing recruitment of pallid sturgeon to age-1 on the Upper Missouri River using the best scientific understanding of biological needs of the fish, recognizing that fish passage at Intake Dam on the Yellowstone River is imminent, and that management actions at Fort Peck should complement, but not detract from, potential for successful recruitment on the Yellowstone River. The Technical Team formulated two hydrographs that could be used to test hypotheses. They are described in the following sections.

A fundamental assumption of the conceptual hydrograph design process was that the unregulated flow regime could be used to fill in gaps and detail where current understanding of biological needs was insufficient to parameterize the hydrograph based on hypothesized functions. In this process, the unregulated flow regime is used as a template for constructing low flows, high flows, peaks, timing, and rates of rise and fall. The argument for using elements of the unregulated flow regime is based on the present lack of specific, quantitative understanding of fish responses to elements of the annual hydrograph (Jacobson and Galat, 2008). Without specific, quantitative understanding, the next-best option is to use elements of the natural flow regime that existed as the species evolved. A counter to this assumption is that the system is highly altered (highly fragmented) and many of the fish are "naïve" hatchery fish. These factors might diminish the value of the natural flow regime in eliciting a behavioral response. For the conceptual hydrographs presented herein, the Technical Team relied on recent information on fish responses to help design parts of the flow regime; and then used the natural flow regime to fill in other components.

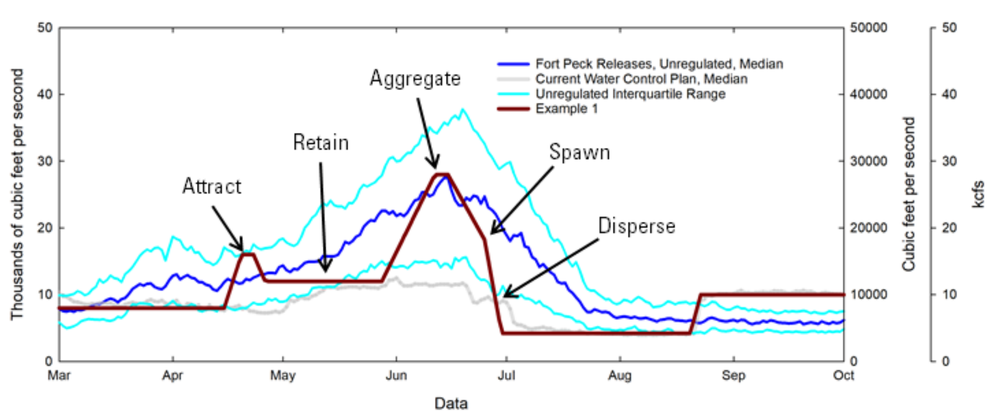
2.2 Example conceptual hydrograph 1

Newly compiled information (Pat Braaten, U.S. Geological Survey, unpublished data) documents consistent movements of fish upstream on the Upper Missouri River (UPMOR) in spring and early summer when discharge on the UPMOR is approximately twice that of the Yellowstone

River (YSTON). This doubled discharge criterion was used therefore as an estimate of an initial attractant flow (in both conceptual hydrographs). Typical early-spring flows in the UPMOR are 8,000 cubic feet per second (cfs) followed by a March-April peak flow of 16,000 cfs. In a departure from the natural flow regime, the Technical Team hypothesized that the attractant pulse would be more effective if moved later in the month of April when it will compete less with the YSTON March-April pulse.

In the unregulated flow regime, the initial March-April pulse is followed by a gradual low flow saddle and then the main May-June peak (Figure 3). The May-June pulse is hypothesized to be important in retaining fish upstream in the UPMOR and to contribute to a spawning cue. An empirical basis for understanding spawning cues is lacking, including how flow functions with or without associated variation in temperature and turbidity (DeLonay and others, 2016; Jacobson and others, 2016). Two relevant pieces of information are an apparent water temperature threshold for pallid sturgeon spawning of 16°C (DeLonay and others, 2016) and the tendency for fish to spawn on the receding limb of the May-June pulse (Carrie Elliott, U.S. Geological Survey, unpublished data). With respect to the latter, 10 verified pallid sturgeon spawning events on the YSTON have ranged 0 to 24 days post peak, with an average of 12.1 days. The conditions that "cue" spawning, therefore, are hypothesized to be a receding flow when water temperatures are in excess of 16 °C.

Figure 3: The conceptual hydrograph 1, compared to median and interquartile range of the unregulated flow regime and median of flows based the current water control plan.



In another departure from the natural flow regime, the Technical Team hypothesized that return to low flows as quickly as possible after spawning will be more effective in minimizing velocities and downstream advection of hatched free embryos. The maximum fall rate to avoid excessive bank erosion is estimated to be 3000 cfs/day. Both conceptual hydrographs use this recession rate to return to prevailing operations in early July.

The Technical Team used the Index of Hydrologic Alteration (IHA) software (The Nature Conservancy, 2005) to calculate percentiles of flow-pulse parameters. We used two datasets: the Daily Routing Model (DRM) (U.S. Army Corps of Engineers, 1998) and a new unregulated flow alternative from ResSim (unpublished data, Ryan Larsen, USACE). The DRM modeled flows 1898 – 1997 and the ResSim modeled 1930 – 2012. A plot of the two datasets for overlapping time periods shows fairly close correspondence, with r-square = 0.948.

IHA was run separately on both the DRM and ResSim to allow for analysis of variability due to input datasets. IHA was configured to produce only high-flow pulses – in other words, to omit other environmental flow components (EFCs) such as sustained high flows and extreme floods. Using this configuration all high flow pulses were lumped in one analysis. IHA was also configured with two different seasons in order to separate early and late pulses (Table 2).

Table 2: Selected IHA-generated environmental flow components expressed in percent exceedance ranges based on HEC-ResSim and Daily Routing Model analyses

Table 1. Selected IHA-generated environmental flow components for DRM and HEC-ResSim modeled datasets. Discharges are in cubic feet per second. Duration is in days. Rates are cubic feet per second per day.

	HEC-ResSim Model (1930 - 2012)					Daily Routing Model (1898 - 1998)				
	10	25	50	75	90	10	25	50	75	90
EFC First Season Flow Parameters										
High flow peak	10,800	11,370	13,260	17,350	34,370	11,310	12,120	13,400	16,630	26,520
High flow duration	2	3	5	11	35	1	2	3	8	22
High flow rise rate	526	750	1,394	2,777	3,889	685	1,000	2,000	3,700	5,851
High flow fall rate	-2,506	-1,544	-1,046	-648	-432	-3,892	-2,642	-1,500	-743	-482
EFC Second Season Flow Parameters										
High flow peak	11,020	12,560	15,920	27,350	47,280	13,000	15,060	23,780	34,970	48,270
High flow duration	2	3	12	47	100	2	4	32	74	102
High flow rise rate	480	675	1,090	1,923	2,806	415	675	1,121	2,030	4,762
High flow fall rate	-3,012	-1,673	-937	-610	-423	-2,850	-1,982	-1,020	-691	-492

The first peak season was limited to March 1 to April 30 and the second peak season was limited May 1 to July 31.

Design of the conceptual flow regime was based on adding to the median flows under the existing water control. Additionally, the magnitudes of flow pulses were scaled to the early spring discharge of 8,000 cfs. Based on the doubled-discharge attraction criterion, the first peak would be 16,000 cfs.

The next step was to evaluate the percentile of 16,000 cfs peak magnitude among the population of March-April pulses. The distributions of percentiles of peak magnitudes for March-April and May-June peaks provide a basis for interpolating the percentile of the March-April pulse and for estimating the magnitude of the May-June peak. Using this approach, the 16,000 cfs March-April peak pulse magnitude is approximately the 68% percentile (ResSim and DRM are in close agreement). Accordingly, the 68% percentile in the May-June peak pulse magnitude is estimated at 24,000 cfs in the ResSim and 32,000 in the DRM.

For analysis, flows up to 14,000 cfs are assumed to be provided by the powerhouse (U.S. Army Corps of Engineers, 2006). Using the powerhouse would maximize energy generation, and thereby potentially minimize impacts. During the March-April attractant flow, warmer temperatures do not seem to be necessary (P. Braaten, US Geological Survey, unpublished data), so providing most of the early pulse with cold water from the powerhouse would be biologically acceptable. Flows in excess of 14,000 cfs would necessarily come from the spillway; spillway flows could also contribute warmer water, hypothesized to help promote spawning and maturation of free embryos.

The proposed pulses for conceptual hydrograph 1 were constructed by using the median rate of rise to bring discharge up to the peak pulse magnitudes, after which the peak was held for 3 days (Figure 3). The median rate of fall was then applied to bring the discharge back to the 1.5 times the base, late-winter flow for the inter-pulse saddle. The magnitude of the inter-pulse saddle is another potential variable that can be adjusted in the future, but for the initial implementation the 1.5 times multiplier was determined by the Technical Team to be a reasonable value for testing. The specified rates of rise and fall, and along with the magnitude and duration of the peak, define the duration of the pulse, so the historical percentile of duration is not used in the calculation. The fall rate after the May-June pulse is set to the 50th percentile of the unregulated regime for 12 days (978.5 cfs/day); after the 12th day the fall rate is 3,000 cfs/day until return to conventional operations in early July. Operating discharge at the end of the May-June pulse will vary depending on system storage and other parameters; however in conceptual hydrograph 1, flow is maintained at 4,200 cfs through August 20 to match median conditions.

As noted previously, the timing of the first pulse departs from the unregulated flow regime. The start date of the first pulse was moved approximately two weeks later compared to the unregulated flow, to April 15. This serves to enhance the contrast between UPMOR and YSTON discharges. The start date for the May-June pulse was set to May 28th from inspection of the unregulated flow regime.

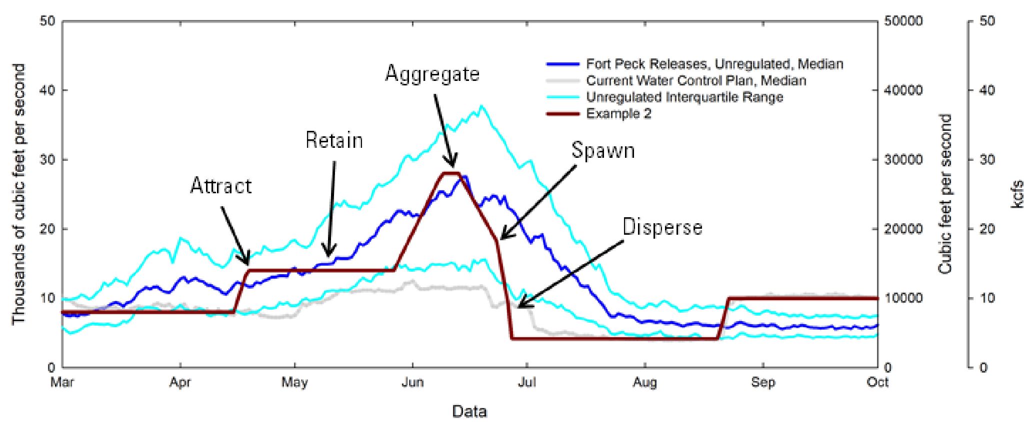
A minimum lake level for Fort Peck Reservoir is necessary to provide spillway flows, a condition which may constrain how often spillway releases can contribute to flow pulses. In general, pulses could be attempted any time the pulse is slated to start and the lake level is above the spillway. In some years, this could mean that pulses will not complete. In such cases, discharges should recede at the rates already described (978.5 cfs/day for 12 days, and then at 3,000 cfs/day until conventional operations resume).

2.3 Example conceptual hydrograph 2

Conceptual hydrograph 2 follows the same principles used in conceptual hydrograph 1, but simplifies the conceptual hydrograph and uses powerhouse flows as a release metric. The attractant flow starts at the same time (April 15) and increases at the same rate as conceptual hydrograph 1, based on early spring flows of 8,000 cfs. The attractant flow is limited to powerhouse capacity, nominally at 14,000 cfs. Moreover, the flows are maintained at powerhouse capacity through the end of May when the May-June pulse starts. The rationale for keeping the flows high through this period – foregoing the inter-pulse saddle – is the hypothesis that persistent high flows will be needed to hold migrated, reproductive adults upstream near the dam.

The second pulse begins on May 28, rises at the rate extracted from the natural flow regime to a peak at double the power house capacity, that is, 28,000 cfs. Discharge over 14,000 cfs comes from the spillway and is presumably warmer than the powerhouse water. Similar to conceptual hydrograph 1, the hypothesis is that the pulse of warmer water will help cue reproductive behavior. The peak magnitude is presently arbitrary and could be adjusted through monitoring of fish behavioral responses and adaptive management. Because the added discharge necessarily comes from the spillway, available lake levels will constrain how often and how large this pulse can be. Similar to conceptual hydrograph 1, the May-June pulse could be initiated in any year when water is available at or above the spillway elevation, but pulses might be cut short due to lack of water. The peak is maintained for two days and then discharges decline at rates extracted from the natural flow regime (978.5 cfs/day) for 12 days. After 12 days, recession rates are the maximum allowable (3,000 cfs/day) until conventional flow operation is achieved. Low flows at this time of year could be adjusted to minimize velocity and downstream advection of free embryos; conceptual hydrograph 2, as shown in Figure 4, uses 4,200 cfs as base discharge from early July to August 20, which is similar to current median conditions; conventional releases would provide somewhat faster downstream advection but may minimize water-supply concerns at irrigation intakes.

Figure 4: Conceptual hydrograph 2, compared to median and interquartile range of the unregulated flow regime and median of flows based on the current water control plan.



2.4 Discussion

The examples presented here are based on the objectives for the pieces of the hydrograph that are hypothesized to support reproductive functions for the pallid sturgeon. These two conceptual hydrographs serve as proof of concept. It is certainly possible to design additional conceptual hydrographs that would reflect other hypotheses about the hydrograph characteristics, whether those characteristics are chosen to support biological functions or to minimize socio-economic conflicts.

Evaluation of the conceptual hydrographs may proceed through several approaches, but the preferred approach is likely to involve: 1) codification of the conceptual hydrograph into release rules, which may include precludes and proration; 2) simulation of release results using a time series of discharges based on the period of record or another appropriate time series (HEC-RESSIM); 3) routing of flows downstream through the river segment below Fort Peck Dam and into Lake Sakakawea (HEC-RAS); and, 4) analysis of flow effects on pallid sturgeon reproductive ecology, bird Emergent Sandbar Habitat (ESH) and nesting, and human considerations. Effects on pallid sturgeon reproductive ecology will be necessarily indirect because reliable, direct models do not presently exist. For example, in the near term, success of the attractant pulse may be evaluated through estimation of the frequency, magnitude, and duration of simulated pulses relative to pulses in the unregulated flow regime. Similarly, effects of low flows intended to maximize drift time may be evaluated through estimation of relative performance calculated through simple advection-dispersion models.

A preliminary example of the four-step evaluation process was developed and presented to MRRIC Fish Work Group and HC Work Group members (May 21, 2018). The preliminary evaluation served as an additional proof of concept and helped the Technical Team understand the steps required. Feedback from Tribes, stakeholders, MRRIC members and agency scientists will be helpful in designing evaluation methods for subsequent analyses.

The models used in the analyses to evaluate relative performance in terms of pallid sturgeon reproductive success will necessarily be indirect and simplified. It is envisioned that the models will improve continuously through application of adaptive management, however. Ongoing research that is focused on improving effects models, and the accumulation of information through monitoring of the results of flow releases, will improve realism and utility of the models. These improvements will assure that future decisions are substantially better informed.

3 AM Framework

3.1 Goals and management objectives for Upper River pallid sturgeon

The objectives for Upper River pallid sturgeon (as well as associated metrics and targets) are discussed in section 4.1.1 of the SAMP. The fundamental objective for pallid sturgeon in the Missouri River is to "Avoid jeopardizing the continued existence of the pallid sturgeon from the U.S. Army Corps of Engineers actions on the Missouri River" (USFWS 2013). This fundamental objective is supported by two sub-objectives:

1. Increase pallid sturgeon recruitment to age-1. (Note that this sub-objective refers to recruitment of naturally produced fish, not hatchery produced fish.)

2. Maintain or increase numbers of pallid sturgeon as an interim measure until sufficient and sustained natural recruitment occurs.

Possible targets for sub-objective 2 are discussed in the SAMP (e.g., a self-sustaining, genetically diverse population in excess of 5000 adult fish in each management unit). These targets may be revised as part of the development of the Range-wide Stocking and Augmentation Plan (U.S. Fish and Wildlife Service, in revision), or through possible future revisions to the Recovery Plan (USFWS 2014). The Great Plains Recovery Planning Management Unit (or RPMU) includes two key sub-regions: 1) the Upper Missouri River below Fort Peck Reservoir to Lake Sakakawea, and 2) the Yellowstone River from Intake Dam at Intake, Montana to its confluence with the Missouri River. Therefore, it is logical (and consistent with the Recovery Plan) to manage pallid sturgeon in these two sub-regions as one population. Actions may be investigated or implemented in either or both of these two sub-regions; harmonious and complimentary actions providing the best opportunity for recruitment to the upper basin pallid sturgeon population would be favored while actions potentially detracting from that aim would generally be avoided.

3.2 Key insights from Activities 2 and 3 - Assessing Factors Potentially Limiting Recruitment to Age 1

Table 3 summarizes the perspectives of ten pallid sturgeon experts regarding the extent to which current evidence supports or refutes the notion that each of 17 potential Effects Pathways (described further in the Appendix) is currently limiting, in whole or in part, the recruitment of a minimum viable population of age-1 pallid sturgeon in the Upper River. (Note that many of the potential pathways, such as drift temperature, distance and rate) are closely interrelated, but they were treated separately for the purposes of this exercise. Also note that this table was developed using the median (to rate the degree of support) and standard deviations of responses (to rate the degree of agreement) to survey questions that are also described in the Appendix. Aggregated information is summarized in a single view in Figure 5.

Table 3: Summary categorization 17 potential Effects Pathways from expert survey

		More Agreement	Some Agreement	Less Agreement
		SD =<1.5	1.5 < SD <= 3	SD >3
Evidence Appears to Support	Median >= 3	A) Attraction - Flow A) Attraction - Temperature Ci) Drift - Drift distance Ci) Drift - Drift temperature Ci) Drift - Drift rate	A) Attraction - Reproductive Fish	
Evidence Possibly Supports	Median >= 1.5		A) Attraction - Turbidity Cii) Drift Mortality - Predation	
Evidence is Ambivalent	Median <1.5 & > -1.5)	D) Post-Drift - Other Mortality	A) Attraction - Chemical Signals B) Spawning - Aggregation Behavior Cii) Drift Mortality - Filamentous algae A) Attraction - Natal Origin B) Spawning - Spawning habitat	
Evidence Possibly Refutes	Median <= -1.5			
Evidence Appears to Refute	Median <= -3		D) Post-Drift - Overwintering	B) Spawning - Mortality

				D) Post-Drift - Food and Foraging

Figure 5: Expert perspectives on Limiting Factors sorted by median response

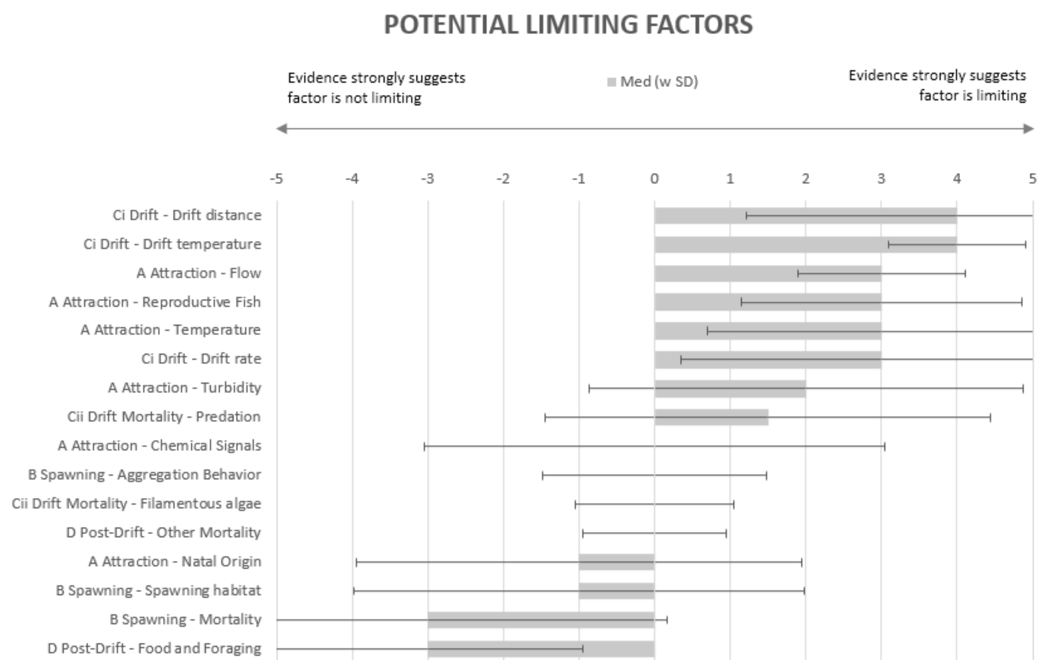


Table 3, along with a close reading of the detailed technical survey responses, suggests that:

- In general across the range of experts, the current interpretation of the available evidence is that pallid sturgeon recruitment in the Upper River is most likely limited, in whole or in part, by flows and temperatures to attract fish to the Missouri River, and by issues related to insufficient larval development (i.e. determined by available distance, temperature and current velocities) during drift.

- There is some (but not complete) agreement that there are presently insufficient numbers of reproductively viable adults in the river.

- There is some agreement that evidence suggests that a lack of turbidity during attraction, and/or excessive mortality during drift, could also be factors that in whole or in part could be limiting pallid sturgeon.

- Most (but not all) experts think that the available evidence appears to refute the notions that post-larval-drift issues (e.g. growth and overwintering) currently contribute to limiting the recruitment of a minimum viable population of pallid sturgeon.

- This leaves a range of potential limiting factors that, with varying degrees of expert agreement, do not appear yet to have sufficient evidence with which to form an opinion, but about which experts were sufficiently concerned to include in the diagrams. These include the role of various forms of mortality in the drift and post-larval-drift periods, the potential for pheromones to be used to supplement or replace attractant flow pulses, problems potentially related to hatchery breeding or acclimation, and the availability of spawning habitat.

In the view of the Technical Team, the leading candidate limiting factors remain the same as they were at the time of the Effects Analysis and, generally, as stated in the BiOp: i.e. those concerning attraction and drift flows, temperatures, and, to a lesser extent, turbidity. These factors, and the Level 1 and Level 2 management actions implied by them, are already quite well addressed in the SAMP, and further elaboration on specifics have been gleaned from the surveys. However, there also remain other factors that could be limiting pallid recruitment and about which it is not possible to comment further for lack of available evidence. In refining the potential management actions, the Technical Team therefore also considered in further detail suggestions from the expert survey regarding reasonable opportunities to provide at least some evidence with which to inform future decision-making cycles.

- Already in SAMP Chapter 4 and Appendix C, previously vetted by experts:
    - Attractant, retention flows (pull, keep fish upstream)
    - Drift flows (maximize development time)
    - Temperature role (maximize development rate)
    - Turbidity role (minimize predation)

    - Food-producing flows (maximize food-producing habitats)
    - Lake Sakakawea elevation modifications (maximize available drift distance)
- Partly in SAMP Chapter 4 and Appendix C, previously vetted by experts:
    - Integrative sensitivity analysis through population modeling (all actions – this will be addressed in the assessment framework described in Appendix D)
    - Turbidity enhancement using local sources (i.e. downstream sediment augmentation instead of bypass through reservoir)
    - Temperature enhancement using Milk River and spillway flows (instead of structure in reservoir)
    - Effect of overbank flows on drift, dispersal (increase range of flows under consideration in drift phase)
    - Models, experiments, condition assessments for condition of age-0 (assess if food is limiting)
- Absent from SAMP; introduced by experts during diagram development and expert survey for this Fort Peck AM Framework. (Please see the subsequent discussion on how these issues were assessed):
    - Chemical attractants assessment (chemical isolation, imprinting, mesocosm studies, experiment)
    - Filamentous algae assessment (assess distribution, mesocosm studies)
    - Predation assessment (assess stomach contents, fish community)
    - Spawning habitat (assess availability in river segment below Fort Peck Dam; evaluate designs for construction if limiting)
    - Overwintering habitat (evaluate whether it is limiting)
    - Natal origin (evaluate wild, Hatchery-Origin Pallid Sturgeon (HOPS), families and reproductive success – augmentation science addressed in BQ 6)

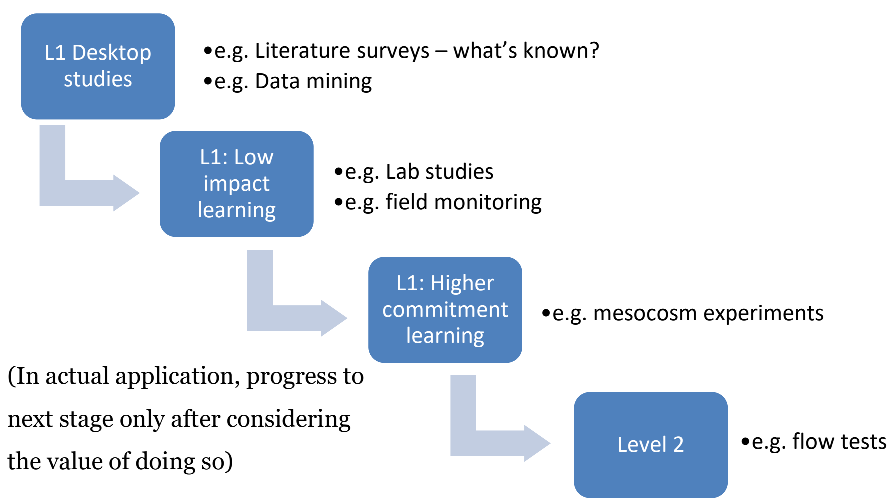
3.3 Concepts for structuring and organizing a framework

Various strategies can be employed to prioritize and sequence activities and to guide the formulation of an AM framework. The following concepts helped guide the structuring of the framework for the Upper River:

- Focus on hypotheses for which there is general agreement among experts that a factor is limiting recruitment
- Focus on quickly and/or inexpensively resolved hypotheses
- Focus on hypotheses that could provide unequivocal results regarding management options
- Be opportunistic, wherein Level 2 experiments are undertaken when relatively infrequent conditions favoring studies occur
- Emphasize early learning opportunities to inform Level 2 experiments and implementation decisions

Some studies are dependent upon others, providing logical sequencing (e.g., establishing telemetry networks prior to Level 2 studies with monitoring of movement). Ideally (i.e. where time was not a pressing concern), we might imagine learning about any given potentially limiting factor as following a logical and sequential cascade as illustrated in Figure 6.

Figure 6: Conceptual cascade of learning from Level 1 to Level 2 studies



If considering a potential limiting factor for which existing information is sparse, a first step might be to perform a literature survey on areas of potential interest, such as pallid sturgeon in other areas, other kinds of sturgeon or other similar species. This might be augmented with desk-based studies of existing bio-physical data (e.g., historical turbidity or flow records) to compile evidence for or against the existence of a limiting factor. For many factors, this process was undertaken during the Effects Analysis.

Next in this concept, if warranted, lower cost learning activities might be undertaken (if they have not been already), such as laboratory studies or smaller scale field monitoring. If the situation further suggests it important, the next level may be some form of mesocosm experiment, again if this has not already been done or is underway. Finally, if the science still suggests that an issue is sufficiently important and if the value of the information is worth the costs, a Level 2 manipulative field experiment such as a flow release may be appropriate.

This model assumes that time is not a pressing factor, which is not the case in this situation. Thus for many of the components of the current SAMP, several Level 1 actions are planned to be implemented in parallel to reduce the time taken to move to Level 2.

The 'cascade of learning' from Level 1 through Level 2 (and ultimately through to L3 and L4) can in theory be applied to each and all of the potential effect pathways shown in the diagrams. Given that resources are limited, it is neither possible nor desirable to pursue all of them in parallel. Instead, the Technical Team proposed focusing attention on Level 1 and Level 2 studies that pertain to Big Questions / effect pathways that are considered to be the most likely liming factors, and/or those that can otherwise provide high information value on other issues for a low cost.

As discussed in Section 2.3 of the SAMP, it is not the role of the Technical Team to say which of the potential Level 2 actions (test flows or projects) should be implemented. Rather, the opportunities for and benefits of any such testing will be assessed and discussed as part of the MRRP Science Update Process, then weighed against the costs, effects and other considerations as part of the MRRP Strategic Plan Update Process. While flow modifications to affect attraction or drift may be likely candidate Level 2 actions to examine in more detail, from a strictly scientific perspective, so too might other management actions. Decisions as to whether these actions should also be examined will be made by agency leadership following the governance process outlined in the SAMP.

3.3.1 Timing of Level 2 test flows

A key consideration in the implementation of this framework concerns the question of how quickly to move along the continuum from Level 1 to Level 2 actions. Much can be learned from monitoring system variables on a passive basis. Many of the Level 1 studies proposed to date, and that have been further suggested in the Appendix to this framework, seek to do so. To be able to take advantage of passive monitoring, this framework has identified monitoring to be implemented when conditions present.

However, relying on only passive monitoring of system conditions may also unnecessarily extend the period required for learning to occur, since there are likely to be sequences of years where the conditions limit the degree to which new information can be gleaned.

Active Level 2 flow interventions are often (but not always) of value because they offer the ability to add contrast to variables to be studied, or to increase the frequency of higher contrast situations. Due to physical limitations on system operations and the large inherent variability in natural inflows, Level 2 flow manipulations cannot be implemented on demand and on a set schedule. Instead, it is necessary to adapt effectively to system conditions that arise and to make the most of them on an opportunistic basis. Thus, a one in-ten-year wet year event that naturally occurs during the attraction hydrograph component period might be ‘nudged’ into being a one-in-twenty-year event through the application of a flow manipulation. Similarly, an unusually dry summer might afford an opportunity for creating unusually low flows to evaluate the drift component of the hydrograph.

Thus it is important to emphasize that much of the value afforded by Level 2 test flows could be gleaned from opportunistic and passive monitoring, and that components of the conceptual hydrographs identified by the Technical Team may occur under the current operations for the System.

There may be circumstances when it is advisable to implement Level 2 flow manipulations to accelerate learning, shortcutting the cascade concept presented above. Certain things need to be in place for a Level 2 flow test to have learning value, however.

To do a Level 2 flow release (as opposed to just passive monitoring), a detailed Level 2 experimental plan (or the ability to develop one quickly) is needed. A detailed plan would specify that, under a given set of conditions (e.g., pool level, projected runoff, etc.,), a specified hydrograph (or component thereof) could be implemented.

The System state conditions that would be necessary for the L2 experiment to take place must exist. These could include particular specifications of system storage, snowpack, tributary conditions, and potentially some HC factors. Such system conditions would need to be within an appropriate range for the Level 2 experiment to be potentially useful in any given year.

A decision to prepare for such a study would necessitate answering a number of questions. What is the experimental hypothesis, what monitoring is needed to obtain meaningful results, etc.? Is appropriate instrumentation in place in the river (or the ability to deploy it quickly)? Is instrumentation in place to measure environmental covariates (e.g., turbidity, dissolved oxygen, etc.)? Are sufficient field crews available to carry out the work?

3.3.2 Considering the trade-off between early Level 2 flow releases versus focused Level 1 studies leading to Level 2 later

All of these factors may require considerable resources to plan for and to be ready to execute in any given year. Before moving to Level 2 flow releases, it would be important to consider the trade-offs that exist between undertaking Level 2 flow releases sooner rather than later.

Notionally, the difference between what might be learned via a flow release relative to passive monitoring of the system or Level 1 work alone can be regarded as the ΔI (i.e. information delta between the two, the net information benefit of performing the test release relative to passive monitoring only).

For some BQs / limiting factors pathways, the understanding of fundamentals is low and so there is a low or possibly zero ΔI. (i.e. doing a flow experiment is unlikely to yield anything to improve learning relative to monitoring ambient conditions because of a lack of scientific understanding regarding which system variables need to be monitored or what to do with the information; indeed, the ΔI could even be worse if it detracts resources from Level 1 activities). For others, precise specifications for what needs to be manipulated under what conditions and why relative to default operations can already be articulated; in these instances there is a more compelling case for a high ΔI.

Therefore, for some BQs / limiting factor pathways, if the understanding of the Level 1 science is low (and presumably therefore the ΔI is quite low), then it might be appropriate to assign quite strict constraints on the definition of the range of conditions under which a flow release might be contemplated. For these situations, *only in the most ideal alignments of system conditions would the framework suggest a flow release in the near term* – such circumstances are rare, but present unique opportunities if they do happen.

As the state of knowledge improves over time and more is learned, the potential ΔI from a flow release improves and the conditions for a Level 2 experiment may be relaxed – making flow releases more likely in any given year. For any BQ where the science is already mature and the ΔI is already high, then the set of conditions for a Level 2 experiment may be defined more aggressively (i.e. in ways more likely in any year to occur).

Ideally, the MRRP will develop an initial summary of Level 1/ Level 2 scientific studies per state / situation during the formulation stages of any follow-on effort under NEPA. As part of the AM process, it will be necessary to periodically update the state conditions for these experiments and to reprioritize the associated Level 1 studies.

3.4 Framework design

3.4.1 Introduction

Upper River Big Questions relate to management actions that are hypothesized to increase natural recruitment were presented in the SAMP (see Table 43). The Level 2 and Level 3 actions described here are based on scientific considerations and focus on implementing fish passage at Intake Diversion Dam and exploring potential flow release changes from Fort Peck Dam, but also include other possible actions that are hypothesized to affect recruitment in the Upper Missouri River. Stocking and population augmentation is currently being implemented and is addressed elsewhere.

The overarching framework for the Upper Missouri River will be reflected in updates to the SAMP once the specific management actions, and in particular the flow actions, have been fully analyzed and the selected actions specified. The information presented in the following sections is based on the conceptual hydrographs developed for this purpose and the associated Level 1 and Level 2 studies that have been identified based upon the current state of the science. These will necessarily evolve as new knowledge is obtained with adjustments occurring as outlined in the existing AM processes outlined in the SAMP.

3.4.2 Description of actions and studies in the framework

The proposed actions, studies, metrics and decision criteria that constitute the Upper River Framework are summarized in the following tables, and their potential implementation is presented in Section 3.5. Note that the tables in this section present only those Level 1 and Level 2 studies judged to be essential based upon the assessments undertaken to date. Additional studies were identified that were considered Optional or In Reserve. A detailed summary of all the Level 1 and 2 actions considered is contained in Section 4 of the Appendix.

3.4.2.1 Notional hydrograph specification

The conceptual hydrographs developed for this exercise are described in Section 2 of this document. Parameters used to describe the hydrographs and employed in their preliminary evaluation using HEC ResSim and HEC RAS are provided in Table 4. Additional criteria for their implementation are required, including the status of Level 1 and 2 studies and their associated decision criteria. These are expected to evolve over time, as described in Section 3.5 and would vary with the hydrograph selected for implementation, which may also vary over time as learning occurs.

Table 4. Summary of parameters defining the conceptual hydrographs.

Hydrograph Component	**Parameter**	**Conceptual Hydrograph 1**	**Conceptual Hydrograph 2**
March Pulse	Minimum Pool Elevation	2225.0 ft	2225.0 ft
	Initiated on	April 16	April 16
	Magnitude	2x Fort Peck winter release	14000 cfs (max powerhouse release)
	Rate of Increase	1700 cfs/day	1700 cfs/day
	Rate of Decrease	1300 cfs/day for 12 days, then decrease by 3000 cfs until interim release is reached	1300 cfs/day for 12 days, then decrease by 3000 cfs until interim release is reached
	Duration at Peak	3 days	3 days
Interim release (post-March - May Pulse)	Flowrate	1.5x Fort Peck winter release, no downstream constraints	14000 cfs (max powerhouse release)
May Pulse	Minimum Pool Elevation	2225.0 ft	2225.0 ft
	Initiated on	May 28	May 28

Hydrograph Component	Parameter	Conceptual Hydrograph 1	Conceptual Hydrograph 2
	Magnitude	3.5x Fort Peck winter release	28000 cfs (2x max powerhouse release)
	Rate of Increase	1100 cfs/day	1100 cfs/day
	Rate of Decrease	1000 cfs/day for 12 days, then decrease by 3000 cfs until post-pulse release is reached	1000 cfs/day for 12 days, then decrease by 3000 cfs until post-pulse release is reached
	Duration at Peak	3 days	3 days
Post-pulse release (post-May Pulse)	Flowrate	4200 cfs; Post-pulse release held until Aug 31, No downstream constraints	Normal operations, No downstream constraints

3.4.2.2 Level 1 and Level 2 studies and metrics

The various studies and actions that comprise the Level 1 and Level 2 components of the framework are presented in the following tables. These tables, once ratified and fully evaluated, would be incorporated into the SAMP (e.g., as updates to Table 43). Implementation of some of the components, and particularly the Level 2 actions, would be predicated upon first establishing the conditions necessary to their implementation. These might include, for example, that System storage be above or below a specified threshold, that projected runoff be above or below a threshold as a percentage of normal, or that discharge on the Upper Missouri River relative to that on the Yellowstone River fall within a specified range at a point in time.

3.4.3 On HC Monitoring

The studies shown in Tables 5 and 6 pertain only to fish science. Establishing appropriate means of resolving key uncertainties relating to HCs (and, for that matter, to endangered birds) that could result from Level 2 actions will be important to the successful implementation of the program. However, no proposals or suggestions for HC or bird monitoring activities have been made in this document for various reasons:

First, although this framework provides suggested lines of scientific inquiry for pallid sturgeon, it is not yet known which of the possible Level 2 actions that might be of interest will actually be implemented.

Second, it is still unknown what aspects of the potential effects to HCs or birds might be uncertain, (as opposed to those which could readily and reliably be predicted from established modelling, knowledge of river / reservoir flows and elevations, etc.,). The identification of key uncertainties would need to follow from an investigation into what might be predictable based on the available information and methods.

Third, USACE already has numerous standard protocols for monitoring HC impacts that need to be reviewed with respect to impacts of actions on HCs for each specific Level 2 action that might be evaluated. For example, SAMP Section 5.3.2 describes the routine System monitoring that occurs and that could inform learning about the impacts of actions on HCs in various ways. Additional HC monitoring creates a tradeoff discussion for consideration prior or during implementation of a Level 2 study. While there are several sources of uncertainty in predicting impacts on HCs, not all uncertainties matter for the purposes of planning, and some are more significant than others for decision making. Section 5.4.7 of the SAMP includes a discussion on new monitoring requests.

In short, while HC monitoring will be an important aspect of the overall monitoring undertaken for the species in this Framework, it is too early in the scoping of the activities to specify specific suggestions on new monitoring activities.. Such discussions and engagement will be a vital role for the HC Work Group with respect to this matter in the future.

Table 5. Summary of Level 1 studies in the framework including metrics and decision criteria, presented in order of the Big Questions.

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Concurrent / Dependent Components
Studies already in-progress			
BQ1/L1/C1–Design study: complementary passive telemetry network	Detectability of telemetry tags by network receivers, variation of tag detectability with discharge-related characteristics, tag cost, tag reliability.	IF fish movements past strategic locations are successfully detected, THEN this supports deploying a larger network of telemetry receivers to help evaluate sturgeon response to flow.	C1-C2 all concurrent. Also with design of lower basin telemetry network (Table 39 - BQ1/L1/C1)
BQ1/L1/C2 – Field study: opportunistic tracking of reproductive behaviors	Degree of association of reproductive behaviors and successful spawning with monitored hydrologic characteristics.	IF there are moderate to strong associations between hydrologic characteristics and reproductive behavior, THEN this provides stronger evidence for L2 studies. However, IF successful reproductive behavior is observed in the absence of the hypothesized hydrologic characteristics AND is sufficient to have a population-level effect THEN this provides evidence against hypothesis H2.	C1-C2 concurrent
BQ2/L1/C2 - Screening: field monitoring of age-0 fish condition and diets; limitations of food or forage habitats	Indicators of starvation or impending death of age-0 sturgeon based on stomach contents (empty/full) or physiological indicators (lipid content).	IF results indicate bioenergetic constraints, THEN this provides stronger evidence for Level 2 experiments.	[In progress]

BQ3/L1/C0– Field tracking of telemetered pallid sturgeon - part of BQ1, C2	Degree of association of reproductive behaviors and successful spawning with monitored temperature characteristics.	IF there are moderate to strong associations between temperature characteristics and reproductive behavior, THEN this provides stronger evidence for L2 studies. However, IF successful reproductive behavior is observed in the absence of the hypothesized temperature characteristics AND is sufficient to have a population-level effect THEN this provides evidence against hypothesis H2.	C0, C1, C2b, C3b, 4b all concurrent
BQ3/L1/C2a- a) food limitation to age-1 - Same as BQ2/L1/C2	Indicators of food availability to age-0 sturgeon based on stomach contents (empty/full/diet inventory) or physiological indicators (lipid content).	IF results indicate that Lake Sakakawea is not limiting, THEN this provides more support for Level 2 experiments.	na
BQ3/L1/C2b - b) lethality of Lake Sakakawea to age-0	Spatial and temporal extent and variability of conditions lethal to benthic larval fish in Lake Sakakawea.	IF results indicate that Lake Sakakawea is not limiting, THEN this provides more support for Level 2 experiments.	C0, C1, C2b, C3b, 4b all concurrent
BQ3/L1/C3b - Field studies: validating advection / dispersion model (studies of age-0 larval distribution)	Spatial and temporal distributions of larvae and surrogate flow tracers to determine larval retention.	IF results indicate that free embryos can be retained in the Fort Peck segment THEN this provides more support for Level 2 experiments.	C0, C1, C2b, C3b, 4b all concurrent
BQ3/L1/C4b - Mesocosm studies: developing quantitative temperature-recruitment relationships	Temperature-dependence of pallid sturgeon developmental rates.	IF there are moderate to strong and reliable associations between temperature variation and productivity, growth, and survival, AND drift/dispersal is not limiting, THEN this provides more support for Level 2 temperature experiments.	C0, C1, C2b, C3b, 4b indicate strong temperature dependencies

BQ4/L1/C0 - Field tracking of telemetered pallid sturgeon, ideally with turbidity monitors attached. Also part of BQ1, C2 and BQ3, C0	Time trace of turbidity, concurrent with information on movement, temperature and flow.		
BQ5/L1/C1 –Field study: functional spawning habitat, Yellowstone River	River depth, velocity, substrate, and habitat stability of documented spawning habitat, and reproductive responses of adults and embryos.	IF there is sustained moderate to strong spawning habitat selection that contrasts strongly with Lower Missouri River results, AND the results agree with spawning habitats quantified for other sturgeon species, THEN this provides more support for spawning habitat designs that mimic Yellowstone spawning.	C1-C3 concurrent
BQ5/L1/C1a– Modeling / engineering study: drift dynamics and effects of anoxia	Integrated model linking hydrodynamics, water temperature increases, developmental rates, and population dynamics	Complete C2 regardless of C1 outcomes. IF model results show that biologically significant movement of the anoxic zone is substantial across management scenarios, THEN this provides more support for L2 reservoir elevation management actions.	C1, C2, C3 and C4 completed concurrently
BQ5/L1/C1b – Modeling / engineering study: drift dynamics and effects of anoxia	Spatial/temporal variation of anoxia in Lake Sakakawea. Overall: length of free-flowing river under drawdown and flow scenarios; frequency of occurrence	Complete C2 regardless of C1 outcomes. IF model results show that biologically significant movement of the anoxic zone is substantial across management scenarios, THEN this provides more support for L2 reservoir elevation management actions.	C1, C2, C3 and C4 completed concurrently

BQ5/L1/C2 – Retrospective study: habitat condition gradients LMOR	River depth, velocity, substrate, habitat stability of documented spawning habitat, and reproductive responses of adults and embryos.	IF there is sustained moderate to strong spawning habitat selection that contrasts strongly with Yellowstone River results, THEN this provides more support for spawning habitat designs that mimic Lower Missouri spawning.	C1-C3 concurrent
BQ5/L1/C2a - Screening: anoxia-dependent recruitment limitation	Spatial / temporal extent and variability of anoxia in Lake Sakakawea.	IF results indicate that anoxic zones are patchy, dispersal into Lake Sakakawea is not necessarily fatal AND suitable spawning habitat exists to take advantage of greater passage, THEN this provides more support for L2 reservoir elevation management actions	C1, C2, C3 and C4 completed concurrently
BQ5/L1/C2b - Screening: anoxia-dependent recruitment limitation	Spatial distributions of suitable spawning habitat upstream of Intake Dam.	IF results indicate that anoxic zones are patchy, dispersal into Lake Sakakawea is not necessarily fatal AND suitable spawning habitat exists to take advantage of greater passage, THEN this provides more support for L2 reservoir elevation management actions..	C1, C2, C3 and C4 completed concurrently
BQ5/L1/C3 - Field studies: validating temperature, drift, and recruitment relationships	Spatial and temporal distributions of larvae and surrogate flow tracers to determine larval retention.	IF drift experiments show that advection is significantly different than predicted in passive transport models, THEN this provides more support for L2 reservoir elevation management actions.	C1, C2, C3 and C4 completed concurrently
BQ5/L1/C4 - Mesocosm experiments:	Virtual velocity of free embryos as a function of time, temperature, and developmental stage in relation to channel complexity.	IF results provide robust relationships among abiotic variables, developmental stages, and dispersal rates AND results of C1-3 indicate anoxia is patchy and retardation mechanisms can be identified and quantified, THEN use this information to inform design of L2 studies.	C1, C2, C3 and C4 completed concurrently. All mesocosm studies designed concurrently.

Studies in years 1 – 5			
BQ3/L1/C1 – Modeling studies: water temperature management options at Fort Peck	Achievable temperature increases, larval developmental stages, increases in productivity, length of river needed for larval retention, and cost effectiveness of alternative engineering designs.	IF model results show a significant increase in larval retention with temperature management, THEN this provides more support for L2 studies. Create additional models to inform feasible mitigation measures.	C0, C1, C2b, C3b, 4b all concurrent
BQ4/L1/C1a - Desktop study to integrate available information regarding turbidity and fish behavior.	Predicted cost and extent and average increase in Upper Missouri River turbidity.	IF results show that sediment bypass bypass or augmentation is practical AND can significantly increase turbidity, THEN supports moving to C2 mesocosm studies.	C1a, C1c and C1d all concurrent
BQ4/L1/C1b - field studies of turbidity levels to fill in gaps	Predicted cost and extent and average increase in Upper Missouri River turbidity.	IF results show that sediment bypass bypass or augmentation is practical AND can significantly increase turbidity, THEN supports moving to C2 mesocosm studies.	Build on C1a.
BQ4/L1/C1c - Mine existing PSPAP data to assess associations between fish movements and turbidity	n/a	n/a	C1a, C1c and C1d all concurrent
BQ4/L1/C1d - Engineering study: feasibility and effects on other authorized purposes	Predicted cost and extent and average increase in Upper Missouri River turbidity.	IF results show that sediment bypass or augmentation is practical AND can significantly increase turbidity, THEN supports moving to C2 mesocosm studies.	C1a, C1c and C1d all concurrent
BQ6/L1/C1 - Engineering studies: feasibility hatchery needs, facilities, operations	Costs and measures of likely survival for a range of propagation facility designs	IF alternative designs are expected to produce population benefits at a reasonable cost, THEN this provides more support for L2 management experiments	C1-C3 done concurrently

BQ6/L1/C2 - Retrospective study: survival linked to hatchery operations	Number and survival probabilities for stocked pallid sturgeon by stocked size, hatchery of origin, location of release and health history.	IF results indicate that changes in propagation facility operations could increase survival, THEN this provides more support for L2 management experiments. IF results indicate that more fish releases are required to estimate survival probabilities, then review alternative designs for BQ6/L2/C4.	C1-C3 done concurrently
BQ6/L1/C3 - Simulation models: population sensitivity to size, health, genetics	Probability of quasi-extinction, instantaneous growth rates, and sensitivity measures under various model scenarios.	IF results indicate that population dynamics are sensitive to changes in augmentation practices AND the information provided by previous components shows the need for L2 studies THEN this provides more support for L2 management experiments	C1-C3 done concurrently
BQX3/L1/C3 - drift studies and predator gut content analyses	Observe predation rates on the experimental larvae	IF predation rates are sufficient to have a population effect THEN consider predator control feasibility or implications.	After C2
BQX4/L1/C1 - Field estimates of distribution of overwintering habitat	Densities of sturgeon by habitat unit	IF overwintering habitat is well-defined THEN supports moving forward with modelling	

Table 6. Summary of Level 2 studies/experiments in the framework including metrics and decision criteria

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Concurrent / Dependent Components
Studies already in-progress			
BQ5/L2/C4 - Engineering studies: sustainable design	Design performances, measured as ability to create the hydraulic and substrate conditions developed in components 1-3. Evaluate appropriate segments for spawning habitat using combined advection dispersion and population model	IF designs are judged capable of achieving functional spawning habitat AND there is a decision document addressing these actions, THEN supports moving to C5 manipulative field experiments.	Build on learning from L1 C1-C3 studies
Studies in years 1 – 5			
BQ1/L2/C4 – Analyses to assess potential fish and HC responses to Level 2 flow manipulations at Fort Peck.	Predicted movement, reproductive behaviors, spawning success and recruitment to age-1 in response to Fort Peck flows. Predicted impacts on human considerations.	IF Fort Peck flows are likely to have biological benefits AND there is a decision document addressing these actions, THEN supports moving to BQ/L2/C5.	Builds on observations from C2 and C3

BQ3/L2/C5 - Field experiments: water temperature management, Fort Peck	Increase in water temperatures above those that would have prevailed without the temperature mitigation / management Should precede L2 experiment to test ability to generate desired temperatures under various flows. Might capitalize on a dry year to do this experiment.	IF demonstrated ability to raise water temperature by a biologically significant increment WITHOUT unacceptable risks to authorized purposes, AND there is adequate drift / dispersal distance, THEN supports moving to C6 field experimentation.	follows BQ2/L1 work if decision criteria met and lines of evidence converge
BQ5/L2/C5a,b - Pilot engineering studies: feasibility of implementing low-flow measures. Evaluate HC impacts and study feasibility of implementing low-flow measures	5a, b - velocities, water surface elevations, and potential dispersal distances compared to authorized purposes.	IF pilot results suggest low-flow pulses will achieve anticipated reductions in flow velocities AND there is a decision document addressing these actions, THEN supports moving forward with C6 field experiments.	Decision criteria met for all four BQ5/L1 studies
BQ5/L2/C6a – Upper Misouri: Manipulative field experiments: effect of low-flow interventions on larval retention	6a - Spatial and temporal distributions of larvae and surrogate flow tracers to determine larval retention		
BQ5/L2/C6b – Yellowstone embryo release to test the effect of low-flows on larval retention	6b - numbers of adults. passing Intake Dam, frequency and location of spawning events, number of free embryos collected downstream.	IF the Intake Project fails to result in recruitment or results are equivocal AND L1/2 results indicate that some combination of flows and drawdown can improve survival to first feeding, THEN this provides evidence for L3 implementation in the Upper Missouri.	

BQ6/L2/C5 -Natal origin: Desk research to investigate natal origin issues.	Summary of the literature on natal origin	IF literature indicates this is a potentially important factor, THEN supports moving forward with subsequent L1 studies	C5 concurrent with C9
Studies in years 6 – 10			
BQ1/L2/C5 – Level 2 experimental flow release from Fort Peck	Observed movement, reproductive behaviors, spawning success, and recruitment to age-1, as well as observed effects on human considerations.	IF results support the hypothesis that Fort Peck flows increase reproduction and recruitment to age-1, THEN supports moving to L3 implementation is supported.	Builds on C3 and C4
BQ3/L2/C6 - Manipulative field experiments releasing warm water over Fort Peck, with appropriate flows, and monitoring response of both: 1) age-0 fish and 2) telemetered, reproductively ready sturgeon.	Test whether increased water temperature contributes substantially to free-embryo survival and recruitment, and also adult movement, spawning and reproduction. Monitor developmental rate and location of embryos relative to Lake Sakakawea; movement, spawning and reproduction of telemetered adult fish; (possibly densities of chironomids); impacts on human considerations.	IF multiple lines of evidence do not reject hypotheses H4 and H5, AND temperature manipulations can be feasibly implemented as reflected in a ROD, THEN this supports the decision to manipulate water temperatures at Fort Peck with L3 action.	Follows BQ/L2/C5 if decision criteria are met
BQ6/L2/C6 - Natal origin: Hatchery and lab studies	Suite of performance measures to determine responsiveness of fish to hatchery versus natural rearing environments	IF hatchery and wild pallid sturgeon show significantly different responses to water from below Fort Peck versus laboratory water THEN this issue becomes elevated.	After C5
BQ6/L2/C7 - Natal origin: field experiments on imprinting and other factors	Suite of performance measures to determine responsiveness of fish to hatchery versus natural rearing environments (but in field)	IF mesocosm experiments indicate water of origin is a significant factor THEN consider field experiments (C8)	After C6

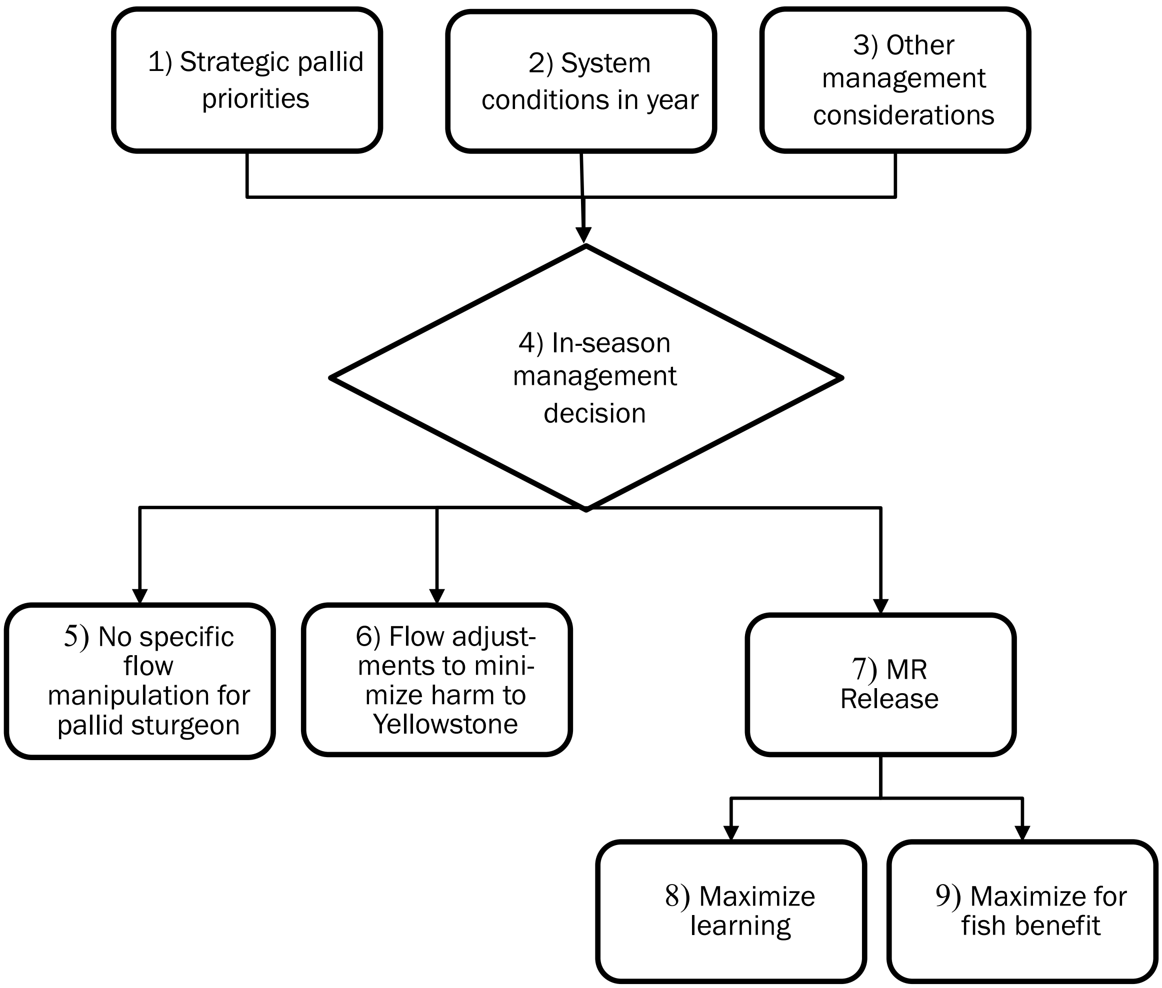
3.5 Framework implementation

Framework implementation would utilize the AM processes outlined in the SAMP. The Science Update process (2.4.1) is used to assess the current state of the science and to assess the status of relevant hypotheses. The Strategic Plan would establish which Level 1 and 2 studies would be pursued in the execution year and which are planned for out-years. Implementation of a Level 2 experimental flow would first be identified in the Strategic Plan, which would then initiate a sequence of decisions regarding the appropriateness of moving forward with the test year-to-year, until conditions support either its implementation or its abandonment, or otherwise lead the program in a different direction.

Figure 7 presents a flow diagram to illustrate the sequence of management decisions for a potential Level 2 flow experiment given current understanding of the system and key unknowns. Precursors to the execution of the flow diagram include those factors outlined in Section 3.3.1 (e.g., an authority, experimental plan, etc.) and a decision to move forward with a flow study as part of the Strategic Plan (see Section 2.4.4 of the SAMP). The diagram could also be employed to support decisions in a given year when unexpected and rare conditions for a study are presented, even if it wasn't anticipated in the Strategic Plan.

Boxes 1, 2 and 3 address factors that are outlined as part of the Strategic Planning process and are reviewed annually as each season approaches. These effectively trigger a tentative decision to implement, subject to the other suite of considerations in the diagram. If these three factors do not support moving forward with a test, the remaining portion of the diagram is ignored (except in rare cases when unusual and unanticipated conditions are present). Box 4 is an agency decision that would be made in season on an annual basis, and other boxes are outcomes of the Box 4 decision. Each of the components of the flow diagram are discussed further below.

Figure 7: Flow diagram for Level 2 flow releases in Missouri River



3.5.1 1 – Assemble strategic priorities

Based on the current state of learning and other priorities as discussed during the AM Workshop, each year's Strategic Plan would summarize the pallid priorities for the coming year(s). Priority actions in the Strategic Plan may be identified for various System Condition year types. (e.g., in a high storage year, prepare to do Study X or Y, and in a dry storage year prepare to do Study R or S).

Each year, most learning will doubtless involve a majority of Level 1 activities. These should be assumed to continue regardless of the following, unless there is a compelling reason not to.

3.5.2 2 - Assemble System conditions in year

System conditions for each year generally come into focus at the March 15 System storage check. These include information on System Storage, snowpack, reservoir levels and other relevant geophysical and biological factors.

As examples: if System storage is unusually low, this may present an opportunity to plan for a Level 2 drift experiment in which flows are kept unusually low during the drift hydrograph component; alternatively, if System Storage is unusually high and other factors align, this may be a good opportunity to consider a flow release for attraction, etc.

3.5.3 3 - Assemble other management issues

There may be other management considerations that are relevant. These may be known well in advance, in which case they could be stated in the Strategic Plan (e.g., potentially conflicting studies, budget constraints, contract requirements). But they might also be issues that arise at short notice (e.g., temporary concerns related to conditions elsewhere in the basin, personnel availability). Any decision-relevant issues should be taken into account.

3.5.4 4 - Weigh and make in-season management decision

Missouri River Water Management may consider annually whether to manage Fort Peck Dam releases for any of the outcomes in boxes 5 through 8. In the case of actions that have been identified in the Strategic Plan, trade-offs between interests may already be understood. In the event the in-season management decision is based on conditions presenting an unexpected study opportunity, then water management will assess whether any additional analyses are needed.

3.5.5 5 – No flow manipulation for pallid sturgeon

One outcome might be to not change the operation of Fort Peck Dam that year. This may be because of a host of reasons, including the state of the System does not allow the flexibility for such a release (e.g., because Storage is too low or too high, etc.,); or managers decide that the value of information from Level 2 flow release is insufficient (see previous discussion on Level 1 versus Level 2 learning).

3.5.6 6 - Flow adjustments to minimize harm to Yellowstone

A second outcome of the Box 4 decision might be to prioritize operations to benefit pallid sturgeon using the Yellowstone River for spawning. This might come about in years with a relatively high flow in the Yellowstone relative to the Missouri River, for example. Background conditions in the other major tributaries could be relevant conditions for this also. In such circumstances, the primary management goal might be to not do anything to impede fish as they move up the Yellowstone to provide optimal opportunity for fish to use the new Intake fish bypass structure once completed

3.5.7 7 - Consider releases

A third outcome of Box 4 could be a decision to focus flow manipulations on benefiting fish in the Missouri River. An important distinction is between whether those flows should be directed towards learning or fish benefits. This distinction is important because there might be situations where trade-offs need to be made between taking what is currently thought to be the best available action for fish in a particular year versus doing what is best for learning over the longer term.

3.5.8 8 - Release to maximize learning

Releases to maximize learning are aimed squarely at increasing knowledge about pallid sturgeon. These include Level 2 actions that are targeted at learning more about attraction and holding flows, for example. They might focus on only one part of the hydrograph, or they might follow prescribed sequences of releases (over various years) at differing discharges to help establish critical thresholds. Importantly, there would be no overriding intent to increase recruitment with such flows; in some years, flows may be needed that are expected to be suboptimal in order to learn about thresholds.

3.5.9 9 - Release to maximize fish benefits based on current knowledge state

In contrast to Box 8, decisions might be made in some years to release a hydrograph with the full intent of triggering a recruitment response based on the best current knowledge. This would likely entail executing the full hydrograph (as opposed to studying individual components).

3.6 Monitoring

The focus of monitoring in this AM framework will be to assist in evaluating the effectiveness of Fort Peck actions and, potentially, to help understand effects on human considerations. Population level monitoring and assessment is not included here since it is the focus of Appendix D of SAMP (i.e., did the effect of the actions propagate to age-1 recruitment in the short term and population growth in the longer term?). Monitoring associated with Level 1 science studies is also not included here and is left to descriptions of the targeted needs of those studies.

Effectiveness monitoring of responses to potential Level 2 actions at Fort Peck would include measuring physical conditions in the river, tracking of adult movement and spawning, as well as monitoring early life stages (e.g., free embryo and larvae). The Upper Missouri River below Fort Peck Dam is part of an integrated system which includes the Yellowstone River. Hence, monitoring would need to occur across this entire system and, as such, include coordination and engagement across multiple state and federal agencies. At this time, monitoring of potential Fort Peck Level 2 actions is expected to include activities described in Table 7, which are aligned with monitoring activities described in Appendix E of the SAMP. By necessity, these activities would also be aligned and integrated with other past, on-going, and/or planned studies (e.g., Pallid Sturgeon Population Assessment Program [PSPAP], Habitat Assessment and Monitoring Project [HAMP], genetic studies, free embryo release experiments).

Table 7: Summary of monitoring activities and performance metrics to evaluate effectiveness of potential Fort Peck Level 2 actions

Monitoring Activity	Performance Metrics
M2: Fixed in-river monitoring to characterize discharge, stage, and temperature conditions. If possible, turbidity or conductivity should also be monitored for their potential roles as covariates.	• Water temperature • Discharge • Turbidity or conductivity
M5: Free embryo sampling (and genetic analysis) using rectangular plankton nets deployed by boat to collect free embryos downstream from identified spawning sites. These samples will be subject to genetic analysis to identify species, and in the case of identified pallid sturgeon, parentage.	• Number of free embryos • Genetic ID
M6: Age-0 sampling (and genetic analysis) using benthic beam or otter trawling methods to collect age-0 fish. This activity is to target potential progeny that have survived to later in the season, further downstream.	• Number of age-0 individuals • Genetic ID
M7: Tagging (and genetic analysis) of reproductive and non-reproductive adults by deploying drifted trammel nets to catch, tag (with acoustic tags), and collect baseline biological information.	• Fish ID • Fish condition (length, weight, Kn, health metrics) • Sex

Monitoring Activity	Performance Metrics
	• Reproductive stage
M8: Passive telemetry network as represented by automated and fixed telemetry logging stations to document location, movement, and potential spawning of tagged individuals across segments and reaches within the Upper Missouri and Yellowstone Rivers.	• Fish ID • River mile location • Movement of tagged adults passing points along network
M9: Manual tracking of tagged adults by boat (or aerial flights if more appropriate) to provide a finer scale resolution of information on the location and movement of tagged individuals at the reach, bend, and macro-habitat scale (equipped with acoustic receivers).	• Fish ID • location, movement • Aggregation and spawning behavior
M10: Detailed monitoring of spawners at a spawning site using 2D / 3D acoustic telemetry arrays and boat-mounted DIDSON acoustic imagery to precisely document fish location and behavior at a spawning site at the time of suspected spawning.	• Fish ID • 2D / 3D location • Movement, aggregation and spawning behavior • Substrate conditions
M11: Adult recapture and reproductive assessment using drifted trammel nets to catch tagged adults after spawning has occurred and confirm spawning outcome (using surgical evaluation, endoscopy, ultrasound, weight, and/or blood samples).	• Fish ID • Spawning outcome

The need for additional monitoring activities to support assessment of effects on human considerations could be considered in conjunction with related analyses of any alternatives developed and evaluated as part of the NEPA process.

3.7 Evaluate and Adjust

As noted above, there remains uncertainty as to which management hypotheses and related actions will address constraints on natural recruitment in the upper Missouri River and/or Yellowstone River. The Assess, Design, and Implement steps of this AM Framework clarify current science priorities, key decisions, and sequencing / implementation of actions. These steps address key unknowns in a way that is consistent with knowledge from the Effects Analysis and evaluation processes described in SAMP (e.g., new information process, pallid sturgeon implementation framework, science updates and governance).

- Q1: Are there attributes of river flow and water temperature that are strongly correlated with upstream movement of reproductive males and female pallid sturgeon?

- Q2: Are there attributes of river flow and water temperature that are strongly correlated with successful spawning (aggregation-fertilization)?

- Q3:Are there attributes of river flow and water temperature that are strongly correlated with synchronous behavior of reproductive male and female pallid sturgeon?

- Q4: Are there attributes of river flow that are strongly correlated with successful reproduction (incubation, hatch, viable embryos)?

- Q5: Does a reduction of flows from Fort Peck Dam decrease mainstem velocities, increase drift distance, and decrease mortality of free embryos and exogenously feeding larvae?

- Q6: Does drawdown of Lake Sakakawea increase effective drift distance and decrease downstream mortality of free embryos and exogenously feeding larvae?

Consistent with the evaluation of other actions in Appendix E of the SAMP, these focal questions will be informed by more specific testable hypotheses and data analyses that have yet to be specified. Evidence about the cause and effect of different actions will take different forms and have varying strengths (as represented by different Levels of action in the pallid sturgeon implementation framework). Hence, a weight of evidence approach and evidentiary framework will be used to assess the information and knowledge gathered to provide responses to the above questions (see example in Table 5). The emerging knowledge will then be disseminated and considered by different entities using the governance process for MRRP described in the SAMP which will assist in the determination and need to adjust decisions / actions in the future.

Table 5. Simplified example of an evidentiary framework to evaluate knowledge gained about the effectiveness of Fort Peck actions.

Focal Questions	Answers				
	Clearly NO.	Likely NO.	Incon-clusive	Likely YES.	Clearly YES.
Q1: Are there attributes of river flow and water temperature that are strongly correlated with upstream movement of reproductive males and female pallid sturgeon?					
Q2: Are there attributes of river flow and water temperature that are strongly correlated with successful spawning (aggregation-fertilization)?					
Q3:Are there attributes of river flow and water temperature that are strongly correlated with synchronous behavior of reproductive male and female pallid sturgeon?					
Q4: Are there attributes of river flow that are strongly correlated with successful reproduction (incubation, hatch, viable embryos)?					
Q5: Does a reduction of flows from Fort Peck Dam decrease mainstem velocities, increase drift distance, and decrease mortality of free embryos and exogenously feeding larvae?					
Q6: Does drawdown of Lake Sakakawea increase effective drift distance and decrease downstream mortality of free embryos and exogenously feeding larvae?					

4 Summary, Conclusions and Next Steps

This document presents two conceptual hydrographs for Fort Peck Dam operations that were formulated to test pallid sturgeon recruitment on the Upper Missouri River. The hydrographs were developed using the best scientific understanding of biological needs of the fish and the unregulated flow regime. Some preliminary analyses of these hydrographs have been conducted and they were described in the 2017 MRRP AM Annual Report.

An adaptive management framework to guide the implementation of either hydrograph (or any component flow management actions) under adaptive management is also presented. The framework includes a series of Level 1 and Level 2 scientific investigations and experiments that address critical uncertainties identified by an expert panel based on the best available scientific information. It also conceptually describes how criteria and mechanisms gained from studies and experimentation could guide decisions about what implementation activities (if any) are warranted, and how they should be structured.

The Fort Peck AM Framework builds on the foundational work in the Effects Analysis and utilizes the processes outlined in the SAMP to provide logical parallel pathways of Level 1 studies and Level 2 experiments that could lead to Level 3 and Level 4 actions in the future if the evidence shows these actions may be warranted. The framework focuses on the issues of flow, temperature and turbidity downstream from Fort Peck Dam, but includes other effects pathways that may be limiting pallid sturgeon recruitment. It emphasizes the need to manage the Upper Basin demographic unit of pallid sturgeon using a systems perspective (i.e. considering the potential for recruitment on either or both the Yellowstone and Missouri Rivers). It also advances an opportunistic strategy wherein the use of passive monitoring and assessment is augmented with focused studies and experiments triggered by advantageous System conditions.

The hydrographs and framework serve as a sound basis for needed discussions and, ultimately, decisions about what activities should be undertaken for the Upper Missouri River. Key decisions must be made before more detail can be developed on some technical issues.

Level 1 and 2 studies directly tied to those uncertainties and management hypotheses that, if resolved, could significantly affect the implementation of management actions can continue. Additionally, both the management actions (e.g., hydrographs) and the component studies of the Framework may be revised during and subsequent to this period following the AM processes outlined in the SAMP. Adjustments to the studies, decision criteria, and ultimately management actions over time in response to new knowledge is fully anticipated and necessary for success of the MRRP.

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Appendix A

A.1 Activity 2: Design and population of Effects Pathway Diagrams

A.1.1 Purpose and origin

The Effects Analysis undertook a comprehensive review of the status of information regarding the potential pathways of effect that could explain pallid sturgeon recruitment failure. Building on this, to initiate the development of this framework, the Technical Team chose to develop a series of Effects Pathway diagrams to help organize this knowledge in a more visual and accessible way, and to provide a platform for the continuous integration of new information moving forward.

These Effects Pathway Diagrams (also sometimes called Influence Diagrams) act as 'map' of the effect mechanisms in the Upper Basin through which the main issues of current interest may be summarized and communicated. By limiting the diagrams only to those issues of most expert interest, the intent is for them to serve as access points for either a basic understanding of an issue or the latest information. Additionally, the Effect Pathway Diagrams are intended to illustrate the major connections between potential management actions and the ultimate effects on pallid sturgeon. In this way, in future, they may also serve to provide scientists, MRRIC and others with a location to organize and present information on the potential linkages between potential actions undertaken for pallid sturgeon, thereby emphasizing the connection between pallid science, actions and the consideration of impacts to HCs. These Pathway Diagrams do not reflect actions the Corps is intending to take, but rather simply provide a way to organize hypothesis and the various studies that could help answer the hypothesis currently believed to be limiting pallid recruitment.

The diagrams were first drafted at a meeting in Kansas City in July 2018. Attendants at this meeting included the Technical Team, pallid sturgeon experts and lead agency staff. They were subsequently modified in minor ways through various video-linked discussions.

A.1.2 Design and function

One diagram was developed for each of the hydrograph components discussed in Activity 1. The current state of these diagrams are presented in Figures 8 through 11.

Figure 8: Diagram A - Pallid Attraction and Holding Hydrograph Component

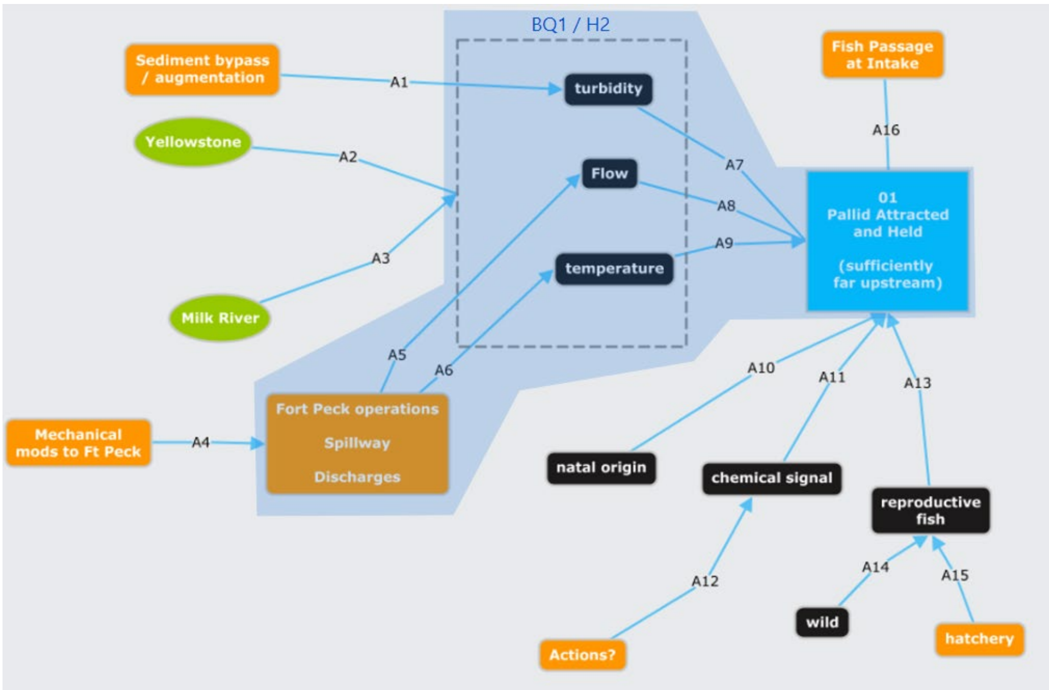


Figure 9: Diagram B - Pallid Spawning Hydrograph Component

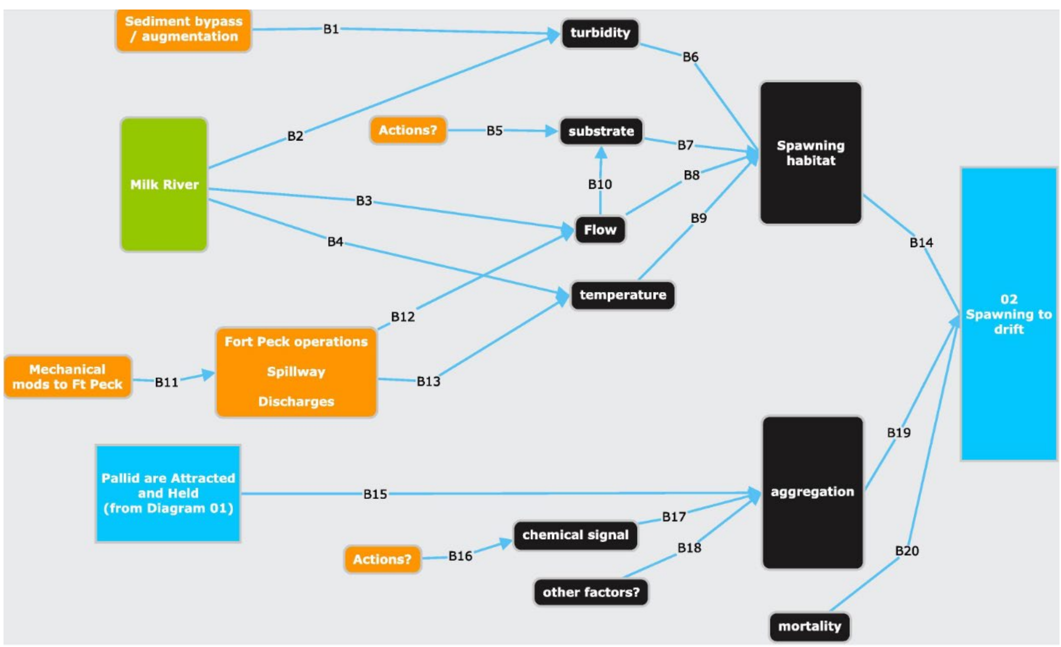


Figure 10: Diagram C - Pallid Drift Hydrograph Component

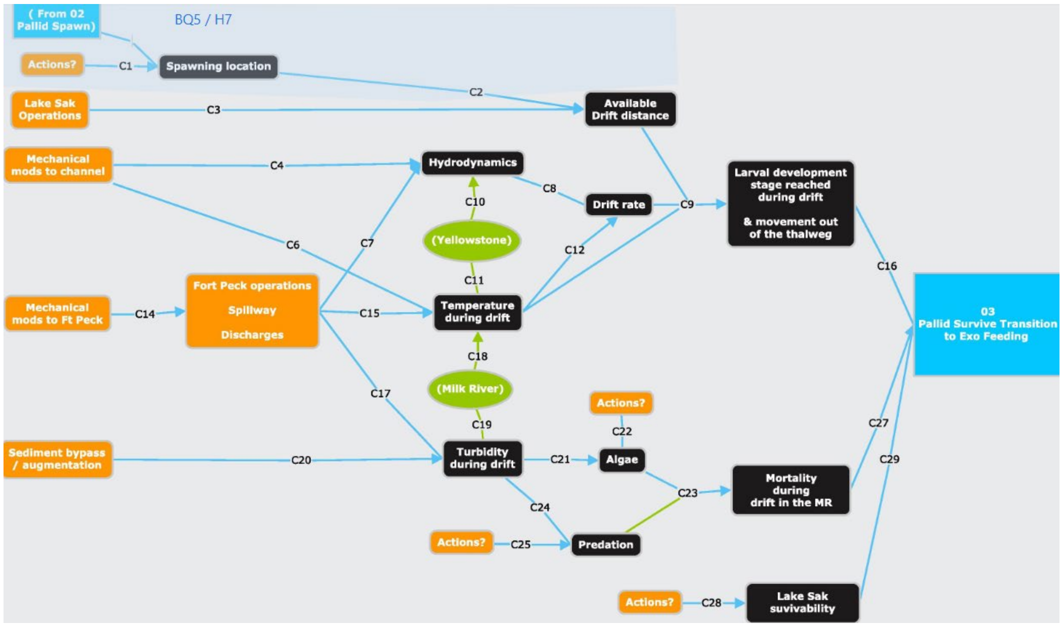
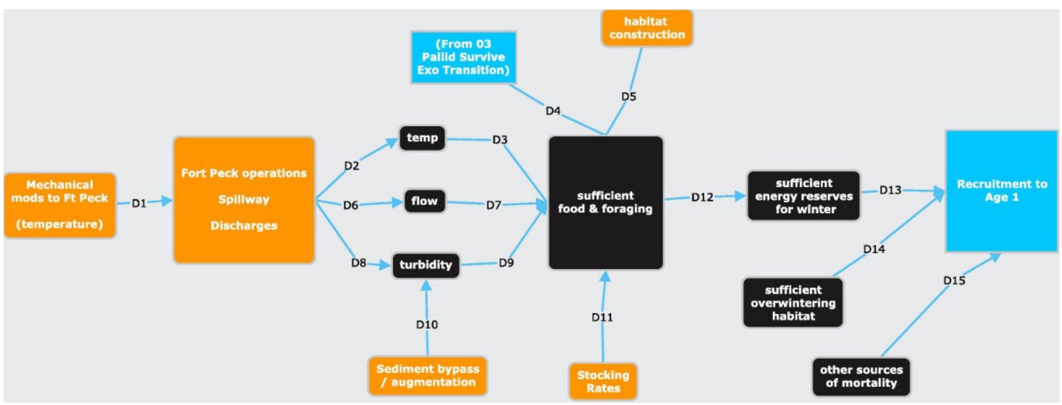


Figure 11: Diagram D - Pallid Post-Drift Hydrograph Component



Each of the diagrams shows a left-to-right progression of a limited number of hypothetical potential cause and effect relationships for various Effects Pathways. At the right of each diagram is a blue box indicating the desired successful conclusion in each hydrograph component. Black boxes are the major geophysical or biological pathway mechanisms thought most relevant for discussion purposes by the diagram's designers. Orange boxes are potential management actions that could affect (or 'influence') the outcome of the pathway. Green shapes show influences that are outside management control but which are nonetheless critical to understanding the cause-effect relationships.

Accompanying documentation was developed by the Technical Team and Upper Basin experts to describe the diagram components, document the literature and assist with the framework development.

As illustrated in Figure 12, each document begins with a description of the linkage, and is followed by a discussion of what is known with confidence about it. A distinction is made between information that was available during the Effects Analysis and more recent findings. Some of the diagrams also contain summaries of the key unknowns. Where there is uncertainty or differences of expert opinion regarding certain issues, these debates are discussed in the documents.

Figure 12: Sample page of documentation associated with each diagram link

A8 – Flow affects adult pallid sturgeon attraction and holding

Description

- **Hypothesized Relationship:** Increased flow in the Upper Missouri River will lead to increased pallid sturgeon attraction and holding, leading to an increased chance for successful spawning, fertilization, hatching, and dispersal.
- **Related:** Flow is related with other water conditions - turbidity (Link A7) and temperature (Link A9).
- **Location:** Upper Missouri
- **Period:** Prior to spawning period (April - May)
- **Relevance for decision making:** Fort Peck dam operations can change the flow, and consequently the temperature of the flow, possibly leading to increased attraction and holding of pallid sturgeon. Changes to flow from Fort Peck Dam are discussed in A5.

Overview / What do we know with confidence?

Key Points

- Temperature and discharge act as indicators for spawning for many other lotic fish species
- Spawning and egg deposition at spawning sites is generally initiated after temperatures reach 16-20°C
- There is some evidence to suggest that Tracked pallid sturgeon may migrate to the Yellowstone River in April-May when discharge is higher than that of the Upper Missouri
- The temperature of water to the Yellowstone River in April-May is higher when discharge is higher than that of the Upper Missouri
- In 2011, high flows from the Milk River, with presumably warmer temperatures and higher turbidity, may be linked to a spawning incident in the Upper Missouri River

Temperature and discharge act as indicators for spawning for many other lotic fish species

Effects Analysis and other documents considered in the EA

"Many lotic fishes are adapted to natural variation in water temperature and discharge, and decoupling of water temperature from discharge variation is thought to result in removal of cues for spawning conditions. The role of discharge-related spawning cues is discussed in Goodman and others (2012)." (EA, pp. 72)

Information published after the EA

N/A

Spawning and egg deposition at pallid sturgeon spawning sites is generally initiated after temperatures reach 16-20°C

Effects Analysis and other documents considered in the EA

Mass spawning for pallid sturgeon was found to occur between 16-20 °C (Kappenman et al. 2013) with "egg deposition at spawning sites … generally initiated after temperatures reach 16-18 °C (DeLonay and others, 2009)." (Delonay et al. 2016, pp. 40)

Information published after the EA

N/A

Another use of the diagrams was to structure the questions for the expert survey (discussed in Activity 3, below). By taking each of the right-most links between black and blue boxes in each of the diagrams, we arrived at the following potential 'limiting factor pathways' that could be explored through the survey. Note that due to its size and complexity, Diagram C was split into two parts.

Figure 13: 17 potential limiting factor pathways

A - PALLID ATTRACTION AND HOLDING

"Pallid sturgeon survival to age 1 is limited by a factor(s) during the attraction and holding hydrograph component"

"Pallid sturgeon survival to age 1 is limited by **turbidity** during the attraction and holding stage"
"Pallid sturgeon survival to age 1 is limited by **flow** during the attraction and holding stage"
"Pallid sturgeon survival to age 1 is limited by **temperature** during the attraction and holding stage"
"Pallid sturgeon survival to age 1 is limited by **natal origin (i.e. hatchery vs wild)** during the attraction and holding stage"
"Pallid sturgeon survival to age 1 is limited by **chemical signals** during the attraction and holding stage"
"Pallid sturgeon survival to age 1 is limited by **reproductive fish** during the attraction and holding stage"

B - SPAWNING

"Pallid sturgeon survival to age 1 is limited by a factor(s) during the spawning hydrograph component"

"Pallid sturgeon survival to age 1 is limited by **spawning habitat during the spawning component**"
"Pallid sturgeon survival to age 1 is limited by **aggregation behavior during the spawning component**"
"Pallid sturgeon survival to age 1 is limited by **mortality during the spawning component**"

Ci - DRIFT, DEVELOPMENT STAGE REACHED

"Pallid sturgeon survival to age 1 is limited by during the drift hydrograph component due to insufficient development stage reached"

"Pallid sturgeon survival to age 1 is limited by available **drift distance**"
"Pallid sturgeon survival to age 1 is limited by **drift rate**"
"Pallid sturgeon survival to age 1 is limited by **temperature** during drift"

Cii - DRIFT, MORTALITY

"Pallid sturgeon survival to age 1 is limited by during the drift hydrograph component due to mortality"

"Pallid sturgeon survival to age 1 is limited by **filamentous algae**"
"Pallid sturgeon survival to age 1 is limited by **predation**"

D - POST-DRIFT

"Pallid sturgeon survival to age 1 is limited by a factor(s) during the post-drift hydrograph component"

"Pallid sturgeon survival to age 1 is limited by **food and foraging** during the post-drift stage"
"Pallid sturgeon survival to age 1 is limited by **overwintering habitat** during the post-drift stage"
"Pallid sturgeon survival to age 1 is limited by **other sources of mortality during the post-drift stage**"

A.1.3 Status and future use

Initial drafts of the documents with content for all four diagrams were made by the Technical Team. Agency and other expert reviews have not yet been conducted. Once these draft scientific reports are finalized and reviewed they will be made available to the public. These documents form the basis for Agency discussion and consideration of actions that could inform management decisions utilizing the most up to date, or best available, science. The documents could be incorporated into the SAMP directly or by reference along with the Fort Peck Framework once finalized and approved.

A.2 Activity 3: Expert survey to review technical priorities and opportunities for studies and actions.

A.2.1 Introduction and design

Concurrent with Activity 2, the Technical Team designed and undertook a technical survey to examine two main areas:

The first was to probe, based on information from the Effects Analysis and updated from information collected since, which parts of the diagrams developed in Activity 2 are viewed, on the balance of evidence available to-day, to be the most important areas on which to focus efforts for this framework in the initial years.

The survey was structured to probe the first three questions of the lines of evidence strategy supporting a transition to Level 3 implementation of actions for pallid sturgeon (SAMP Table 41). It asked, first for each hydrograph component as a whole, and then for each of the 17 potential limiting factor pathways:

1. What is your degree of confidence, based on the balance of evidence known today, that [component / pathway X] contains some element that could be considered to be limiting pallid sturgeon?[*]

2. What is your degree of confidence, based on the balance of evidence known today, there is sufficient understanding to correctly specify the physical or biological requirements for a management response?

3. What is your degree of confidence, based on the balance of evidence known today, that there could be a Level 3 or Level 4 solution that could, if needed be available to remove the issue as a limiting factor

Second, the survey was additionally used to probe for detailed views on the entirety of issues relating to Upper River Pallid Sturgeon – which studies should be prioritized and why, which studies are missing etc. The survey also asked experts to engage in hypotheticals – to help the Technical Team think through what studies might be needed IF new evidence were to emerge that some of the pathways that are considered of lesser priority to-day were to become of more interest at some point in the future. In this way, the survey cast a wide net in order to capture the broadest possible range of expert views and opinions. The experts represented a range of institutional, technical and geographical perspectives.

A.2.2 Some initial findings

[*] Limiting is defined here as being or containing a system variable for which the current state does not meet a minimum value or threshold required to enable recruitment to age 1 to occur to a sufficient extent to sustain a minimum viable population, and therefore for which some change from the current condition would be essential for recruitment to age 1 to happen. It may function as such independently or as a co-limiting factor (i.e. when coupled with another variable).

The survey yielded a large array of expert views on the wide range of potential limiting factors discussed above. This information is detailed and is too large to present in its entirety.

Some summary statistics that have emerged from the survey are presented here. How, we emphasize that *each expert's views and suggestions were studied in detail and in context*. These summary statistics are therefore only a small aspect of the value that was gleaned from this exercise.

Respondents were asked to express their views on Question 1 using the scale shown in Figure 14 – they were also encouraged to provide a detailed written description of their views which have been collated in a table too large to present here.

Figure 14: Scale used for Question 1

5	Evidence strongly suggests this is TRUE
4	
3	Evidence likely suggests this is TRUE
2	
1	Evidence weakly suggests this is TRUE
0	Equal chance of being TRUE or FALSE
-1	Evidence weakly suggests this is FALSE
-2	
-3	Evidence likely suggests this is FALSE
-4	
-5	Evidence strongly suggests this is FALSE
??	Insufficient evidence to say
UNQ	Unqualified to say

Figure 15 and Figure 16 show the experts' responses to the first of the question (What is your degree of confidence, based on the balance of evidence known today, that [pathway X] contains some element that could be considered to be limiting pallid sturgeon?).

In these figures, each colored bar represents a single expert's response. The grey bar is the median value and the standard deviation is shown with a whisker on the grey bar. Not all experts responded to each category – non-responses were not counted in the median and standard deviation calculations.

Figure 15: Expert perspectives on Limiting Factors – Diagrams A, B and Ci

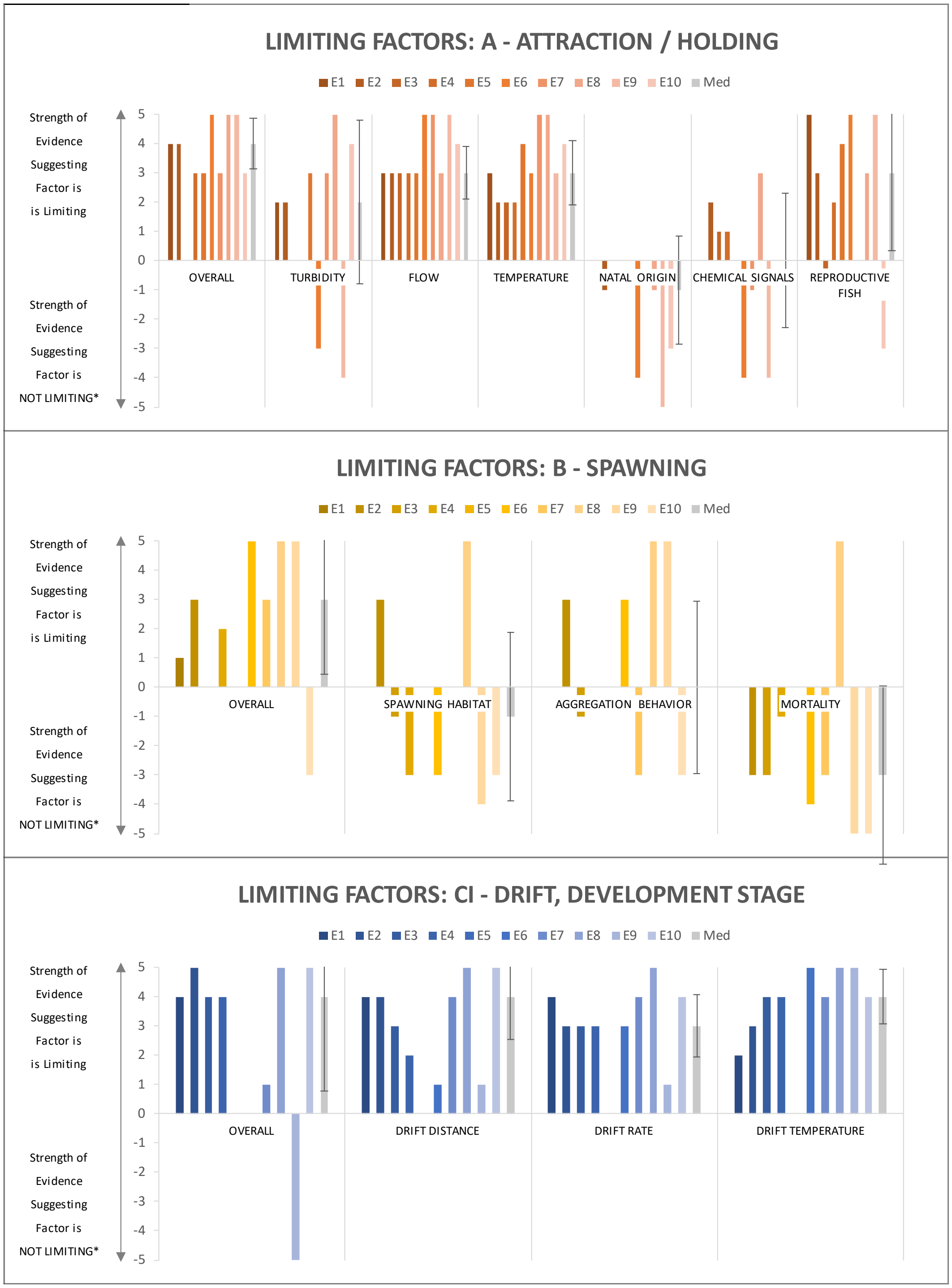


Figure 16: Expert perspectives on Limiting Factors – Diagrams Cii and D

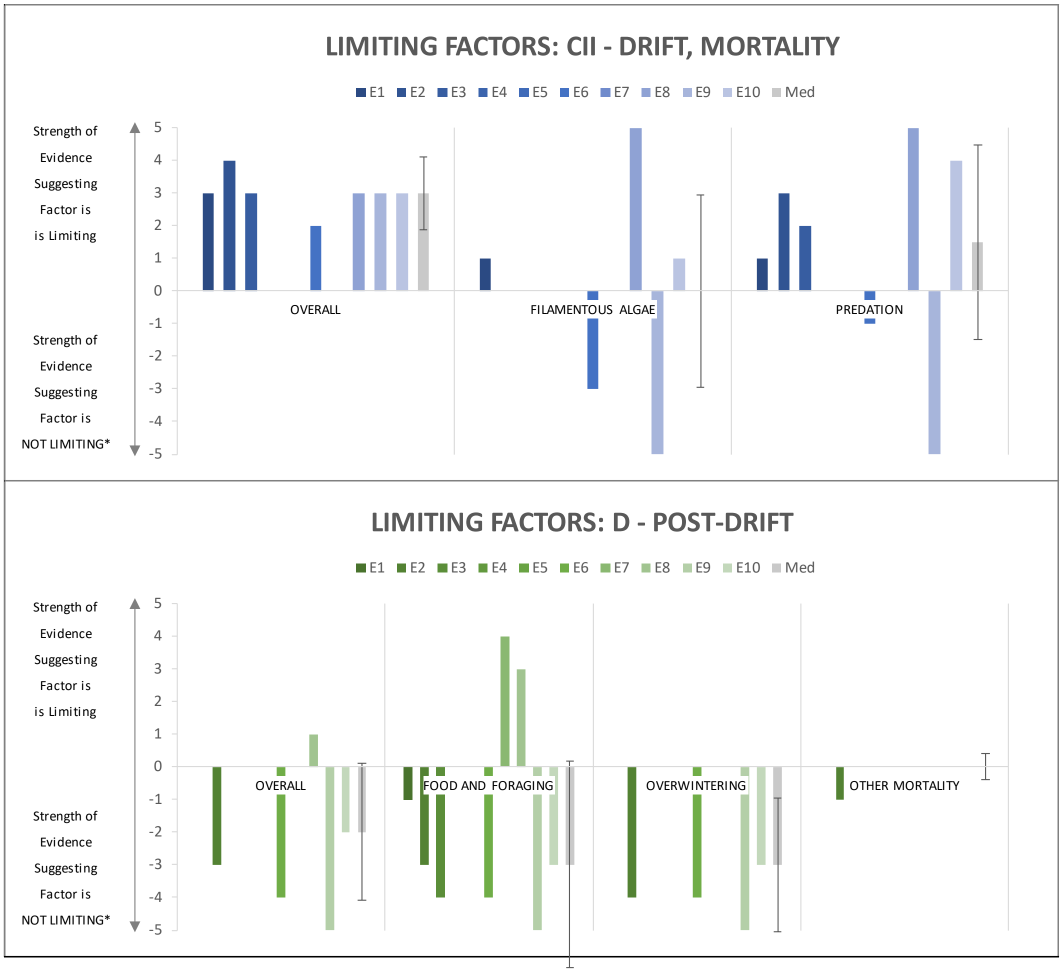


Figure 15 (A) shows a consistent view among experts that the evidence supports flow and temperature during attraction and holding as likely limiting. There is greater disagreement about the role of turbidity, though the median response suggests this may be an important consideration. No experts believe the evidence suggests natal origin (hatchery-related disorientation) problems might be limiting recruitment, though more than half of the people who responded appear to think that chemical signals may be an issue to investigate further. Belief in the capacity for an insufficient number of reproductive fish to limit recruitment is fairly high, though with a high variability.

Figure 15 (B) shows a reduced and more variable degree of concern about issues during spawning. This is in contrast to Figure 15 (Ci), where there are high median responses indicating belief in the strength of evidence that the drift distance, temperature and rate factors (which are, of course, inter-related, but which are treated separately for the purposes of this exercise) are indicated in recruitment failure. Experts appear to have less information on which to build views on drift mortality (Figure 16 (Cii)).

Finally, Figure 16 (D) demonstrates that just two experts believe the evidence supports the idea of food and foraging as a limiting issue.

	Confidence that this is limiting?		Confidence we know what would be needed?		Confidence that something could fix it?	
	Med'n (+5/-5)	SD	Med'n (+5/0)	SD	Med'n (+5/0)	SD
A - PALLID ATTRACTION AND HOLDING						
Hydrograph component as a whole	4	0.87				
turbidity during the attraction and holding	2	2.79	3	1.37	2	1.58
flow during the attraction and holding	3	0.90	3	0.83	3	0.68
temperature during the attraction and holding	3	1.10	2	1.62	2	1.62
natal origin (i.e. hatchery vs wild) during the attraction and holding	-1	1.85	1	1.49	1	1.84
chemical signals during the attraction and holding	0	2.30	0	0.99	1	1.17
reproductive fish during the attraction and holding	3	2.65	3.5	1.70	3	1.69
B- SPAWNING						
Hydrograph component as a whole	3	2.55				
spawning habitat during the spawning component	-1	2.87	3	1.41	2	1.85
aggregation behavior during the spawning component	0	2.94	2	1.31	3	0.71
mortality during the spawning component	-3	3.04	1	1.66	1	0.94
Ci - DRIFT, DEVELOPMENT STAGE REACHED						
Hydrograph component as a whole	4	3.22				
available **drift distance** during drift	4	1.47	3	1.47	2	2.26
drift rate during drift	3	1.05	3	1.17	2.5	1.65
temperature during drift	4	0.94	3	1.42	2	1.59
Cii - DRIFT, MORTALITY						
Hydrograph component as a whole	3	1.11				
mortality due to **filamentous algae** during drft	0	2.95	2	1.64	1.5	0.96
mortality due to **predation** during drift	1.5	2.98	2	1.93	1.5	0.96
D - POST-DRIFT						
Hydrograph component as a whole	-2	2.10				
food and foraging during post-drift	-3	3.16	3	1.39	3	2.24
overwintering habitat during post-drift stage"	-3	2.05	2	1.60	1	1.90
other sources of mortality during post-drift	0	0.40	0	0.70		

Figure 17: Median scores and standard deviations from expert surveys.

A.3 Activity 4: Consolidation of expert views and proposed modification of Level 1 and Level 2 studies

The expert survey yielded a very large number of ideas, suggestions and reflections on the studies that could be undertaken to further reduce uncertainties in the Upper River.

These new ideas needed to be reconciled and integrated with two existing sets of Level 1 and Level 2 actions that had previously been compiled in SAMP version 5 (which had a broader time horizon) and the final distributed with the FEIS (which considers only the first 1-5 years).

This reconciliation took place over several rounds of discussion within the Technical Team. The steps followed were:

A.3.1 Step 1: Identify new and potentially different comments

Flag any ideas or suggestions that are not obviously already incorporated in the SAMP. More than 200 specific ideas were taken forward past this stage

A.3.2 Step 2: Consolidate these ideas within a learning cascade

The ideas were then consolidated for each of the 17 potential limiting factor pathways. They were organized as per Figure 6, which illustrates a general concept of a cascade of learning from L1 to L2 studies for each.

(Note that at this point, this thinking is conceptual – considerations of cost and value of information are applied later in Step 3)

A.3.3 Step 3: Consolidate further with existing program (reorganized under the Big Questions) and make suggestions on relative importance

In the next stage of organization, these ideas were further consolidated primarily by integrating ideas into the existing SAMP components. At this stage, the ideas were therefore folded into the previous Big Question format from the Effects Analysis.

The tables in the Appendix show the outcome of this work. These tables mirror Table 43 in the SAMP, but there are four additional columns:

1. **Survey**: Significance of Limiting Factors – from Activity 2, the category of relative importance is identified here

2. **Cost category**: shown as estimated **H**igh, **M**edium and **L**ow cost activities. To provide an informative relative difference between High, Medium and Low, categorical definitions of each were developed based on terciles (i.e. dividing into three even sets) of previous cost estimates. The categories were defined as follows: H = >$600K, M = $340K to $600K and L = <$340K

3. **Timing**: a suggestion on when, in the coming years, a particular time window within which each study might best be implemented.

4. **Suggested relative priority for implementation**: the Technical Team's initial perspective on the relative importance of implementing the study, based on the balance of factors listed above, along with any other issues noted in in the rationale column. These fall into three categories: (**Essential** – item seems good value to fund, i.e. have a reasonable ratio of information value, cost and other factors as far as is possible to predict at this point in time; **Optional** – item might be omitted, but with some management consequences; and **Preserve as Reserve** – commitments to fund or not are not required at this point).

It is important to note that Table 9 shown below is an initial assessment. It contain judgments that require further review in the coming months.

A.4 Components for Upper Missouri River AM Framework

Categories for Degree of Certainty: 1 = Definitive, 2 = Statistically rigorous, 3 = Indicative but not authoritative, 4 = Expert judgment of multiple lines of evidence required. BQ = Big Question, L = Level, C = Component (e.g., BQ1/L1/C2 is Big Question 1, Level 1, Component 2).

Categories for Significance of Limiting Factors: These follow from the expert survey, please see Appendix discussion for Activity 3. More Agreement, Some Agreement, Less Agreement / Evidence Appears to Support, Evidence Possibly Supports, Evidence is Ambivalent, Evidence Possibly Refutes, Evidence Appears to Refute.

Categories for Cost: **H**igh, **M**edium and **L**ow cost activities. Based on terciles of previous cost estimates, the categories were defined as follows: H = >$600K, M = $340K to $600K and L = <$340K.

Colors:

Blue indicates that the base description comes from the SAMP, although some modifications may have been made as a result of the expert survey.
Yellow indicates that the base description comes from Version 5 of the SAMP, although some modifications may be expected as a result of the expert survey that are not detailed here.
Green indicates that the base description comes is new and is a result of the expert survey.

Table 8. Overview of Level 1 and 2 components, metrics, and decision criteria with associated degrees of certainty for the working management hypotheses identified for the Upper Missouri in Jacobson et al. (2016b), which also contains a list of reserve hypotheses.

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Degree of Certainty*	Survey: Significance of Limiting Factors	Cost Category	Suggested relative priority for implementation	Suggested Timing	Concurrent / Dependent Components
Big Question 1 – Spawning Cues: Can spring pulsed flows from Fort Peck synchronize reproductive fish, increase chances of reproduction and **recruitment**?								
Associated Hypotheses [and relative priority of Level 1 work on these hypotheses]**:** H2. Naturalized flow releases at Fort Peck will result in increased reproductive success through increased aggregation and spawning success of adults. [Medium]								
BQ1/L1/C1--Design study: complementary passive telemetry network	Detectability of telemetry tags by network receivers, variation of tag detectability with discharge-related characteristics, tag cost, tag reliability.	IF fish movements past strategic locations are successfully detected, THEN supports deploying a larger network of telemetry receivers to help evaluate sturgeon response to flow.	1	More agreement that ... is limiting	**H**	**ESSENTIAL**	In Progress	C1-C2 all concurrent. Also with design of lower basin telemetry network (Table 39 - BQ1/L1/C1)
BQ1/L1/C2 – Field study: opportunistic tracking of reproductive behaviors	Degree of association of reproductive behaviors and successful spawning with monitored hydrologic characteristics.	IF there are moderate to strong associations between hydrologic characteristics and reproductive behavior, THEN this provides stronger evidence for L2 studies. However, IF successful reproductive behavior is observed in the absence of the hypothesized hydrologic characteristics AND is sufficient to have a	4	More agreement that ... is limiting	**H**	**ESSENTIAL**	In Progress	C1-C2 concurrent

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Degree of Certainty*	Survey: Significance of Limiting Factors	Cost Category	Suggested relative priority for implementation	Suggested Timing	Concurrent / Dependent Components
		population-level effect THEN this provides evidence against hypothesis H2.						
BQ1/L1/C3 – Mesocosm experiments to better understand fish responses to flow	Degree of association of reproductive behaviors with manipulated hydrologic characteristics.	IF observed responses to flow are within the envelope of feasible flow releases from Fort Peck, this increases the potential for a Level 2 flow experiment.	2	More agreement that … is limiting	**H**	**OPTIONAL**	**Yrs 1-5**	Builds on observations from C2
BQ1/L2/C4 – Analyses to assess potential fish and HC responses to Level 2 flow manipulations at Fort Peck.	Predicted movement, reproductive behaviors, spawning success and recruitment to age-1 in response to Fort Peck flows. Predicted impacts on human considerations.	IF Fort Peck flows are likely to have biological benefits without causing unacceptable impacts to human considerations, THEN supports moving to BQ/L2/C5.	4	More agreement that … is limiting	**L**	**ESSENTIAL**	**Yrs 1-5**	Builds on observations from C2 and C3
BQ1/L2/C5 – Level 2 experimental flow release from Fort Peck	Observed movement, reproductive behaviors, spawning success, and recruitment to age-1, as well as observed effects on human considerations.	IF results support the hypothesis that Fort Peck flows increase reproduction and recruitment to age-1, THEN supports moving to L3 implementation.	4	More agreement that … is limiting	**H**	**ESSENTIAL**	**Yrs 6-10**	Builds on C3 and C4

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Degree of Certainty*	Survey: Significance of Limiting Factors	Cost Category	Suggested relative priority for implementation	Suggested Timing	Concurrent / Dependent Components
Big Question 2 – Food and Forage: Can naturalization of the flow regime from Fort Peck contribute to increased food production, foraging habitat, and survival of age-0 sturgeon?								
Associated Hypotheses [and relative priority of Level 1 work on these hypotheses]**::** **H1.** Naturalized flow releases at Fort Peck will result in increased productivity through increased hydrologic connections with low-lying land and floodplains in the spring, and decreased velocities and bioenergetic demands on exogenously feeding larvae and juveniles during low flows in summer and fall. [Medium]								
BQ2/L1/C0 - Desktop modelling study to assess survival rates of late fall hatchery-origin pallid sturgeon, including effects of predation	Existing data on estimated survival rates of hatchery-origin pallid sturgeon and stomach contents of predators	IF predation on age-0 sturgeon appears to be a significant LF, THEN consider other L1 or L2 actions.	3	More agreement that ... is not limiting	L	PRESERVE AS RESERVE	Yrs 6-10	C0, C1, C3, C4 concurrent
BQ2/L1/C1 - Engineering study: assessment of feasibility and effects on authorized purposes	Effects of experimental flow pulses on other authorized purposes, measured as relationship between levels of naturalized flows and proxy performance measures as well as costs (see Chapter 5)	IF functional relationships are reliable AND required flow pulses do not cause unacceptable impacts to other authorized purposes THEN this provides stronger evidence for Level 2 experiments.	1	More agreement that ... is not limiting	L	PRESERVE AS RESERVE	Yrs 6-10	C0, C1, C3, C4 concurrent
BQ2/L1/C2 - Screening: field monitoring of age-0 fish condition and diets; limitations of food or forage habitats	Indicators of starvation or impending death of age-0 sturgeon based on stomach contents (empty/full) or physiological indicators (lipid content).	IF results indicate bioenergetic constraints, THEN this provides stronger evidence for Level 2 experiments.	3	More agreement that ... is not limiting	**M**	**ESSENTIAL**	**In Progress**	[In progress]

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Degree of Certainty*	Survey: Significance of Limiting Factors	Cost Category	Suggested relative priority for implementation	Suggested Timing	Concurrent / Dependent Components
BQ2/L1/C3 - Field study: food and forage habitat gradients, including both high quality and poor quality habitats	Depths, velocities, substrate, and spatial complexity of habitat, and whether habitats are occupied by food items (chironimids) and foragers (age-0 sturgeon).	IF results demonstrate a systematic spatial relationship between habitat characteristics and selection of food sources by age-0 fish, THEN this provides stronger evidence for Level 2 experiments.	3	More agreement that … is not limiting	H	PRESERVE AS RESERVE	Yrs 6-10	C0, C1, C3, C4 concurrent
BQ2/L1/C4 - Mesocosm studies: quantitative habitat-survival relations	Depths, velocities, substrate, and spatial complexity of habitat, as well as relative growth rates and survival as a function of habitat characteristics.	IF results demonstrate a systematic relationship between habitat characteristics and growth/survival, THEN this provides stronger evidence for Level 2 experiments.	2	More agreement that … is not limiting	H	PRESERVE AS RESERVE	Yrs 6-10	C0, C1, C3, C4 concurrent
BQ2/L2/C5 - Use 2D models to design flow naturalization experiments and assess associated effects	Relative performance of designs, measured as areas of functional habitat, flux of food items, predicted growth and survival.	IF multiple lines of evidence demonstrate ability to increase habitat components benefiting growth and survival without unacceptable risks to other authorized purposes, THEN supports moving to C6 field experimentation.	4	More agreement that … is not limiting	M	PRESERVE AS RESERVE	Yrs 6-10	follows BQ2/L1 work if decision criteria met and lines of evidence converge
BQ2/L2/C6 - Manipulative field experiments using altered flow and releases of late fall fingerlings: effects	Area of food-producing habitat, area of foraging habitat, catch per unit effort of age-0 sturgeon,	IF multiple lines of evidence do not reject hypothesis H1, AND there is adequate drift / dispersal distance, THEN supports moving to L3	4	More agreement that … is not limiting	M	PRESERVE AS RESERVE	Yrs 11-15	follows BQ2/L2/C5 work if decision criteria met

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Degree of Certainty*	Survey: Significance of Limiting Factors	Cost Category	Suggested relative priority for implementation	Suggested Timing	Concurrent / Dependent Components
of flow regimes on food and foraging	stomach contents, and lipid content.	implementation of more naturalized flows at Fort Peck.						
Big Question 3 – Temperature Control: Can water-temperature manipulations at Fort Peck contribute significantly to increased chance of reproduction and recruitment?								
Associated Hypotheses [and relative priority of Level 1 work on these hypotheses]:: **H4.** Warmer flow releases at Fort Peck will increase system productivity and food resource availability, thereby increasing growth and condition of exogenously feeding larvae and juveniles. [Medium] **H5.** Warmer flow releases from Fort Peck will increase growth rates, shorten drift distance, and decrease mortality by decreasing free embryos transported into headwaters of Lake Sakakawea. [Medium]								
BQ3/L1/C0– Field tracking of telemetered pallid sturgeon - part of BQ1, C2	Degree of association of reproductive behaviors and successful spawning with monitored temperature characteristics.	IF there are moderate to strong associations between temperature characteristics and reproductive behavior, THEN this provides stronger evidence for L2 studies. However, IF successful reproductive behavior is observed in the absence of the hypothesized temperature characteristics AND is sufficient to have a population-level effect THEN this provides evidence against hypothesis H2.	4	More agreement that … is limiting	H	ESSENTIAL	In Progress	C0, C1, C2b, C3b, 4b all concurrent
BQ3/L1/C1 – Modeling studies: water temperature	Achievable temperature increases, larval developmental stages,	IF model results show a significant increase in larval retention with temperature	2	More agreement	M	ESSENTIAL	Yrs 1-5	C0, C1, C2b, C3b, 4b all concurrent

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Degree of Certainty*	Survey: Significance of Limiting Factors	Cost Category	Suggested relative priority for implementation	Suggested Timing	Concurrent / Dependent Components
management options at Fort Peck	increases in productivity, length of river needed for larval retention, and cost effectiveness of alternative engineering designs.	management, THEN this provides more support for L2 studies. Create additional models to inform feasible mitigation measures.		that ... is limiting				
BQ3/L1/C2a- a) food limitation to age-1 - Same as BQ2/L1/C2	Indicators of food availability to age-0 sturgeon based on stomach contents (empty/full/diet inventory) or physiological indicators (lipid content).	IF results indicate that Lake Sakakawea is not limiting, THEN this provides more support for Level 2 experiments.	na	More agreement that ... is limiting	na	na	In Progress	na
BQ3/L1/C2b - b) lethality of Lake Sakakawea to age-0	Spatial and temporal extent and variability of conditions lethal to benthic larval fish in Lake Sakakawea.	IF results indicate that Lake Sakakawea is not limiting, THEN this provides more support for Level 2 experiments.	3	More agreement that ... is limiting	L	ESSENTIAL	In Progress	C0, C1, C2b, C3b, 4b all concurrent
BQ3/L1/C3a - Field studies: validating advection / dispersion model (surveys of chironomid densities)	Densities of chironomid larvae along natural gradients of temperature, depth, and velocity.	IF associations indicate likely food limitations, associated with cold temperatures, THEN this provides more support for L2 temperature experiments	3	More agreement that ... is limiting	M	PRESERVE AS RESERVE	Yrs 6-10	Only do this study IF study BQ2/L1/C2 shows food limitation
BQ3/L1/C3b - Field studies: validating advection / dispersion model (studies of age-0 larval distribution)	Spatial and temporal distributions of larvae and surrogate flow tracers to determine larval retention.	IF results indicate that free embryos can be retained in the Fort Peck segment THEN this provides more support for Level 2 experiments.	3	More agreement that ... is limiting	H	ESSENTIAL	In Progress	C0, C1, C2b, C3b, 4b all concurrent

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Degree of Certainty*	Survey: Significance of Limiting Factors	Cost Category	Suggested relative priority for implementation	Suggested Timing	Concurrent / Dependent Components
BQ3/L1/C4a - Mesocosm studies: developing quantitative temperature-recruitment relationships	Densities of chironomid larvae and associated growth rates of pallid sturgeon larvae.	IF data on developmental rates and other evidence indicates that drift/dispersal is not limiting, THEN this provides more support for Level 2 temperature experiments.	4	More agreement that … is limiting	H	OPTIONAL	Yrs 6-10	Only do this study IF study BQ2/L1/C2 shows food limitation
BQ3/L1/C4b - Mesocosm studies: developing quantitative temperature-recruitment relationships	Temperature-dependence of pallid sturgeon developmental rates.	IF there are moderate to strong and reliable associations between temperature variation and productivity, growth, and survival, AND drift/dispersal is not limiting, THEN this provides more support for Level 2 temperature experiments.	4	More agreement that … is limiting	H	ESSENTIAL	In Progress	C0, C1, C2b, C3b, 4b indicate strong temperature dependencies
BQ3/L2/C5 - Field experiments: water temperature management, Fort Peck	Increase in water temperatures above those that would have prevailed without the temperature mitigation / management	IF demonstrated ability to raise water temperature by a biologically significant increment WITHOUT unacceptable risks to authorized purposes, AND there is adequate drift / dispersal distance, THEN supports moving to C6 field experimentation.	4	More agreement that … is limiting	L	ESSENTIAL	Yrs 1-5	follows BQ2/L1 work if decision criteria met and lines of evidence converge
BQ3/L2/C6 - Manipulative field experiments releasing warm water over Fort Peck, with appropriate	Test whether increased water temperature contributes substantially to free-embryo survival and	IF multiple lines of evidence do not reject hypotheses H4 and H5, AND temperature manipulations can be	4	More agreement	H	ESSENTIAL	Yrs 6-10	Follows BQ/L2/C5 if decision

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Degree of Certainty*	Survey: Significance of Limiting Factors	Cost Category	Suggested relative priority for implementation	Suggested Timing	Concurrent / Dependent Components
flows, and monitoring response of both: 1) age-0 fish and 2) telemetered, reproductively ready sturgeon.	recruitment, and also adult movement, spawning and reproduction. Monitor developmental rate and location of embryos relative to Lake Sakakawea; movement, spawning and reproduction of telemetered adult fish; (possibly densities of chironomids); impacts on human considerations.	feasibly implemented without unacceptable human considerations impacts, THEN this supports the decision to manipulate water temperatures at Fort Peck with L3 action.		that ... is limiting				criteria are met
Big Question 4 – Sediment Augmentation: Can sediment bypass at Fort Peck contribute significantly to increased chance of reproduction and recruitment?								
Associated Hypotheses [and relative priority of Level 1 work on these hypotheses]:: **H6.** Installing sediment bypass at Fort Peck will increase and naturalize turbidity levels, resulting in decreased predation on embryos, free embryos, and exogenously feeding larvae. [Low]								
BQ4/L1/C0 - Field tracking of telemetered pallid sturgeon, ideally with turbidity monitors attached. Also part of BQ1, C2 and BQ3, C0	Time trace of turbidity, concurrent with information on movement, temperature and flow.		4	Some agreement that ... is limiting	**na**	ESSENTIAL	In Progress	
BQ4/L1/C1a - Desktop study to integrate available information regarding turbidity and fish behavior.	Predicted cost and extent and average increase in Upper Missouri River turbidity.	IF results show that sediment bypass or augmentation is practical AND can significantly	1	Some agreement that ... is limiting	L	ESSENTIAL	Yrs 1-5	C1a, C1c and C1d all concurrent

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Degree of Certainty*	Survey: Significance of Limiting Factors	Cost Category	Suggested relative priority for implementation	Suggested Timing	Concurrent / Dependent Components
		increase turbidity, THEN supports moving to C2 mesocosm studies.						
BQ4/L1/C1b - field studies of turbidity levels to fill in gaps	Predicted cost and extent and average increase in Upper Missouri River turbidity.	IF results show that sediment bypass bypass or augmentation is practical AND can significantly increase turbidity, THEN supports moving to C2 mesocosm studies.	1	Some agreement that ... is limiting	L	ESSENTIAL	Yrs 1-5	Build on C1a.
BQ4/L1/C1c - Mine existing PSPAP data to assess associations between fish movements and turbidity.				Some agreement that ... is limiting	L	ESSENTIAL	Yrs 1-5	C1a, C1c and C1d all concurrent
BQ4/L1/C1d - Engineering study: feasibility and effects on other authorized purposes	Predicted cost and extent and average increase in Upper Missouri River turbidity.	IF results show that sediment bypass or augmentation is practical AND can significantly increase turbidity, THEN supports moving to C2 mesocosm studies.	1	Some agreement that ... is limiting	L	ESSENTIAL	Yrs 1-5	C1a, C1c and C1d all concurrent
BQ4/L1/C2 - Mesocosm studies: qualitative turbidity-survival relations	Survival by life stage and predator exposure as a function of turbidity.	IF results demonstrate that turbidity has a significant effect on larval survival, THEN supports moving to C3 mesocosm studies.	2	Some agreement that ... is limiting	H	OPTIONAL	Yrs 6-10	C2 implemented if decision criteria met for C1
BQ4/L1/C3 - Mesocosm studies: quantitative turbidity-survival relations	Survival by life stage and predator exposure as a function of turbidity.	IF results produce reliable quantitative relationships between turbidity and larval	2	Some agreement	H	OPTIONAL	Yrs 6-10	C3 implemented if decision

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Degree of Certainty*	Survey: Significance of Limiting Factors	Cost Category	Suggested relative priority for implementation	Suggested Timing	Concurrent / Dependent Components
		survival AND the results of C1 and C2 indicate sediment bypass is feasible, THEN supports moving to L2 field experiments.		that ... is limiting				criteria met for C1 and C2
BQ4/L2/C4 - Manipulative field experiments: feasibility of sediment bypass or augmentation	Actual cost and extent and average increase in Upper Missouri River turbidity relative to predictive models.	IF results demonstrate success in raising turbidity to biologically meaningful levels, THEN supports moving to C5 field experiments.	1	Some agreement that ... is limiting	H	OPTIONAL	Yrs 6-10	Decision criteria met for all three BQ4/L1 studies
BQ4/L2/C5 - Manipulative field experiments: sediment bypass or augmentation	Extent and average increase in Upper Missouri River turbidity, as well as costs and effects on other authorized uses.	IF multiple lines of evidence from C2-C5, do not reject hypothesis H6, AND sediment bypass can be feasibly implemented without unacceptable impacts on human considerations, THEN supports moving on to design of L3 sediment bypass action.	4	Some agreement that ... is limiting		OPTIONAL	Yrs 6-10	Decision criteria met for BQ4/L2/C4
Big Question 5 – Drift Dynamics: Can combinations of flow manipulation from Fort Peck, drawdown of Lake Sakakawea, and fish passage at Intake Dam on the Yellowstone River increase probability of successful dispersal of free embryos and retention of exogenously feeding larvae?								
Associated Hypotheses [and relative priority of Level 1 work on these hypotheses]:: **H3**. Reduction of mainstem Missouri flows from Fort Peck Dam during free-embryo dispersal will decrease mainstem velocities and drift distance thereby decreasing mortality by decreasing numbers of free embryos transported into headwaters of Lake Sakakawea. [Medium]								

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Degree of Certainty*	Survey: Significance of Limiting Factors	Cost Category	Suggested relative priority for implementation	Suggested Timing	Concurrent / Dependent Components
H7. Fish passage at Intake Diversion Dam on the Yellowstone River will allow access to additional functional spawning sites, increasing spawning success and effective drift distance, and decreasing downstream mortality of free embryos and exogenously feeding larvae. [High] **H10.** Drawdown of Lake Sakakawea will increase effective drift distance, decreasing downstream mortality of free embryos and exogenously feeding larvae. [Medium]								
BQ5/L1/C1a– Modeling / engineering study: drift dynamics and effects of anoxia	Integrated model linking hydrodynamics, water temperature increases, developmental rates, and population dynamics	Complete C2 regardless of C1 outcomes. IF model results show that biologically significant movement of the anoxic zone is substantial across management scenarios, THEN this provides more support for L2 drawdown management actions.	1	More agreement that ... is limiting	L	ESSENTIAL	In Progress	C1, C2, C3 and C4 completed concurrently
BQ5/L1/C1b – Modeling / engineering study: drift dynamics and effects of anoxia	Spatial/temporal variation of anoxia in Lake Sakakawea. Overall: length of free-flowing river under drawdown and flow scenarios; frequency of occurrence	Complete C2 regardless of C1 outcomes. IF model results show that biologically significant movement of the anoxic zone is substantial across management scenarios, THEN this provides more support for L2 drawdown management actions.	1	More agreement that ... is limiting	L	ESSENTIAL	In Progress	C1, C2, C3 and C4 completed concurrently
BQ5/L1/C2a - Screening: anoxia-dependent recruitment limitation	Spatial / temporal extent and variability of anoxia in Lake Sakakawea.	IF results indicate that anoxic zones are patchy, dispersal into Lake Sakakawea is not necessarily fatal AND suitable spawning habitat exists to take	1	More agreement that ... is limiting	M	ESSENTIAL	In Progress	C1, C2, C3 and C4 completed concurrently

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Degree of Certainty*	Survey: Significance of Limiting Factors	Cost Category	Suggested relative priority for implementation	Suggested Timing	Concurrent / Dependent Components
		advantage of greater passage, THEN this provides more support for L2 drawdown management actions, and potentially other actions.						
BQ5/L1/C2b - Screening: anoxia-dependent recruitment limitation	Spatial distributions of suitable spawning habitat upstream of Intake Dam.	IF results indicate that anoxic zones are patchy, dispersal into Lake Sakakawea is not necessarily fatal AND suitable spawning habitat exists to take advantage of greater passage, THEN this provides more support for L2 drawdown management actions, and potentially other actions.	1	More agreement that … is limiting	L	ESSENTIAL	In Progress	C1, C2, C3 and C4 completed concurrently
BQ5/L1/C3 - Field studies: validating temperature, drift, and recruitment relationships	Spatial and temporal distributions of larvae and surrogate flow tracers to determine larval retention.	IF drift experiments show that advection is significantly different than predicted in passive transport models, THEN this provides more support for L2 drawdown management actions.	2	More agreement that … is limiting	M	ESSENTIAL	In Progress	C1, C2, C3 and C4 completed concurrently
BQ5/L1/C4 - Mesocosm experiments:	Virtual velocity of free embryos as a function of time, temperature, and developmental stage in relation to channel complexity.	IF results provide robust relationships among abiotic variables, developmental stages, and dispersal rates AND results of C1-3 indicate anoxia is patchy and	4	More agreement that … is limiting	M	ESSENTIAL	In Progress	C1, C2, C3 and C4 completed concurrently. All mesocosm studies

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Degree of Certainty*	Survey: Significance of Limiting Factors	Cost Category	Suggested relative priority for implementation	Suggested Timing	Concurrent / Dependent Components
		retardation mechanisms can be identified and quantified, THEN use this information to inform design of L2 studies.						designed concurrently.
BQ5/L2/C5a,b - Pilot engineering studies: feasibility of implementing low-flow measures. Evaluate HC impacts and study feasibility of implementing low-flow measures	5a, b - velocities, water surface elevations, and potential dispersal distances compared to authorized purposes.	IF pilot results suggest low-flow pulses will achieve anticipated reductions in flow velocities AND there are no unacceptable impacts on human considerations, THEN supports moving with C6 field experiments.	1	More agreement that … is limiting	L	ESSENTIAL	Yrs 1-5	Decision criteria met for all four BQ5/L1 studies
BQ5/L2/C6a – Upper Missouri: Manipulative field experiments: effect of low-flow interventions on larval retention	6a - Spatial and temporal distributions of larvae and surrogate flow tracers to determine larval retention		4	More agreement that … is limiting	H	ESSENTIAL	Yrs 1-5	
BQ5/L2/C6b – Yellowstone embryo release to test the effect of low-flows on larval retention	6b - numbers of adults. passing Intake Dam, frequency and location of spawning events, number of free embryos collected downstream.	IF the Intake Project fails to result in recruitment or results are equivocal AND L1/2 results indicate that some combination of flows and drawdown can improve survival to first feeding, THEN this provides evidence for L3 implementation in the Upper Missouri.	4	More agreement that … is limiting	H	ESSENTIAL	Yrs 1-5	

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Degree of Certainty*	Survey: Significance of Limiting Factors	Cost Category	Suggested relative priority for implementation	Suggested Timing	Concurrent / Dependent Components
Big Question 6 – Population Augmentation. Can population augmentation (stocking) processes be enhanced to increase survival and genetic fitness of stocked fish?								
Associated Hypotheses [and relative priority of Level 1 work on these hypotheses]: H8. Stocking at optimal size classes and in optimal numbers will increase growth rates and survival of exogenously feeding larvae and juveniles. [High] H9. Stocking with appropriate parentage and genetic diversity will result in increased survival of embryos, free embryos, exogenously feeding larvae, and juveniles. [High]								
BQ6/L1/C1 - Engineering studies: feasibility hatchery needs, facilities, operations	Costs and measures of likely survival for a range of propagation facility designs	IF alternative designs are expected to produce population benefits at a reasonable cost, THEN this provides more support for L2 management experiments	4	Some agreement that … is limiting	L	ESSENTIAL	Yrs 1-5	C1-C3 done concurrently
BQ6/L1/C2 - Retrospective study: survival linked to hatchery operations	Number and survival probabilities for stocked pallid sturgeon by stocked size, hatchery of origin, location of release and health history.	IF results indicate that changes in propagation facility operations could increase survival, THEN this provides more support for L2 management experiments. IF results indicate that more fish releases are required to estimate survival probabilities, THEN review alternative designs for BQ6/L2/C4.	3	Some agreement that … is limiting	L	ESSENTIAL	Yrs 1-5	C1-C3 done concurrently
BQ6/L1/C3 - Simulation models: population sensitivity to size, health, genetics	Probability of quasi-extinction, instantaneous growth rates, and sensitivity measures under various model scenarios.	IF results indicate that population dynamics are sensitive to changes in augmentation practices AND the information provided by	4	Some agreement that … is limiting	L	ESSENTIAL	Yrs 1-5	C1-C3 done concurrently

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Degree of Certainty*	Survey: Significance of Limiting Factors	Cost Category	Suggested relative priority for implementation	Suggested Timing	Concurrent / Dependent Components
		previous components shows the need for L2 studies THEN this provides more support for L2 management experiments						
BQ6/L2/C4 - Manipulative field experiments: varying size, location of stocking	Estimated number and survival probabilities for stocked pallid sturgeon by stocked size and age, hatchery of origin; fish condition; water year conditions, and release location.	IF results indicate that survival is sensitive to size or age at stocking, THEN supports moving to L3 implementation.	4	Some agreement that ... is limiting	H	PRESERVE AS RESERVE	Yrs 6-10	Decision criteria met for all three BQ6/L1 studies
BQ6/L2/C5 -Natal origin: Desk research to investigate natal origin issues.	Summary of the literature on natal origin	IF literature indicates this is a potentially important factor, THEN supports moving with subsequent L1 studies	4	Some agreement that ... is ambivalent	L	ESSENTIAL	Yrs 1-5	C5 concurrent with C9
BQ6/L2/C6 - Natal origin: Hatchery and lab studies	Suite of performance measures to determine responsiveness of fish to hatchery versus natural rearing environments	IF hatchery and wild pallid sturgeon show significantly different responses to water from below Fort Peck versus laboratory water THEN this issue becomes elevated.	3	Some agreement that ... is ambivalent	M	ESSENTIAL	Yrs 6-10	After C5
BQ6/L2/C7 - Natal origin: field experiments on imprinting and other factors	Suite of performance measures to determine responsiveness of fish to hatchery versus natural	IF mesocosm experiments indicate water of origin is a significant factor THEN consider field experiments (C8)	4	Some agreement that ... is ambivalent	H	ESSENTIAL	Yrs 6-10	After C6

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Degree of Certainty*	Survey: Significance of Limiting Factors	Cost Category	Suggested relative priority for implementation	Suggested Timing	Concurrent / Dependent Components
	rearing environments (but in field)							
BQ6/L2/C8 - Natal origin: Testing new hatchery practices to build on learning from Level 1 experiment (e.g., Relocation experiments)	Behaviors of older juvenile-adult fish released under standard and alternate practices	IF evidence suggests that changing hatchery practices are warranted, THEN share this information with the hatcheries	4	Some agreement that … is ambivalent	M	PRESERVE AS RESERVE	Yrs 6-10	After C7
BQ6/L2/C9 - Reproductive fish: Desktop studies	Summary of the literature on the number and type of reproductive fish	IF literature indicates this is a potentially important factor, THEN supports moving forward with subsequent L1 studies	4	Some agreement that … is ambivalent	M	PRESERVE AS RESERVE	Yrs 6-10	Concurrent with C5
BQ6/L2/C10 - Reproductive fish: Modelling analyses to estimate #s, sex ratios, genetics required to maintain a mvp, etc	Sensitivity analyses of the effect of different numbers, sex ratio and genetics on probability of successful reproduction	IF modelling shows some of the population attributes could significantly affect the rates of reproduction THEN share the need for hatchery practice changes	4	Some agreement that … is ambivalent	L	PRESERVE AS RESERVE	Yrs 6-10	After C9
BQ6/L2/C11 - Reproductive fish: Stocking strategies and hatchery studies	Change in the frequency of successful reproduction and recruitment	NA	4	Some agreement that … is ambivalent	H	PRESERVE AS RESERVE	Yrs 6-10	After C10
Other potential Big Question candidates. It may be desirable to undertake due diligence to evaluate whether the following areas should be elevated to the status of Big Questions. An outline of associated sequences of studies are outlined here for completeness and for further discussion.								

Question, Level and Study Components	Key Metrics / *Rationale*	Simplified IF - THEN Decision Criteria	Degree of Certainty*	Survey: Significance of Limiting Factors	Cost Category	Suggested relative priority for implementation	Suggested Timing	Concurrent / Dependent Components
Chemical attraction (pheromones) - "Pallid sturgeon survival to age 1 is limited by chemical signals during the attraction and holding stage"								
BQX1/L1/C1 - Desktop studies	Summary of the literature	IF literature indicates this is a potentially important factor, THEN supports moving forward with subsequent L1 studies	4	Some agreement that ... is ambivalent	L	OPTIONAL	Yrs 1-5	C1 (perform concurrent with other desk studies)
BQX1/L1/C2 - lab studies to produce pheromones or assess response to pheromones			2	Some agreement that ... is ambivalent	M	PRESERVE AS RESERVE	Yrs 6-10	After C1
BQX1/L1/C3 - mesocosm studies to assess response to pheromones	Changes in behavior in response to releases of pheromones	IF behavioral changes are observed THEN supports doing a field validation	3	Some agreement that ... is ambivalent	M	PRESERVE AS RESERVE	Yrs 6-10	After C2
BQX1/L1/C4 - field monitoring of chemical signals in Fort Peck, Milk and YS	Concentrations of pheromones	IF concentrations are below a level that triggers reproductive behaviors in mesocosms THEN consider augmenting in river during the spawning period	2	Some agreement that ... is ambivalent	M	OPTIONAL	Yrs 1-5	After C3
BQX1/L1/C5 - L2 expt; release pheromones	Behavioral responses to released pheromones	IF reproduction is successfully stimulated, THEN consider undertaking at L3.	4	Some agreement that ... is ambivalent	H	PRESERVE AS RESERVE	Yrs 6-10	After C4
Filamentous Algae - "Pallid sturgeon survival to age 1 is limited by filamentous algae during the drift stage"								

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BQX2/L1/C1 - field reconnaissance of problem	Map distribution of densities of algal growth	IF distribution is sufficient to potentially cause a problem THEN supports moving forward with other L1 studies	1	Some agreement that ... is ambivalent	L	OPTIONAL	Yrs 1-5	
BQX2/L1/C2 - desktop studies	Determination from literature on relative potential importance of this issue	IF literature suggests is feasible THEN continue with other L1 activities	4	Some agreement that ... is ambivalent	L	OPTIONAL	Yrs 1-5	Concurrent with C1
BQX2/L1/C3 - mesocosm studies of effects of algae on age-0 fish	Survival studies based on algae density; algae density as a function of turbidity and controls	IF mesocosm shows that survival is adversely affected by algae, AND IF algae can be controlled, THEN supports moving to L2	3	Some agreement that ... is ambivalent	M	PRESERVE AS RESERVE	Yrs 6-10	After C1 and C2
BQX2/L1/C4 - L2 experiments	Evaluate if control options could control algea; evaluate whether there is a positive effect on survival	IF field experiments validate potential control THEN consider L3 implementation	4	Some agreement that ... is ambivalent	H	PRESERVE AS RESERVE	Yrs 6-10	After C3
Non-turbidity-related predation - "Pallid sturgeon survival to age 1 is limited by non-turbidity related predation"								
BQX3/L1/C1 - fish community survey and EDNA analyses	Presence / absence of predator species based on EDNA and presence / absence of sturgeon EDNA based on stomach contents	IF predation appears to be a possible limiting factor THEN consider other studies to quantify the effect	3		M	OPTIONAL	Yrs 1-5	
BQX3/L1/C2 - modelling study of predator impact	Predation rates required to have a significant effect on the population	IF predation rates are sufficient to have a population effect THEN	3		L	OPTIONAL	Yrs 1-5	After C1

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and benefits of predator removal		consider validation in the field						
BQX3/L1/C3 - drift studies and predator gut content analyses	Observe predation rates on the experimental larvae	IF predation rates are sufficient to have a population effect THEN consider predator control feasibility or implications.	4		M	ESSENTIAL	Yrs 1-5	After C2
Overwintering habitat - "Pallid sturgeon survival to age 1 is limited by overwintering habitat"								
BQX4/L1/C1 - Field estimates of distribution of overwintering habitat	Densities of sturgeon by habitat unit	IF overwintering habitat is well-defined THEN supports moving forward with modelling	3	Some agreement that ... is not limiting	M	ESSENTIAL	Yrs 1-5	
BQX4/L1/C2 - 2D modelling of sensitivity of overwintering habitat	Discharge-habitat availability curve	IF habitat is sensitive to discharge THEN supports conducting field experiment	4	Some agreement that ... is not limiting	L	PRESERVE AS RESERVE	Yrs 6-10	After C1
BQX4/L1/C3 - field experiments with either tagged fingerlings or tagged yearling sturgeon	Distribution of habitat and survival of fish	IF overwintering mortality is significant THEN consider adjusting winter flows at L3.	4	Some agreement that ... is not limiting	H	PRESERVE AS RESERVE	Yrs 6-10	After C2
Spawning habitat - "Pallid sturgeon survival to age 1 is limited by spawning habitat" [L1 research being undertaken in both the Yellowstone River and the Lower Missouri can serve to address these questions; items below are copied from Table 44 of SAMP for Lower Missouri]								
BQ5/L1/C1 –Field study: functional spawning habitat, Yellowstone River	River depth, velocity, substrate, and habitat stability of documented	IF there is sustained moderate to strong spawning habitat selection that	3	Some agreement	H	ESSENTIAL	In Progress	C1-C3 concurrent

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	spawning habitat, and reproductive responses of adults and embryos.	contrasts strongly with Lower Missouri River results, AND the results agree with spawning habitats quantified for other sturgeon species, THEN this provides more support for spawning habitat designs that mimic Yellowstone spawning.		that … is ambivalent				
BQ5/L1/C2 – Retrospective study: habitat condition gradients LMOR	River depth, velocity, substrate, habitat stability of documented spawning habitat, and reproductive responses of adults and embryos.	IF there is sustained moderate to strong spawning habitat selection that contrasts strongly with Yellowstone River results, THEN this provides more support for spawning habitat designs that mimic Lower Missouri spawning.	3	Some agreement that … is ambivalent	M	ESSENTIAL	In Progress	C1-C3 concurrent
BQ5/L1/C3 - Mesocosm studies: spawn conditions, behaviors	Hatch rate as a function of different combinations of depth, velocity, substrate, and hydraulic variables, with water quality and fish behaviors as covariates.	IF results provide quantitative criteria for abiotic (and biotic) variables influencing spawning behavior from aggregation of adults to hatch of embryos, THEN supports moving to L2 field experiments.	3	Some agreement that … is ambivalent	M	OPTIONAL	Yrs 6-10	C1-C3 concurrent C3 concurrent w other mesocosm studies
BQ5/L2/C4 - Engineering studies: sustainable design	Design performances, measured as ability to create the hydraulic and substrate conditions developed in components	IF designs are judged capable of achieving functional spawning habitat while minimizing adverse effects to other authorized	1	Some agreement that … is ambivalent	M	ESSENTIAL	In Progress	Build on learning from L1 C1-C3 studies

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	1-3. Evaluate appropriate segments for spawning habitat using combined advection dispersion and population model	purposes, THEN supports moving to C5 manipulative field experiments.						
BQ5/L2/C5 - Manipulative field experiments: spawning habitat	Use of spawning sites compared to other areas; Hatch rate, as determined by catch per unit effort of free embryos or alternative techniques. See Appendix E3 for a description of effectiveness monitoring.	IF created spawning patches are functioning as intended to improve spawning success, THEN supports moving to L3 implementation	4	Some agreement that ... is ambivalent	H	PRESERVE AS RESERVE	Yrs 6-10	Build on learning from L1 C1-C4 studies