Middle Rio Grande Endangered Species Collaborative Program

# Adaptive Management Plan Version 1

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Prepared for:

**Middle Rio Grande Endangered Species Collaborative Program**


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# Executive Summary

The Middle Rio Grande Endangered Species Collaborative Program (Program) is a partnership for the purposes of protecting and improving the status of endangered species in the Middle Rio Grande (MRG) of New Mexico while simultaneously protecting existing and future regional water uses. Two species of particular concern are the Rio Grande silvery minnow (*Hybognathus amarus*) (silvery minnow) and Southwestern Willow Flycatcher (*Empidonax traillii extimus*) (flycatcher), both of which are Federally Endangered.

This is Version 1 of the first Adaptive Management (AM) Plan for the Program. It provides a framework for conducting Program activities to deliberately and explicitly reduce management uncertainties. Based on an assessment of the building blocks for AM in Section 1, it identifies a preliminary example AM design in Section 2 and takes this example through the remaining steps in the AM cycle. A more prescriptive Version 2 will take more time to develop, and a process featuring both policy/management and technical roles is recommended for the Program to move to Version 2. It involves a systematic simulation and evaluation of alternative sets of actions, exploring what will best meet the Program's goals and concurrently reduce critical management uncertainties under a wide range of possible future conditions. The result would be an accepted and scientifically defensible AM design to be implemented, monitored and evaluated. It also suggests that an AM pilot be considered in the near term, to be done in parallel with the process of developing Version 2.

Section 1 (*AM Cycle Step 1 – Assess*) presents the building blocks for AM and a roadmap for using science-based learning to assess how best to implement AM to inform MRG decision-making. This section summarizes the goals the Program hopes to achieve (as any learning that occurs through AM should relate back to these goals), and a preliminary set of measurable objectives and indicators for some of these goals. It describes the types of decisions MRG managers make, some key questions they face when making these decisions, and a preliminary collection of scientific uncertainties and hypotheses. It provides several conceptual models representing relationships between Program management actions, riverine processes, and responses of the silvery minnow, flycatcher, and the MRG system, which serve as a visual framework for articulating what is known and what is uncertain regarding these relationships, which can help in the exploration and refinement of indicators, uncertainties and hypotheses. Details of the suggested simulation process for exploring alternative sets of actions are provided to help the Program select which actions it plans to implement. (Version 2 of the AM Plan would then describe the details of the design, implementation, monitoring, and evaluation process for these selected actions). Lastly, it describes the spatial and temporal bounds of the AM Plan.

Section 2 (*AM Cycle Step 2 – Design*) suggests example adaptive management actions (extensions and alternatives to current management) that could be considered to address some of the hypotheses that participants identified as being high priority. For example, if considered appropriate by the Program and applicable agencies, these could include the following:

- Deliberately explore a range of flow magnitudes and durations during the spawing period, and implement channel rehabilitation actions to increase the floodplain area inundated, improve spawning success and increase recruitment across a range of flows.
- Allow the river to dry in various sections for certain periods, while maintaining wetted refugia in key sub-reaches.
- Release flows to provide wetted breeding habitat for flycatchers and to stimulate growth of cottonwoods and willows, and rehabilitate habitat near the largest current population of

flycatchers at Elephant Butte Reservoir to determine if population re-distribution is possible. This could include creating off-channel wet areas near nesting locations to provide a foraging area for nesting flycatchers.

- Deliberately stock tagged hatchery fish in the vicinity of particular channel rehabilitation sites, as well as in reference or control areas, to determine silvery minnow utilization of different spawning habitats.

It is vital that management actions be designed to deliberately create contrasting conditions where appropriate, or to take advantage of already existing variability in hydrologic and habitat conditions, and that the responses of the silvery minnow and flycatcher are monitored across that variation. This section contains a discussion of design considerations. A set of principles for designing AM actions is also provided, to assist the Program in moving from Version 1 to Version 2 of the AM Plan and selecting a set of AM actions to implement. These principles cover a wide range of considerations Program participants felt were important, including the idea of 'safe-fail' provisions to ensure that implementing AM does not cause jeopardy to the silvery minnow or the flycatcher.

Section 3 (*AM Cycle Step 3 – Implement*) provides sample implementation and project oversight and management flowcharts. These are based on the AM example actions from Section 2 and include experience-based guidance from what has been learned from another river recovery program. A detailed implementation plan can be developed once the Program selects a set of AM actions to implement.

Section 4 (*AM cycle Step 4 – Monitor*) discusses the relative roles and types of monitoring needed in AM, both in general and for the example actions from Section 2. For silvery minnow it describes four categories of indicators or performance measures which should be monitored across a range of conditions over the study area: (a) the area of suitable habitats over time, (b) continuation of the catch per unit effort index of population density, (c) relatively precise estimates of the abundance, distribution and/or movement of tagged fish, and (e) covariates which are helpful in explaining biological response. For the flycatcher it describes three categories of indicators or performance measures which should be monitored across a range of conditions over the study area: (a) habitat performance measures, (b) a full habitat availability analyses at three scales, and (c) population performance measures. The details of a monitoring plan can be developed for this section once the Program selects and designs a set of AM actions to implement. This monitoring plan should adopt and modify existing monitoring protocols to ensure collected data will address the questions at hand while also ensuring that long term time series are maintained.

Section 5 (*AM cycle Step 5 – Evaluate*) discusses how evaluation of AM activities builds a path from monitoring data to management decision-making. Evaluation approaches are suggested for the data that might be collected based on the description of the example actions and monitoring from Sections 2 and 4. Guidance is provided on analysis, reporting, and synthesis of monitoring results, as well as on engaging independent science review.

Section 6 (*AM cycle Step 6 – Adjust*) outlines three different timescales for making adjustments based on what has been learned – within-season adjustments consistent with plans made in advance to deal with different kinds of flows, annual adjustments based on the previous years' observations, and adjustments to management practices after several years of implementing AM. It also outlines the types of adjustments that should be considered at each of these timescales. Lastly it describes a mechanism for informing decision-makers about what has been learned.

# Acknowledgements

We would like to thank the Bureau of Reclamation for engaging us to help with AM Plan development, and all of the Program members who actively participated in the process of researching and writing this AM Plan by attending our interviews, meetings and workshops, and providing written and verbal feedback on various drafts. Their contribution of time, knowledge, ideas and perspectives was invaluable and enormously appreciated. It was also an indication of a strong desire within the Program to collaboratively wrestle with tough issues for mutual benefit towards implementation of adaptive management in the Middle Rio Grande.

# Glossary

**Adaptive management:** Adaptive management (AM) is a rigorous approach for designing and implementing management actions to maximize learning about critical uncertainties that affect decisions, while simultaneously striving to meet multiple management objectives. It involves synthesizing existing knowledge and identifying critical uncertainties, developing hypotheses related to those critical uncertainties, exploring alternative actions to test those hypotheses, making explicit predictions of their outcomes including level of risk involved with implementation, selecting one or more actions to implement, conducting monitoring and research to see if the actual outcomes match those predicted, and then using these results to learn and adjust future management and policy.

**Critical uncertainties**: From a decision analysis perspective, critical uncertainties are gaps in knowledge of a system which significantly affect the relative performance of alternative management decisions against stated objectives. Reducing critical uncertainties can therefore change the choice of management actions. Other uncertainties may limit our understanding of system behavior, but do not have as much impact on management decisions.

**Effectiveness monitoring:** Monitoring to assess whether project objectives are achieved. Generally, the monitoring variables focus on indicators that are closely linked with project objectives and relate to items of physical habitat quality. The monitoring methods should be sensitive enough to detect changes in indicators that have biological significance (e.g. an increase in successful flycatcher nesting pairs (modified from MRGESCP, 2006b)).

**Goals:** Broad statements of desired outcomes. These are often somewhat intangible, and it is the objectives underlying the goals that are tangible and measurable.

**Implementation monitoring:** Monitoring after project completion to assess whether the project was completed as designed; has important implications for interpretation of the results of effectiveness monitoring (modified from MRGESCP, 2006b).

**Indicator:** Used interchangeably with ‘performance measure’.

**Management actions:** Within the context of the AM Plan, these are on-the-ground interventions that entities in the MRG already undertake or could undertake. Such actions occur within the ‘decision space’ for the Program or its member agencies, and comprise the potential suite of actions to which adaptive management could be applied, depending on the uncertainties being targeted.

**Management decisions:** Within the context of the AM Plan, these are items the entities in the MRG have some degree of decision-making control over. These decisions help bound the AM Plan, which should focus on reducing critical uncertainties affecting confident management decisions.

**Management strategy:** The logical collection of management actions that would be employed to achieve one or more management objectives.

**Objectives:** The proposed means of achieving goals, disaggregating goals into a logical hierarchy of desired attributes of the system.

**Performance measure:** Variables that estimate the performance of one or more actions against objectives. Performance measures can be proxies for something that cannot be measured directly. In this document ‘performance measure’ and ‘indicator’ are used interchangeably.

**Priority hypotheses:** Hypotheses which need to be addressed first in a sequence of investigative efforts for a number of possible reasons (e.g., strong influence on the design of actions, most feasible to test, key decision node in a decision tree). The outcomes of tests of priority hypotheses will often inform decisions on which of various candidate hypotheses and investigations need to be pursued subsequently.

**Validation monitoring:** Monitoring of target species (silvery minnow and flycatcher) to determine if these target species are responding to management actions, critical cause-effect linkages between actions and species' responses, and overall progress towards the Program's biological objectives.

**Water year:** A term for conveying the fact that the volume of spring flows entering the MRG system varies greatly from year-to-year. The 2003 BO defines 'dry', 'average' or 'wet' years based on the Natural Resources Conservation Service's April 1 streamflow forecast. The water year runs from October 1 to September 30.

# Abbreviations

| | |
|---|---|
| a-ft | acre-feet |
| AM | Adaptive management |
| BO | Biological Opinion |
| BOR | Bureau of Reclamation |
| cfs | Cubic feet per second |
| CPUE | Catch per unit effort |
| ESA | Endangered Species Act |
| LFCC | Low flow conveyance channel |
| MRG | Middle Rio Grande |
| MRGCD | Middle Rio Grande Conservancy District |
| MRGESCP | Middle Rio Grande Endangered Species Collaborative Program |
| NMDGF | New Mexico Department of Game and Fish |
| NMESFO | New Mexico Ecological Services Field Office |
| NMISC | New Mexico Interstate Stream Commission |
| NMFRO | New Mexico Fishery Resources Office (currently the New Mexico Fish and Wildlife Conservation Office, or NMFWCO) |
| NRCS | Natural Resources Conservation Service |
| PVA | Population Viability Analysis |
| RGSM | Rio Grande silvery minnow |
| RPA | Reasonable and Prudent Alternative |
| SWFL | Southwestern Willow Flycatcher |
| USACE | US Army Corps of Engineers |
| USFWS | US Fish and Wildlife Service |

# Table of Contents

# List of Figures

# List of Tables



# List of Boxes

# Introduction

This is the first Adaptive Management (AM) Plan for the Middle Rio Grande Endangered Species Collaborative Program (MRGESCP) (Program). It provides a framework for conducting Program activities to deliberately and explicitly reduce management uncertainties.

Not all Program activities *need* to be done using the AM approach, such as those for which there is little uncertainty. Similarly, not all Program management activities for which uncertainties exist *can* be done using the AM approach, for practical reasons, because AM at this scale takes considerable time and resources. Therefore, only a subset of the critical uncertainties facing the Program should be addressed through AM. Identifying this subset among the larger suite of possibilities is an important part of AM planning.

This is Version 1 of the AM Plan. Based on an assessment of the building blocks for AM in Section 1, it identifies a preliminary example AM design in Section 2 and takes this example through the remaining steps in the AM cycle. A more prescriptive Version 2 will take more time to develop. Doing so now is premature for the following reasons:

- Identifying the critical uncertainties – which drive the rest of the AM cycle – requires more time and participation from the Program's Executive Committee members, the technical Work Groups and other Program participants. The uncertainties presented in this version were submitted by Program participants who attended the technical sessions held as part of the process for drafting the Plan. These uncertainties have not been endorsed by the Program and it will take more time by Program participants to thoroughly examine and refine them, articulate the underlying hypotheses, and sequence these to identify and agree on which priority hypotheses to address using AM.
- AM actions have not yet been selected by the Program. Some potential management actions for testing hypotheses using AM are listed in the 2003 Biological Opinion (BO) (USFWS, 2003a). However the 2003 BO is about to expire, and it is not yet known which actions the 2013 BO will prescribe or what it may contain regarding either opportunities or constraints for experimental management. Typically AM Plans are developed once actions are agreed upon, allowing the Plan to be much more specific.
- The Long Term Plan, another document that directs the Program, is undergoing development and is not finalized.
- Population Viability Analysis (PVA) models are still being refined. Such models, together with other tools in a linked framework, will help in sequencing hypotheses, quantifying performance measures related to some of the management objectives and simulating/screening candidate management actions and implementation designs. Existing models will need to be put into a common framework to evaluate alternative actions and hypotheses and linked to other tools dealing with flow and physical habitat. Additional models and decision analysis tools, such as the framework developed and applied by Alexander et al. (2006), will likely also be needed, and will take time to develop.

This Version 1 of the AM Plan includes a recommended process for the Program to move to Version 2, which would detail an accepted and scientifically defensible AM design to be implemented, monitored and evaluated.

## Program Background

The Program is a partnership for the purposes of protecting and improving the status of endangered species in the Middle Rio Grande (MRG) of New Mexico while simultaneously protecting existing and future regional water uses. The partnership currently consists of the following 16 signatories:

Bureau of Reclamation (BOR)
U.S. Fish and Wildlife Service (USFWS)
U.S. Army Corps of Engineers (USACE)
New Mexico Interstate Stream Commission (NMISC)
New Mexico Department of Game and Fish (NMDGF)
New Mexico Attorney General's Office
Santo Domingo Tribe
Pueblo of Sandia
Pueblo of Isleta
Pueblo of Santa Ana
Middle Rio Grande Conservancy District (MRGCD)
City of Albuquerque
Albuquerque-Bernalillo County Water Utility Authority
Assessment Payers Association of the Middle Rio Grande Conservancy District
New Mexico Department of Agriculture
University of New Mexico

Two species of particular concern are the Rio Grande silvery minnow (*Hybognathus amarus*) (silvery minnow) and Southwestern Willow Flycatcher (*Empidonax traillii extimus*) (flycatcher), both of which are Federally Endangered. Relevant documents issued by the U.S. Fish and Wildlife Service include a BO (USFWS, 2003a), a silvery minnow critical habitat designation (USFWS, 2003b) and recovery plan (USFWS, 2010), and a flycatcher critical habitat designation (USFWS, 2005a) and recovery plan (USFWS, 2002). The 2003 BO concluded that actions by the Bureau of Reclamation, U.S. Army Corps of Engineers, and related non-federal actions jeopardized the continued existence of the silvery minnow and flycatcher and adversely modified silvery minnow critical habitat. The 2003 BO includes a Reasonable and Prudent Alternative (RPA) to avoid jeopardy to the two species and adverse modification to silvery minnow critical habitat. The recovery plans for both species, as well as aspects of the RPA, describe numerous actions designed to aid species recovery. Actions from the RPA and the species recovery plans include spawning flows, providing surface water to flycatcher breeding sites, continuous minimum river flows, fish passage and salvage, habitat restoration, and monitoring.

Many recovery actions for the silvery minnow and flycatcher are being implemented through the Program. The Program has assisted the Bureau of Reclamation and the U.S. Army Corps of Engineers with BO compliance, ensuring *Endangered Species Act* (ESA) compliance for federal and non-federal water and river maintenance operations affecting the silvery minnow and flycatcher. The Program is governed by an Executive Committee, which established a Coordination Committee to identify concerns associated with Program activities and to develop consensus recommendations for action by the Executive Committee. The Program Management Team provides management and technical support to the Executive Committee and Coordination Committee, as well as to additional Program Work Groups. Current Program Work Groups include:

- Habitat Restoration
- Science
- Species Water Management
- PVA/Biology
- Public Information Outreach
- Monitoring Plan Team (ad hoc)
- San Acacia Reach (ad hoc)
- Population Habitat Viability Analysis/Hydrology (ad hoc)
- Database Management System (ad hoc)

The Executive Committee adopted a Long Term Plan in 2006 to guide implementation of Program actions. This Long Term Plan describes activities to be implemented that are within the authorities of the Program, provides budget estimates through the year 2014, and identifies measurable objectives and an annual Program assessment process. The Bureau of Reclamation and U.S. Army Corps of Engineers, in coordination with the Program, are in the process of developing new Biological Assessments. Concurrently, the Program is revising the Long Term Plan which will include beneficial activities tied to the species recovery plans. After receipt of the Biological Assessments from the action agencies, the USFWS will produce a new BO by 2013. The revised Long Term Plan and the AM Plan will implement any terms and conditions, RPAs or Reasonable and Prudent Measures included in the 2013 BO allowing the Program to serve as the primary ESA compliance vehicle for the 2013 BO.

AM can be a helpful approach to uncertainties regarding the effectiveness of various management actions related to the silvery minnow and flycatcher. Certain conditions must be fulfilled in order for AM to be successful. These include feasibility for conducting a test of management actions, potential for learning about action effectiveness within a reasonable time frame, acceptable risk from failure of those tests, and flexibility to change management practices based on what is learned. AM is seen by the Program as an important learning framework, and this Adaptive Management Plan Version 1 serves as the first step for applying an AM approach to the Program.

## About Adaptive Management

AM is a rigorous approach for deliberately designing and implementing management actions to test hypotheses and maximize learning about critical uncertainties that affect management decisions, while simultaneously striving to meet multiple management objectives. It was first developed under the name 'Adaptive Environmental Assessment and Management' in the 1970s by C.S. Holling, C. Walters and associates at the University of British Columbia and the International Institute for Applied Systems Analysis in Vienna (Holling, 1978). It has since been applied to a wide range of resource and ecosystem management problems throughout North America and elsewhere (ESSA, 1982; McDonald et al., 1999; Gregory et al., 2006). AM is an approach to management that involves synthesizing existing knowledge and identifying critical uncertainties, developing hypotheses related to those critical uncertainties, exploring alternative actions to test those hypotheses, making explicit predictions of their outcomes including level of risk involved with implementation, selecting one or more actions to implement, conducting monitoring and research to see if the actual outcomes match those predicted, and then using these results to learn and adjust future management and policy (Walters, 1986; Walters, 2007; Taylor et al., 1997; Murray and Marmorek, 2003; Williams et al., 2009; Smith, 2011). This sequence is summarized in a six-step process (Figure 1), although this is a simplification of a process which in practice does not flow so sequentially through the steps but is more often iterative between certain steps. The AM cycle depicted in Figure 1 and the description below is in alignment with the US Department of Interior's technical guide to AM (Williams et al., 2009).

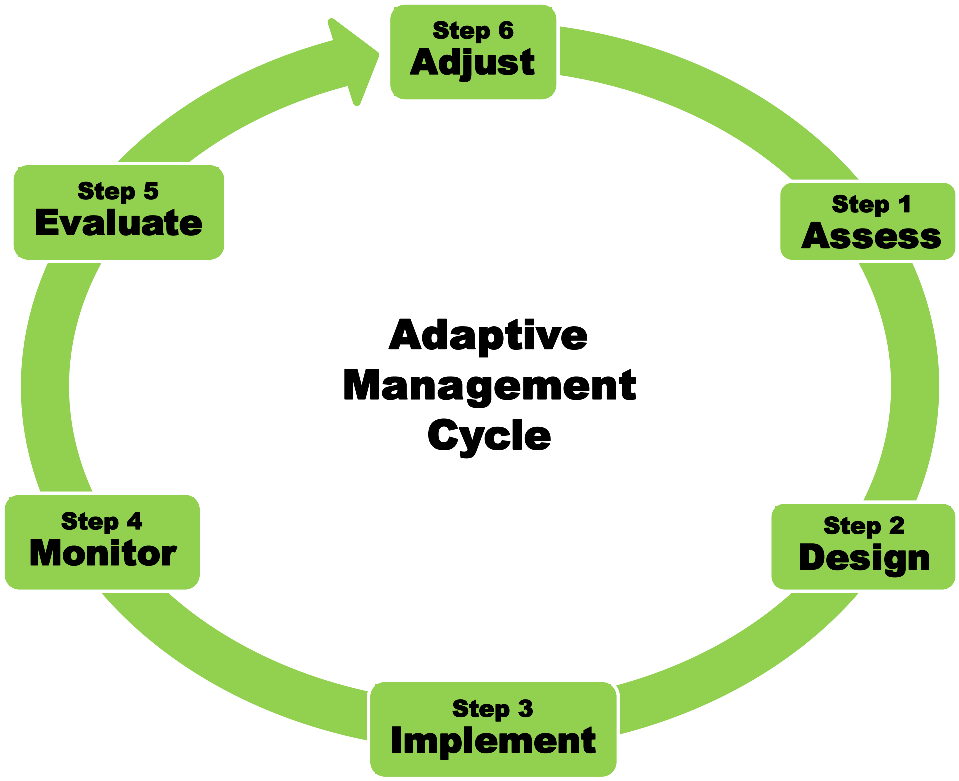



**Figure 1.** Adaptive management cycle.

AM is not needed for all environmental management situations, but can be very useful where there is significant uncertainty about the effectiveness of policies and practices. Applying the rigor of AM often requires a considerable commitment of effort and resources, but can lead to better decisions more quickly than the status quo (illustrated in Figure 2). Unfortunately the term 'adaptive management' has been widely misused and applied to largely ad hoc approaches, diluting its original rigorous intent. Common misconceptions about AM include:

- It is the same as trial-and-error, or simply means adapting your policies as you go (whereas it is a very rigorous and systematic process).
- It requires sophisticated modeling skills and tools (which it may not for simpler problems over smaller spatial and temporal scales).
- It is something only scientists do (whereas scientists are essential, but managers and policy-makers are also essential as it is their uncertainties that should drive AM, and stakeholders must also be involved).
- It can solve all problems, or resolve all uncertainties (whereas it is only one tool for resolving uncertainty, best suited for questions about what management actions will best achieve management objectives at an operational scale where contrasts can be created and compared).
- It requires consensus from all stakeholders (whereas there should be agreement on desired outcomes, but it does not require agreement on how to achieve those outcomes – this is what AM can help resolve).

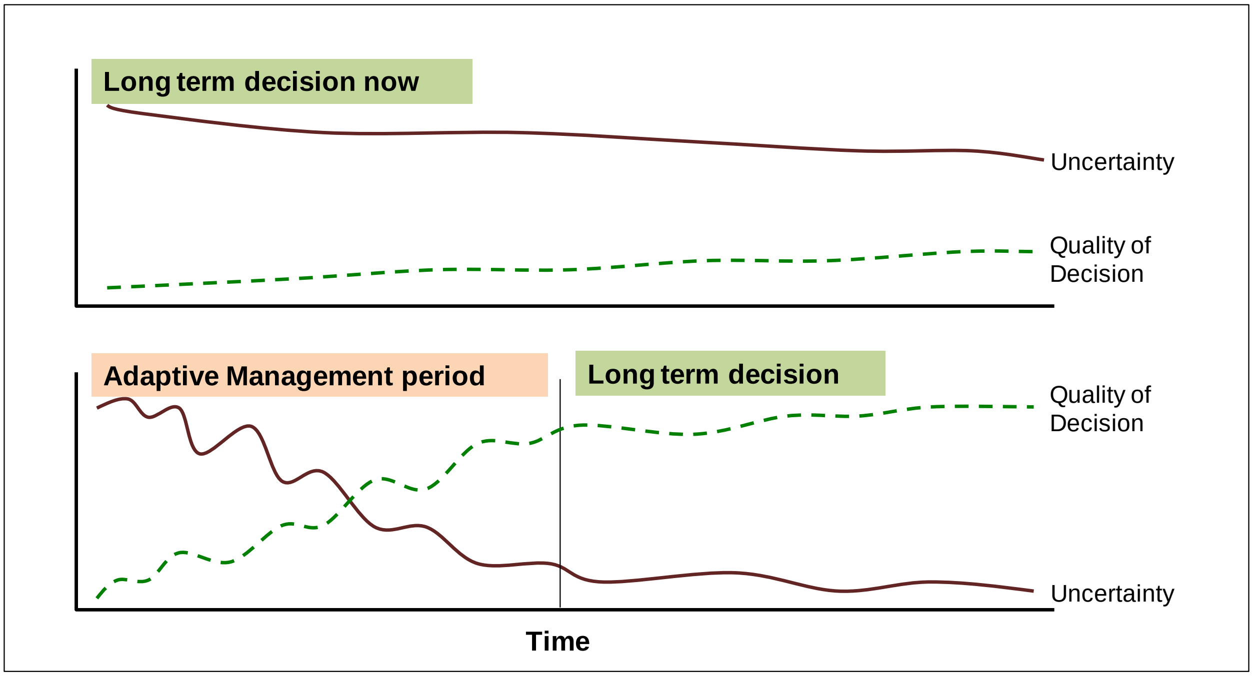



**Figure 2.** How adaptive management can lead to better decisions. The graph on the top illustrates the status quo, when decisions for long-term management have inherent uncertainty but no formal mechanism is implemented to explicitly reduce this uncertainty (i.e., to learn). With no formal structured learning process, discoveries of what might work better will be serendipitous and slow, leading, at best, to very gradual improvements in the 'quality of the decision' (the effectiveness of the outcomes when compared against objectives). The graph on the bottom shows an alternative approach where by AM is used to actively probe the system and test competing hypotheses for the explicit purpose of learning what works best and improving decisions – learning and the resulting improvements to decisions occurs much more quickly. Better decisions are made at the end of the AM period based on this active learning.

Table 1 lists the basic elements in each of the six steps in the AM cycle. Inclusion of all listed elements in each step is the ideal, although in practice some may be left out for reasons of feasibility or the specifics of the particular situation. However each element has an important function and there are consequences for leaving any out. As more elements are dropped, the application of AM becomes less rigorous and begins to move out of the domain of AM into a less formal and potentially much less effective learning paradigm.

The first element of Step 2 in Table 1 is 'active' AM. Active AM is an experimental approach whereby, when faced with uncertainty, several alternatives are implemented as concurrent (ideally, otherwise sequential) experiments to see which will best meet management objectives. It is characterized by 'actively probing' the system in order to distinguish between competing hypotheses (where the different hypotheses suggest different 'optimal' actions). A key aspect to learning through active AM is that there are contrasting alternatives that can be compared. A more cautious approach, called 'passive' AM, is to implement the alternative managers think is 'best' with respect to meeting management objectives, then monitoring to see if that assumption proves correct, and making adjustments if expected outcomes are not achieved.

The AM process (either in passive or active form) is intended to be iterative. After management actions are completed and rigorously assessed, the knowledge gained should be applied to improve the next round of management. However, it is often not possible to resolve all uncertainties through a single set of management actions. Also, the influence of external drivers of the ecosystem should be expected to change over time, influencing the effectiveness of management strategies. Consequently, subsequent rounds of management actions should also be treated as formal management evaluations, leading to subsequent iterations of the AM cycle.

Adjustments in Step 6 can occur at different temporal scales. Treatments and monitoring protocols may need within-year adjustments. There may be annual adjustments of the state of knowledge, some hypotheses, and models. It may take several years or longer before results provide compelling evidence for adjusting management practices.

### *The Role of Research*

In the context of adaptive management, research is meant to fill critical holes that impede the completion of the steps within the adaptive management cycle. Research activities should be short, focused studies on key topics, which might include:

- Within the Assess step, research to better assess the situation and design more effective management actions, such as literature reviews, retrospective analyses of existing data, and studies of geomorphic processes, habitat use or reproduction triggers.
- Within the Design or Monitoring steps, pilot studies to improve methods of monitoring so as to more accurately assess the effects of management actions on population abundance and distribution.
- Within the Evaluation step, analyses and modeling to more effectively detect the signals of management actions (and species' status) within the background of natural variation over space and time.

Research can also support AM monitoring to provide more detailed understanding of the cause and effect relationships between management actions and outcomes. Together, monitoring and research will help identify the best way to modify management, and build links between the application of science and decision-making by managers. Research projects should be implemented according to existing protocols and independently peer reviewed.

**Table 1.** Elements within each step in the adaptive management cycle. Modified from Marmorek et al. (2006).

| AM Steps | Ideal Elements within each Step |
|---|---|
| **Step 1.**<br>Assess and define the problem | a. Clearly state management goals and objectives<br>b. Review existing information to identify critical uncertainties and management questions<br>c. Build conceptual models<br>d. Articulate hypotheses to be tested<br>e. Explore alternative management actions (experimental 'treatments')<br>f. Identify measurable indicators<br>g. Identify spatial and temporal bounds<br>h. Explicitly state assumptions<br>i. State up front how what is learned will be used<br>j. Involve stakeholders, scientists, and managers |
| **Step 2.**<br>Design | a. Use active AM<br>b. When and where possible, include contrasts, replications, controls<br>c. Obtain statistical advice, building on analyses of existing data<br>d. Predict expected outcomes and level of risk involved<br>e. Consider next steps under alternative outcomes<br>f. Develop a data management plan<br>g. Develop a monitoring plan<br>h. Develop a formal AM plan for all of the remaining steps<br>i. Peer-review (internal, external) the design<br>j. Obtain multi-year budget commitments<br>k. Involve stakeholders |
| **Step 3.**<br>Implement | a. Implement contrasting treatments<br>b. Implement as designed (or document unavoidable changes)<br>c. Monitor the implementation |
| **Step 4.**<br>Monitor | a. Implement the Monitoring Plan as it was designed<br>b. Undertake baseline ('before') monitoring<br>c. Undertake effectiveness and validation monitoring |
| **Step 5.**<br>Evaluate results | a. Compare monitoring results against objectives<br>b. Compare monitoring results against assumptions, critical uncertainties, and hypotheses<br>c. Compare actual results against model predictions<br>d. Receive statistical or analysis advice<br>e. Have data analysis keep up with data generation from monitoring activities |
| **Step 6.** Adjust hypotheses, conceptual models, & management | a. Meaningful learning occurred, and was documented<br>b. Communicate this to decision makers and others<br>c. Actions or instruments changed based on what was learned |

## How to get from Version 1 to Version 2 of the AM Plan

To move from Version 1 to Version 2 of the AM Plan, we suggest the Program conduct a systematic *simulation and evaluation of alternative sets of actions*, converging to the best possible approach that appears to both meet the Program's goals and concurrently reduce critical management uncertainties under a wide range of possible future conditions. We recommend this be done collaboratively by a policy group comprised of policy and management representatives and a technical group comprised of scientists in various disciplines who work together illustrated in Figure 3.

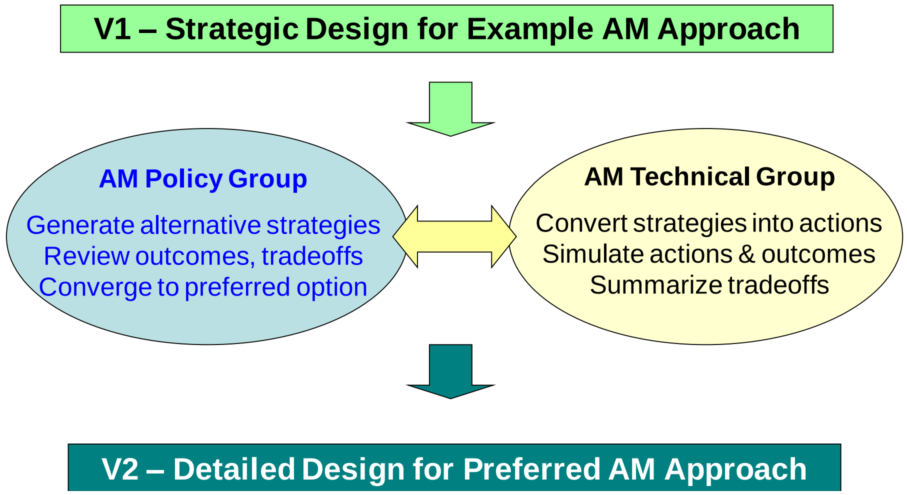



**Figure 3.** Illustration of overall process to move from Version 1 of the AM Plan to Version 2.

While these two groups would have different responsibilities, they would interact in an iterative process of creating and evaluating alternative sets of actions. The policy group would identify a set of actions to explore in order to reduce critical uncertainties. The technical subgroup would *simulate* the expected outcomes of each combination of actions under a range of environmental conditions, including what would be monitored and how, how the acquired data would be analyzed, how accurate these methods would be in detecting actual effects, and what might be changed based on different outcomes. The policy group would then evaluate the simulated outcomes and work with the technical group to develop the next set of actions to be simulated (building on the strengths of the previous set, and reducing its weaknesses). Simulating and evaluating different actions and conditions using formal procedures provides the rigor necessary for successful (and lower-risk) AM design, particularly in large systems such as the MRG. More detail on this simulation process is provided in Section 1.6. These chosen actions that emerge from this iterative simulation and evaluation process would then be the focus of the content when revising Sections 2-6 in Version 2 of the AM Plan.

The policy group could be drawn from the Executive Committee and the Coordination Committee. The technical group could be comprised of a few members from each of the current scientific and technical Work Groups, or as designated by each Program signatory. While the bulk of the time and effort will be borne by the technical group, the policy function is essential to provide some degree of focus and direction at the technical level and ensure the work of the technical group has relevance for operational management[1], and these groups must be mutually supportive.

Table 2 describes the specific roles of the policy and technical groups. These groups need to be involved in two processes: simulations of the AM cycle towards the development of Version 2 of the AM Plan (roles shown below in the first two rows – Assess, Design), and then later, iterative evaluation of real results once Version 2 of the AM Plan is actually implemented (rows 3 through 6: Implement, Monitor, Evaluate, Adjust).

[1] This is one way in which AM differs from traditional research. Technical explorations of research projects tend to occur under a slightly different process, whereby technical groups generate and explore ideas and a policy body might only have a decision-making role at the proposal stage (e.g. regarding funding).

**Table 2.** Suggested policy/management and technical roles in developing, and then also implementing, Version 2 of the AM Plan. Adapted from Marmorek and Parnell (2002), and Province of British Columbia (1998). Roles are numbered in approximate sequence within each step, although frequent iteration within each step will occur.

| Step in AM Cycle | Policy/Management Roles | Technical Roles |
|---|---|---|
| 1. Assess | 1.2 Raise issues and concerns.<br>1.3 Develop fundamental objectives (what is desired, not how to get there).<br>1.4 Explain to technical scientists why each fundamental objective matters (i.e. keep scientists focused on what matters to the policy makers).<br>1.5 Ask questions about efficacy of different management approaches and cause-effect relationships. | 1.1 Summarize existing knowledge about the ecosystem, and its history.<br>1.6 Develop performance measures/indicators associated with each fundamental objective, so that policy group can use these to evaluate options.<br>1.7 Develop formal sets of alternative hypotheses that would inform critical uncertainties and are tied to fundamental Program objectives.<br>1.8 Filter these hypotheses down by summarizing what is known, what is not known, and what is unknowable. Focus in on critical uncertainties affecting resource management decisions.<br>1.9 Explain to policy stakeholders the results of the filtering process (i.e. keep policy makers realistic about what is known and unknown). |
| 2. Design | 2.1 Develop broad strategies and alternatives to achieve the fundamental objectives, and resolve critical uncertainties concurrently.<br>2.4 Evaluate the alternative sets of management actions under consideration, and tradeoffs among objectives (including learning as an objective).<br>2.6 Assess what level of investment is acceptable in monitoring and evaluation (depends on both funding and the risks of incorrect decisions based on faulty inferences).<br>2.7 Assess what policy responses would be depending upon the outcome of the AM experiment.<br>2.9 Provide input on politically acceptable experimental designs, and approve the design of the AM experiment. | 2.2 Convert broad strategies and alternatives into hypotheses to be tested based on Step 1. Translate into specific sets of management actions that can be conducted in an AM experiment.<br>2.3 Simulate alternatives in a suite of models to evaluate expected outcomes of proposed alternatives, help design the AM experiment, and assess rates of learning.<br>2.5 Use models to assess the likely level of certainty in conclusions with different levels of investment in monitoring and evaluation, and with different designs of the AM experiment.<br>2.8 Through dialogue with the policy group, converge to a design for the AM experiment which best meets both policy considerations and statistically reliability. |
| 3. Implement | 3.1 Ensure that the implementation planned in Version 2 of the AM Plan is followed.<br>3.4 Review and approve annual implementation plans. | 3.2 Work through all of the technical details of implementation consistent with Version 2 of the AMP Plan and annual decisions.<br>3.3 Suggest annual revisions to implementation plan (if required) to policy group, and revise as required. |
| 4. Monitor | 4.1 Ensure that the monitoring planned in Version 2 of the AM Plan is followed.<br>4.6 Review and approve annual monitoring plans. | 4.2 Carry out field monitoring consistent with Version 2 of the AM Plan and annual decisions.<br>4.3 Enter data into databases.<br>4.4 Conduct research necessary to support monitoring methods, including analyses of costs and benefits.<br>4.5 Present proposed annual monitoring plan (if required) to policy group, and revise as required. |

| Step in AM Cycle | Policy/Management Roles | Technical Roles |
|---|---|---|
| 5. Evaluate | 5.4 Provide feedback to technical group on presentations of interim results from evaluations, and presentations from peer reviews.<br>5.5 Request additional evaluations to help in decision making. | 5.1 Perform analyses and evaluations as described in Version 2 of the AM plan and annual data analysis plans.<br>5.2 Compare monitoring results against Program objectives, hypotheses, model predictions.<br>5.3 Synthesize evaluations for policy and management personnel; provide summaries and presentations at annual symposia.<br>5.6 Respond to peer reviews and requests from policy group for additional evaluations. |
| 6. Adjust | 6.2 Decide if adjustments to actions are warranted based on information from technical scientists, and other factors affecting decisions. | 6.1 Clarify implications of evaluations for possible adjustments to actions and hypotheses, including risks and benefits of alternative decisions. |

A blue shaded box is provided a the end of Sections 2 through 6 which briefly describes for each section how the content of Version 2 would differ from the content provided in Version 1.

Moving from Version 1 to Version 2 will take time and will require substantial work from Program participants. During development of Version 1 several discussions centered on the need to try to apply interim AM actions sooner, rather than wait until the process described here (and in greater detail in Section 1.6) is completed, as the results of interim actions may help inform the finalization of the Long Term Plan and the preparation of the 2013 BO. One option for the Program to consider is to use the framework provided in Version 1 to develop a 'pilot project' for AM implementation. This would occur in parallel with developing Version 2 of the AM Plan. It would involve policy/management and technical participants specifying one or two hypotheses to be tested, and using an abbreviated version of the approach described here for moving from Version 1 to Version 2 to quickly reach agreement on the wording of those hypotheses, key performance measures, details on the action(s) to be taken, and associated monitoring and analysis procedures. A flow action in 2012 and/or channel rehabilitation projects could serve as the action to be taken through this full design process as a pilot project.

As an example, the Platte River Program is developing a design document for a pilot 'Proof of Concept' management action experiment at one of its habitat complexes revolving around critical uncertainties related to the response of terns, plovers, and whooping cranes to management actions such as short-duration high flows, sediment augmentation, and flow consolidation. This document, when finalized, can be shared with interested Program participants to suggest a framework for how an AM pilot in the MRG could be detailed and implemented.

# 1.0 AM Cycle Step 1 – Assess

AM is a rigorous approach for learning through deliberately designing and implementing management actions to reduce critical uncertainties while at the same time meeting management objectives. Management decisions involve choosing among alternative actions that best balances competing objectives and societal values. That is learned through AM is only one input to decisions, and is no replacement for the dialogue required to reach consensus on acceptable tradeoffs between competing objectives and values (e.g., water for agriculture vs. water for minnows and flycatchers). However, AM *can* help to reduce critical uncertainties regarding the *effectiveness* of alternative management actions, which is one key factor in the decision making-processes by the Program and each of the involved entities.

This section describes the building blocks for the AM Plan and provides a roadmap for using science-based learning to assess how best to implement AM to inform MRG decision-making.

- **Goals (1.1)** –Broad statements of desired outcomes which form the direction for the Program, and therefore also guide the AM Plan. AM should focus on reducing critical uncertainties about how best to achieve these goals.
- **Objectives (1.2) –** An articulation of the goals in quantitative terms to facilitate identification of uncertainties and evaluate the effectiveness of AM actions.
- **Management Decisions and Uncertainties (1.3) –** The 'decision space' within which managers operate, and uncertainties affecting these decisions. Uncertainties are the 'big questions' that describe critical scientific questions related to management decisions to achieve the goals and objectives, and which comprise the drivers for doing AM. (What uncertainties are relevant to the achievement of management objectives, or the selection of management actions?) In some places they are conveyed as 'broad hypotheses' which frame uncertainties as opinions, but lack the quantitative nature of more specific hypotheses.
- **Conceptual Models (1.4)** – Visual frameworks for representing relationships between management actions and the system being managed, as well as where the uncertainties lie.
- **Hypotheses, Performance Measures, and Benchmarks (1.5) –** Competing hypotheses clearly articulate a range of opinions about critical uncertainties as specifically as possible. Performance measures should be monitored when testing each hypothesis. Benchmarks identify the target or threshold quantities of these performance measures needed to draw conclusions regarding each hypothesis.
- **Management Actions (1.6)** – What management actions will be used to test the hypotheses – and for this Version 1 of the AM Plan, how to identify those actions.
- **Spatial and Temporal Bounding (1.7)** – Important dimensions for the AM Plan that will depend on the results of the previous building blocks.

## 1.1 Goals

The purposes of the Program are *to protect and improve the status of endangered listed species along the Middle Rio Grande (MRG) and to simultaneously protect existing and future regional water uses while complying with state and federal laws, including Rio Grande compact delivery obligations* (MRGESCP, 2006a). To fulfill these purposes, the Program has identified the following goals[2]:

[2] From http://www.mrgesa.com/Default.aspx?tabid=176 [accessed October 22, 2011].

1) *Alleviate jeopardy to the listed species in the Program Area.*
    - *Identify and articulate the critical scientific questions that will help evaluate flexibility in the system that wasn't known to be there in 2003.*
    - *Understand the system well enough to develop adaptive management tools to support a sustainable Biological Opinion.*
2) *Conserve and contribute to the recovery of the listed species.*
    - *Stabilize existing populations.*
    - *Develop self-sustaining populations.*
3) *Protect existing and future water uses.*
4) *Report to the community at large about the work of the Program.*

The Rio Grande Silvery Minnow (*Hybognathus amarus*) Recovery Plan (USFWS, 2010) and the Southwestern Willow Flycatcher Recovery Plan (USFWS, 2002) elaborate on the Program's second goal. Silvery minnow recovery goals (USFWS, 2010) are:

- *Prevent the extinction of the Rio Grande silvery minnow in the Middle Rio Grande of New Mexico.*
- *Recover the Rio Grande silvery minnow to an extent sufficient to change its status on the List of Endangered and Threatened Wildlife from endangered to threatened (downlisting).*
- *Recover the Rio Grande silvery minnow to an extent sufficient to remove it from the List of Endangered and Threatened Wildlife (delisting).*

Flycatcher recovery goals (USFWS, 2002) are:

- *Recovery to the point that reclassification to "threatened" is warranted.*
- *Recovery to the point that delisting is warranted.*

Specific silvery minnow and flycatcher recovery criteria related to these goals are provided in these recovery plans.

The Program is a collaborative effort on the part of numerous parties in the MRG to meet these goals. The purpose of the AM Plan is to describe a rigorous approach for Program learning, directed at reducing critical uncertainties about the effectiveness of management actions toward achieving these goals. These goals will frame the management objectives identified in Section 1.2, and thereby guide the identification and exploration of uncertainties, hypotheses and actions to ensure that the learning that is done through AM clearly relates back to these goals.

## 1.2 Management Objectives & Strategies

Management objectives are descriptions of tangible outcomes that the Program is trying to achieve. They provide the means to both quantitatively describe the desired on-the-ground outcomes and evaluate the effectiveness of different Program actions in achieving those outcomes. Within an AM framework, management objectives are essential for bounding the critical uncertainties. As mentioned in Section 1.1, they must also be consistent with the goals, providing greater specificity to what those goals actually mean in measurable terms.

The broad goals of the Program are directed at alleviating jeopardy to listed species and contributing to recovery while protecting existing and future water uses. The AM approach requires the articulation of quantifiable objectives or milestones in the Program that relate species and system metrics to broader

Program goals. The current versions of the recovery plans may provide this context for management objectives for the silvery minnow and flycatcher. For example, silvery minnow Recovery Criterion 1-A-1 seeks to document the presence of unmarked silvery minnows at three quarters of all sites in each of three reaches in October each year (USFWS, 2010).

Figure 4 presents a preliminary 'organizational hierarchy' for management objectives and potential strategies that are measurable and should ultimately provide a clear path between data collection, analysis, synthesis, and determining if the Program is meeting its broader goals. The figure suggests two management objectives and several indicators for each:

1) **Silvery minnow population viability – meet some meaningful standard.** This standard still needs to be defined, perhaps in the new Biological Opinion. Indicators of population viability include:
    - Population abundance and distribution
    - Population genetic diversity
    - Population age structure
    - Population stability
2) **Flycatcher population viability – meet some meaningful standard.** This standard still needs to be defined, perhaps in the new Biological Opinion. Indicators of population viability include:
    - MRG population abundance and distribution
    - Number and geographic distribution of territories
    - Number of individuals
    - Reproductive metrics
    - Population stability

These management objectives are suggestions to stimulate discussion among Program participants. These objectives should be refined as the AM Plan evolves from Version 1 to Version 2. The resulting objectives must be adequately detailed and measurable. The indicators come from the silvery minnow and flycatcher conceptual models (Section 1.4). As with the management objectives posed above, these indicators should be refined as the AM Plan, Long Term Plan, and 2013 BO development process advances.

Figure 4 also suggests three general management strategies (logical packages of management actions) that span a gradient of possibilities. The first is composed primarily of flow-related actions. Some habitat restoration or site preparation will likely have to be paired with flow actions to achieve the desired results. The second is composed primarily of habitat restoration activities. Some flow management will likely be required to maximize habitat restoration efforts, such as ensure riparian habitat is wetted or that silvery minnow have access to overbank spawning areas. The third strategy composed of equal amounts of flow management and habitat restoration.

As with the management objectives and indicators in Figure 4, these management strategies are offered to stimulate discussion among Program participants. The process described in Section 1.6 for exploring and identifying a set of actions to implement using AM will further inform the utility of these suggested strategies and how the actions might be grouped to provide contrasts and evaluation potential. Careful thought and planning will be needed regarding design, implementation, data collection and analysis. The individual actions comprising each of the potential strategies will be refined when moving from Version 1 to Version 2 of the AM Plan as the Program converges on a specific set of management actions to be implemented. Section 2.2 of this report provides a more specific example of potential AM actions.

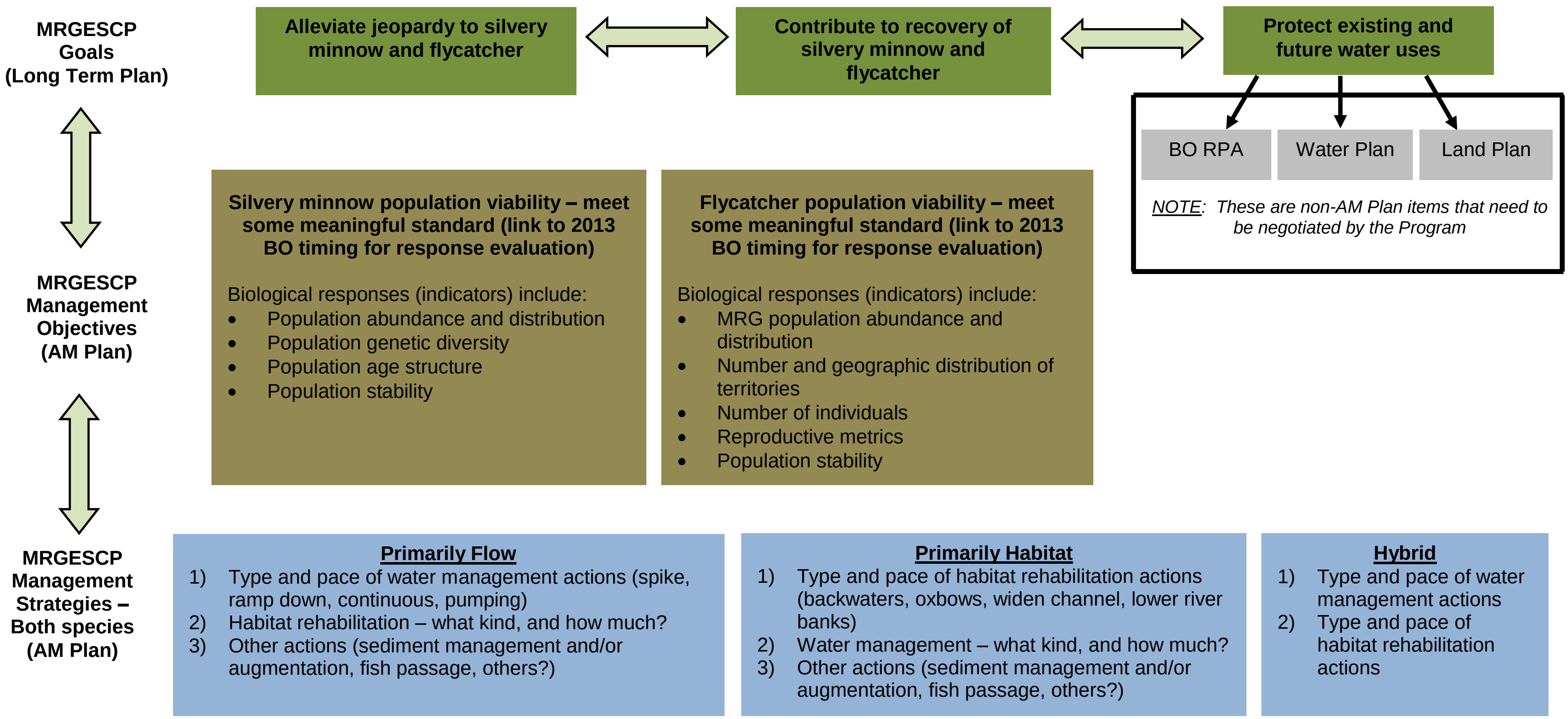



**Figure 4**. Organizational hierarchy for management objectives and strategies for the AM Plan.

## 1.3 Management Decisions and Critical Uncertainties

What makes AM different from traditional research is the relevance to management: AM focuses on operational-scale learning that is specific to enabling greater confidence in management decisions, answering questions of greatest importance in making management decisions. This is why the identification of critical uncertainties, and participation of senior managers, is so important in the AM approach: successful and meaningful AM requires understanding what it is that managers need to know to increase their confidence in decision-making. It also requires understanding their ‘decision space’ – the range of decisions currently facing managers in the MRG, and the degree of flexibility they have in making these decisions. **Understanding the ‘decision space’ pertaining to management affecting Program goals is important when determining what critical uncertainties and underlying hypotheses will be the focus of learning through AM as well as when designing how to test these hypotheses.** It also helps clarify the intended audience for what is learned through the application of AM.

The 2003 BO (USFWS, 2003a), Federal and state laws, interstate compacts, Supreme Court decrees, and federal trust responsibilities to the Tribes define much of this decision space. The opportunities for learning how management can be done *differently* in order to meet all of the Program’s goals must be found within this decision space.

Table 3 summarizes entities and their relevant management responsibilities as described in the 2003 BO, which along with those of the USFWS and other Program signatories comprises the broad suite of management decisions and actions that could be *informed* by what is learned through AM. Table 4 summarizes the RPA elements and actions in the 2003 BO, which help to both identify areas of uncertainty that AM could focus on and bound what may be permissible when designing AM actions to test hypotheses. The original text describing RPA elements and actions in the 2003 BO is provided in Appendix B. The 2006 Long Term Plan (MRGESCP, 2006a) identifies which of these RPA actions fits under each of the three Program goals.

The recovery plans for the silvery minnow (USFWS, 2010) and the flycatcher (USFWS, 2002) also list actions that provide opportunities for learning through AM. While not identified explicitly as such in these plans[3], we believe these opportunities exist under minnow recovery action #2 to *restore, protect, and modify habitats as necessary to alleviate threats to the Rio Grande silvery minnow*, and under flycatcher recovery action category #1 *to increase and improve occupied, suitable, and potential breeding habitat*, #2 to *increase metapopulation stability*, and #3 to *improve demographic parameters*.

[3] The recovery plan for the minnow (USFWS, 2010) includes adaptive management under recovery action #4, *develop and implement an adaptive management program,* but the actions listed there focus on monitoring and data management (step 4 in the AM cycle). The implication is that the recovery plan equates adaptive management with effectiveness monitoring and then making adjustments based on new knowledge. What is missing are other elements that characterize AM including explicit recognition of uncertainty and identification and operational testing of hypotheses. The recovery plan for the flycatcher (USFWS, 2002) conveys a similar view of adaptive management as the monitoring and adjustment aspects of research activities, missing the importance of the other steps in the AM cycle.

**Table 3.** Summary of entities and their relevant management responsibilities in the 2003 BO (USFWS, 2003a)

| Entity | Relevant Management Responsibilities |
|---|---|
| **State of New Mexico**<br>State engineer | ○ Supervise State waters – measurement, appropriation and distribution.<br>○ Grant State water rights permits and ensure permit requirements are met.<br>○ Enforce State water laws. |
| NMISC | ○ Develop, conserve, and protect the waters and stream systems of the State.<br>○ Represent New Mexico's interests in making interstate stream deliveries, and for investigating, planning, and developing the State's water supplies.<br>○ Cooperate with BOR to perform annual construction and maintenance.<br>○ Work under the State of New Mexico Cooperative Program (including some river maintenance on the Rio Chama, maintenance of Drain Unit 7, drain and canal maintenance within the Refuge, similar work at the State refuges, and temporary pilot channels into Elephant Butte Reservoir). |
| NMDGF | ○ Administer programs concerned with conservation of endangered species and game and fish resources.<br>○ Manage La Jolla State Game Refuge and Bernardo Waterfowl Area. |
| Environment Department | ○ Administer State's water quality program. |
| **Counties** | ○ General development and infrastructure, e.g. pumping wells and land-use regulations. |
| **Villages, Towns, Cities** | ○ Pump groundwater and/or use surface water for municipal and industrial purposes<br>○ Manage wastewater treatment systems that discharge into the Rio Grande. |
| **Irrigation Interests***<br>MRGCD | ○ Operate diversion dams of the MRG Project to deliver irrigation water to lands in the Middle valley including MRG Pueblos. |
| **US Army Corps of Engineers** | ○ Operate and maintain five flood control dams on the Rio Grande and its tributaries for flood control, sediment control, water supply, recreation, and fish and wildlife conservation. |
| **Bureau of Reclamation** | ○ Operate and maintain and/or provide oversight of Federal projects on the mainstem Rio Grande and its upper basin tributaries. |

* Includes acequias, individual irrigators and ditches, however responsibilities for irrigation interests beyond the MRGCD are not specified in the Non-Federal Actions section of the 2003 BO.

**Table 4.** Summary of RPA actions, and authorities for each, in the 2003 BO (USFWS, 2003a).The locations of diversion dams and gages mentioned in some RPA elements are shown in Figure 22 (Section 4).

| RPA Element and Action | Authority |
|---|---|
| **Water Operations Elements** | |
| A) Between April 15 and June 15 of each year, provide a one-time increase in flows (spawning spike) to cue spawning. | BOR, USACE (in co-ordination with parties to the consultation, USFWS) |
| B) Release any supplemental water in a manner that will most benefit listed species. | BOR, USACE (in coordination with USFWS) |
| C) Routine monitoring of river flow conditions when flows are 300 cubic feet per second (cfs) or less at San Acacia. | BOR (in coordination with parties to the consultation) |
| D) Ensure that active flycatcher territories supported by low flow conveyance channel (LFCC) pumping are provided with surface water or moist soils in the Rio Grande from Jun 15 to Sep 1. If active territories are dried along the Rio Grande or irrigation drains, pursue options for providing these territories with surface water or moist soils if at all practicable. * | BOR (in coordination with parties to the consultation) |
| E) Provide continuous river flow from Cochiti Dam to the southern boundary of minnow critical habitat from Nov 16 to Jun 15. *[in dry yrs and/or when Compact storage restrictions are in effect]* | BOR, USACE (in coordination with parties to the consultation) |

| **RPA Element and Action** | **Authority** |
|---|---|
| F) Provide year-round continuous river flow from Cochiti Dam to Isleta Diversion Dam with a minimum flow of 100 cfs at the Central Bridge gage. *[in dry yrs and or when Compact storage restrictions are in effect]* | BOR, USACE (in coordination with parties to the consultation) |
| G) Pump from the LFCC as soon as needed to manage river recession. Pumping capacity must meet or exceed 150 cfs. Continue pumping when it will benefit the flycatcher and its habitats. *[in dry yrs and or when Compact storage restrictions are in effect]* * | BOR (in coordination with USFWS) |
| H) Provide continuous river flow from Cochiti Dam to the southern boundary of silvery minnow critical habitat from November 16 to June 15. *[in average years]* | BOR, USACE (in coordination with parties to the consultation) |
| I) From June 16 to July 1 of each year, ramp down the flow to achieve a target flow of 50 cfs over San Acacia Diversion Dam through November 15. *[in average years]* | BOR, USACE (in coordination with parties to the consultation) |
| J) Provide year-round continuous river flow from Cochiti Dam to Isleta Diversion Dam with a target flow of 100 cfs over Isleta Diversion Dam. *[in average years]* | BOR, USACE (in coordination with parties to the consultation) |
| K) Pump from the LFCC if needed to manage river recession and maintain connectivity. The pumping capacity must meet or exceed 150 cfs. Continue pumping when it will benefit the flycatcher and its habitats. *[in average years]* | BOR (in coordination with USFWS) |
| L) Provide continuous river flow from Cochiti Dam to the southern boundary of silvery minnow critical habitat from November 16 to June 15, with a target flow of 100 cfs at the San Marcial Floodway gage. *[in wet years]* | BOR, USACE (in coordination with parties to the consultation) |
| M) From June 16 to July 1 of each year, ramp down the flow to achieve a target flow of 100 cfs over San Acacia Diversion Dam through November 15. *[in wet years]* | BOR, USACE (in coordination with parties to the consultation) |
| N) Provide year-round continuous river flow from Cochiti Dam to Isleta Diversion Dam with a target flow of 150 cfs over Isleta Diversion Dam. *[in wet years]* | BOR, USACE (in coordination with parties to the consultation) |
| O) Pump from the LFCC if needed to manage river recession and maintain river connectivity. The pumping capacity must meet or exceed 150 cfs. Pumping shall continue to maintain river connectivity. *[in wet years]* | BOR |
| **Habitat Improvement Elements** | |
| P) Prevent or minimize destruction of potential or suitable flycatcher habitat when installing pumps or groundwater wells. | BOR, USACE (in co-ordination with parties to the consultation, USFWS) |
| Q) Improve gaging and real-time monitoring of water operations to provide dependable, accurate readings, including installation of gages near Los Lunas, and Highway 380, and all diversions, drains, returns and main ditches. | BOR, USACE (in coordination with parties to the consultation) |
| R) Complete fish passage at San Acacia Diversion Dam to allow upstream movement of silvery minnows by 2008, and at Isleta Diversion Dam by 2013. In the interim, implement all feasible short-term fish passage/river reconnectivity actions. | BOR (in coordination with USFWS, Isleta Pueblo, parties to the consultation) |
| S) Conduct habitat/ecosystem restoration projects in the Middle Rio Grande to increase backwaters and oxbows, widen the river channel, and/or lower river banks to produce shallow water habitats, overbank flooding, and regenerating stands of willows and cottonwood to benefit the silvery minnow, the flycatcher, or their habitats. Projects should be depletion neutral. Complete additional restoration totaling 1,600 acres (648 hectares) by 2013. In the short term (≤5 years), place the emphasis for minnow habitat restoration projects on river reaches north of the San Acacia Diversion Dam. This restoration will be distributed throughout the action area. Projects should result in the restoration/creation of blocks of habitat 60 acres (24 hectares) or larger. Monitoring will be conducted for each project annually for 10 years in order to assess whether created habitats are self-sustaining, successfully regenerating, and are supporting the flycatcher and silvery minnow. | BOR, USACE (in consultation with USFWS, Pueblos, and in coordination with parties to the consultation) |
| T) When bioengineering cannot be used in BOR river maintenance projects, implement habitat restoration to offset adverse environmental impacts resulting from river alteration. Habitat restoration efforts should replace the ecological functions and values of the affected area, both temporally and spatially. A restoration plan should be produced for each restoration site that includes (but is not limited to): (1) the acreage and ecological value of the habitat to be impacted and restored, (2) measurable success criteria, (3) time frames for achieving project objectives, and (4) a remediation plan should the restoration site not succeed. | BOR (plan approval by USFWS) |

| RPA Element and Action | Authority |
|---|---|
| U) Collaborate on the river realignment and proposed relocation of the San Marcial Railroad Bridge project to increase safe channel capacity within the MRG. | BOR, USACE (in coordination with parties to the consultation) |
| V) Each year that the Natural Resources Conservation Service (NRCS) April 1 Streamflow Forecast is at or above average at Otowi and flows are legally and physically available, bypass or release floodwater during the spring to provide for overbank flooding. The overbank flooding will be used to create an increased number of backwater habitats for the silvery minnow and flycatcher. | USACE (in conjunction with USFWS and in coordination with compact deliveries) |
| W) Investigate and increase sediment transport through Jemez Canyon Dam and Galisteo Dam. Complete an environmental baseline study and investigate the feasibility of transporting sediment from Cochiti Lake, including addressing the issue of contaminated sediment. Investigate other locations in which sediment transport could be improved. | USACE (in coordination with Pueblos of Santa Ana, Santo Domingo, and Cochiti), BOR and parties to the consultation |
| X) Prevent encroachment of saltcedar on the existing channel and destabilize islands, point bars, banks, or sand bars in the Angostura, Isleta, and San Acacia Reaches. | BOR, USACE (in coordi-nation with parties to the consultation and in consultation with USFWS) |
| **Salvage and Captive Propagation Elements** | |
| Y) Provide $300,000 annually to the New Mexico Ecological Services Field Office (NMESFO) for distribution to propagation facilities for the continuation of captive propagation activities (including egg collection, transportation, relocation, rearing, breeding, etc.). Coordinate egg collection activities for propagation efforts. | City (in coordination with USFWS, BOR, USACE, and parties to the consultation) |
| Z) Provide $200,000 annually for the first three years of this consultation for the expansion of facilities propagating silvery minnows (the Hatchery, New Mexico Fishery Resources Office (NMFRO), New Mexico State University, the City, Rock Lake State Fish Hatchery, and any other approved locations). | BOR, USACE (in coordination with parties to the consultation) |
| AA) Construct two new naturalized refugia breeding and rearing facilities for the captive propagation of the silvery minnow, one in the Cochiti or Angostura Reach and the other in the Isleta or San Acacia Reach. | BOR, USACE (in coordination with parties to the consultation) |
| BB) Beginning in 2008, provide the NMESFO $100,000 annually for five years for monitoring and augmentation of silvery minnows reintroduced into its historic range under section 10(j) (experimental populations) of the ESA. | BOR, USACE (in coordination with parties to the consultation) |
| CC) Conduct silvery minnow surveys and habitat assessment studies in the Rio Grande above Cochiti Lake in preparation of silvery minnow releases under the Service's Regional Director's 10(a)(1)(A) permit. | USFWS (in coordination with NMDGF and Pueblos) |
| **Water Quality Elements** | |
| DD) Ensure the addition of treated wastewater to the river provides water quality conditions protective of silvery minnow. | City |
| EE) Provide funding for a comprehensive water quality assessment and monitoring program in the Middle Rio Grande to assess water quality impacts on the silvery minnow. | BOR, USACE (in coordination with parties to the consultation) |
| **Reporting Elements** | |
| FF) Action agencies, in coordination with parties to the consultation, shall provide a consolidated report on the status of all RPA elements to the Service by December 31 of each year. | BOR, USACE, parties to the consultation (submitted to USFWS) |

*Regarding elements D and G: during extreme drought years, with coordination with the Service, pumping directly to flycatcher territories prior to June 15$^{th}$ may not be necessary (USFWS, 2011).

When thinking about critical uncertainties pertaining to these decisions it is helpful to divide those decisions into several categories:

1. **Water.** Flow management in each reach over each period of the year in each type of water year, in particular during minnow spawning and rearing periods and flycatcher breeding periods.
2. **Physical system.** Channel rehabilitation and management actions in each reach, including minnow spawning and rearing habitat and flycatcher breeding habitat.
3. **Species.** Minnow hatchery stocking and genetic management decisions in each reach; and minnow salvage and rescue decisions.
4. **Monitoring and research.** Design and implementation of monitoring and evaluation to determine effectiveness of management actions (categories 1-3 above); and prioritization of research to support monitoring and evaluation and to test hypotheses that cannot or will not be addressed through management actions.

Table 5 connects *some* of these decisions with the entities responsible for making them, the relevant RPA elements within the 2003 BO, and specific **questions of interest to decision makers** – which may differ from the questions of interest to scientists. Before exploring what hypotheses to test (Section 1.5), it is important to first identify critical questions that managers have when making these management decisions, as these uncertainties should be the focus for identifying specific hypotheses to test. Table 5 also outlines how these decisions vary along a number of dimensions which are relevant to iterative evaluation and adjustment (i.e., degree of management flexibility; timescale to implement; timescale to evaluate and adjust; reversibility). Collectively this information will also help to identify the management actions to be considered in the Plan (Section 1.6).

Not all decisions require adaptive management. Some decisions such as methods to monitor river flow conditions or flycatcher abundance do not have sufficient uncertainty to require a detailed analysis or management experiment; managers can just do what needs to be done according to well-established procedures (or legal requirements, such as flow decisions for water delivery under the Rio Grande Compact).

**Table 5.** Examples of critical decisions, who makes them, relevant RPA elements from the 2003 BO, questions decision makers have, and attributes of these decisions.

| Critical Decisions | Who makes them | 2003 BO RPA elements | Questions decision-makers have | Management flexibility | Time to implement | Time to evaluate and adjust | Reversibility of the action[4] |
|---|---|---|---|---|---|---|---|
| 1. **Flow** management in each reach over each period of the year in each type of water year. | BOR, USACE, USFWS, NMISC, District, Counties, Villages /towns /cities | A, B, D to O | How much water does the silvery minnow need for species recovery, where, and for how long (in all types of water years)?<br>How much water is required to provide wetted breeding habitat for flycatchers?<br>Are efforts cost-effective? | **Low.** Although flow can be tweaked (e.g. Cochiti deviation), there is very little flexibility, due to contractual obligations for water deliveries. San Juan-Chama water is only 12,000 acre-feet (a-ft), and will soon be 8,000 a-ft. Strategic Water Reserve could help to increase management flexibility to alter flows. | **Fast** (i.e., with agreement, flows in reservoirs and waste ways can be changed within hours or days, although the time to reach agreement can be highly variable, depending on the agency and the desired change). | **Variable.** Feedback on wetted area is fast (days), but feedback on biological responses will depend on how long it takes to get sufficient contrasts and replication in delivered flows, including analyses of historical data. | **High**. Actions are completely reversible in the subsequent year. Within a year, actions are less reversible (i.e., once water is over the spillway or under the bridge, it is gone). |
| 2. **Habitat** rehabilitation and management actions in each reach. | BOR, USACE, USFWS, NMISC, Pueblos | P, R to X | How much of what type of habitat do the silvery minnow really need, when, and where?<br>How wet should flycatcher habitat be, how long should it be wetted, and what distance to water?<br>Are efforts cost-effective? | **Medium-High** (except for flood control). Requires willing landowners, but there is significant flexibility in site selection and design. Some channel rehabilitation sites could be located near sources of groundwater or waste ways to maintain wetted summer refugia.<br>**Variable**, for longitudinal connectivity of minnow habitat. Trap and truck fish past barriers is flexible in theory, though feasibility and survival need to be evaluated. Building passage structures involves a much larger commitment with less overall flexibility.<br>**Variable**, for connectivity/expansion of | **Variable.** Land acquisition, design, permitting, construction could take 2-4 years; creation of aquatic habitat features would be fast; decades for vegetation establishment.<br>For longitudinal connectivity of minnow habitat, **Short** to trap and truck (months); **Long** for passage facilities (5+ years).<br>**Variable**, for connectivity /expansion of flycatcher habitat. | **Variable.** Same as for flow, since habitat and flow actions must be evaluated together.<br>For longitudinal connectivity, **Short** (months) as recapture of tagged fish can determine changes in distribution. | **Medium.** Design of channel rehab sites can be tweaked (e.g., reshape, alter vegetation), but if major redesign is required, this lowers reversibility.<br>For longitudinal connectivity, **High.** Trap and truck is easily reversed (just stop doing it), and the gates on upstream passage facilities can be closed at any time if desired. The passage facilities themselves cannot be removed. |

[4] Some *effects* may persist after the action has been reversed.

| **Critical Decisions** | **Who makes them** | **2003 BO RPA elements** | **Questions decision-makers have** | **Management flexibility** | **Time to implement** | **Time to evaluate and adjust** | **Reversibility of the action**[4] |
|---|---|---|---|---|---|---|---|
| | | | | flycatcher habitat. Flexibility of site selection may be more limited given nest fidelity and the need for restoration in proximity to existing habitat and breeding sites. | **Short** to implement individual restoration projects, decades for vegetation establish-ment and continued projects to maintain dynamic nature of riparian habitat. | | |
| 3a. Minnow **hatchery** stocking and genetic management decisions in each reach. | USFWS | Y to BB | How much fish production and stocking are needed, where, and for how long? How much egg collection is needed to support captive propagation efforts?<br>Are efforts cost-effective? | **Variable. High** flexibility to change where eggs are collected and minnows are stocked in any given year.<br>**Medium** flexibility to expand capacity. | **Medium.** Annual decisions on where and how much egg collection, and where to stock. Expanding capacity could take 1-3 years, including decision analysis of hatchery-wild tradeoffs. | **Short to Medium.** Since all stocked minnows are marked, the percentage of marked-unmarked minnows during spawning allows a primary analysis to evaluate success. Multiple years are required to determine relative success of hatchery and wild fish, and changes to genetic diversity. | **Variable.** Easy to ramp down hatchery production or change location of stocking. Changes to genetic diversity of minnow population may not be reversible, or could take many years to reverse. |
| 3b. Minnow **salvage** actions. | USFWS | Reason-able and Prudent Measure regarding 'take' | Are efforts cost-effective? Where to salvage and release, following what criteria? | **Variable.** Bound by BO to undertake salvage and assess incidental take; some flexibility in where fish are relocated. | **Short**, but very labor intensive. | **Short**, as effectiveness could be evaluated annually (e.g. % of population salvaged). | **Variable.** With legal authority, could stop salvage and simply estimate loss. Prior salvage relocations or mortalities from deciding not to salvage are not reversible. |
| 4. Design of **monitoring** & evaluation techniques to assess these decisions. | BOR, USACE, USFWS | C, Q, BB, CC | What to monitor, where, and how?<br>Are efforts cost-effective? | **Medium.** While many forms of monitoring are possible, the minnow's listed status and risk of take of wild fish reduces management flexibility. Also want to maintain time series using existing methods. | **Medium.** 6-month lead time required for permits to sample, so need to plan ahead. | **Medium.** Monitoring and evaluation can be adjusted annually based on what is learned, but need to maintain long term trend data using consistent methods. | **High.** In theory it is easy to stop a given method of monitoring and do something better, but sometimes it is more difficult in practice. |

Numerous **scientific uncertainties** regarding the response of the silvery minnow and the flycatcher to management actions in the MRG were provided to our team during and following the February 2011 Adaptive Management Planning Session. These have been compiled and organized into broad categories, and are provided in Appendix C. While the compilation has not yet been endorsed by the Program, it is sufficiently robust for illustrating a process for sorting and filtering uncertainties that could be addressed through adaptive management. This process begins with grouping uncertainties into meaningful categories. The following principles were used in categorizing the list of uncertainties in Appendix C:

- They were categorized according whether they pertained to the silvery minnow, the flycatcher, or the overall MRG system. These categories were also used to differentiate the three conceptual models presented in Section 1.4.
- It is easier to work with a small set of overarching critical uncertainties that encapsulate several individual but related uncertainties. The uncertainties were grouped according to similar themes, from which a higher-level set of questions emerged.
- It is most informative from an AM perspective to focus on critical uncertainties that could be addressed in whole or in part by something the MRG Program can do on the ground (i.e., management actions). This principle informed the higher-level questions.
- Stating critical uncertainties as broad hypotheses (these do not provide specific metrics but focus on understandings about relationships) about target species or habitats and how those species or habitats might respond to management actions can help frame the range of underlying views (but still at a high level). The management actions do not need to be explicitly stated in the wording of the uncertainty, but there should be an understanding that the uncertainty will be addressed at some point by implementing management actions, research, and/or monitoring.

The three tables below list what emerged as the main themes and overarching uncertainties across those listed in Appendix C once they were grouped according to the conceptual models and after further refinement by and input from Program participants:

- Table 6**:** Overarching uncertainties for the silvery minnow
- Table 7: Overarching uncertainties for the flycatcher
- Table 8: Overarching uncertainties for the MRG system

These tables suggest potential management actions and decisions that might need to be explored as AM treatments to address these uncertainties, and that might need to be considered as long-term management strategies depending on what is learned. Table 6, Table 7 and Table 8 provide a cross-link with Table 5 which lists critical management decisions and questions facing decision-makers in the MRG. Additional considerations related to evidence, actions, contrast, and monitoring precision are also included to illustrate how the Program can evaluate each major uncertainty and the potential for addressing it as a testable question. While broad hypotheses help group uncertainties, additional considerations will focus efforts to develop detailed quantitative hypotheses in Section 1.5.

Further deliberation is needed within the Program to examine, refine and reach agreement on the list of uncertainties to be addressed in the AM Plan. The U.S. Fish and Wildlife Service's Strategic Habitat Conservation Handbook (USFWS, 2008) may provide useful examples of examining management questions for hypothesis testing. Greater alignment between the management questions in Table 5 and the scientific uncertainties in these next three tables is required to ensure that the hypotheses identified in Section 1.5 are focusing on the critical uncertainties.

**Table 6.** Preliminary sample of critical uncertainties for Rio Grande silvery minnow, associated hypotheses, management implications, and strategies/challenges in testing hypotheses. The precise wording of the hypotheses will need to be further revised as the experimental design and monitoring methods are specified in greater detail in AM Plan Version 2.

| Overarching critical uncertainty | Broad hypothesis | Potential management implications | What would be compelling evidence one way or the other to alter management? | How might this be tested? | Challenges in generating enough spatial/temporal contrast | Challenges in obtaining enough precision in monitoring |
|---|---|---|---|---|---|---|
| What frequency of years with what level of recruitment is needed to achieve silvery minnow population viability, including reaching a stable population and then a self-sustaining population in the MRG? | **M-0a** In years of very poor spring flow, recruitment is much lower, but still non-zero. In years of good spring flow recruitment is stronger. Exact flow threshold is undetermined (see M1).<br>**M-0b** In years of very poor spring flow, survival is not unusually low (see M2).<br>**M-0c** Some small fraction of minnows survive to older ages (limit unknown, exact fraction unknown).<br>**M-0d** Some frequency of years with poor recruitment should be tolerable, need to determine limit. | Determines criticality of interventions needed in years of very poor spring flow. | Synthesis in a credible population model of pertinent empirically based and statistically justified demographic and environmental parameter estimates, propagating statistical uncertainty through the model. | Build and validate such a model.<br>Use PVA modeling and population statistics as an initial analysis to test this uncertainty. | See comments on testing and contrast and precision for all the other hypotheses.<br>As possible, capitalize on natural variation when it takes place, and deliberately probe with experiments. | See comments on testing and contrast and precision for all the other hypotheses.<br>Precision of parameter estimates will increase with time as data accumulate, but more accurate and precise monitoring data can accelerate learning. |
| What magnitude and duration of flows are required for successful silvery minnow spawning and recruitment, and population viability?[5] | **M-1:** Spring spawning peak of at least W cfs at days X1 to X2, followed by maintenance of Y cfs for Z days after spawning for successful silvery minnow recruitment.<br>Alternative hypotheses have different values for W and Y (e.g., peak spawning flows of 3000 cfs), X1 and X2 (hydrograph driven vs. fixed dates), and Z (e.g., 30 days).<br>Hypotheses M-1 and M-3 are closely linked, as flow and habitat actions need to be designed to work together. | Consider modifying volume and timing of flows from current rules expressed in 2003 BO.<br>Use Cochiti deviation to create desired contrasts. | Increased area of floodplain inundation by reach, and evidence of sufficient contribution of those areas to species spawning, recruitment, and population viability.<br>Larger numbers of eggs/larvae.<br>Larger numbers of young from monthly catch per unit effort (CPUE) monitoring.<br>Higher October CPUEs than years of low flow. | Cochiti Deviation.<br>Establish sample design to monitor and evaluate flow, timing, floodplain inundation, egg/larval abundance, Oct CPUE (by reach; during and after peak flow); analysis of all years with spring hydrograph and silvery minnow CPUE. | Looking at Oct CPUE alone does not account for intermediate effects on minnow survival.<br>Must monitor before/after flow, and monthly to follow survival (CPUE already being done 9 months of the year). | Need robust sampling design to account for sampling and resource variability in CPUE.<br>If not already completed, perform power analysis to determine sample strategy and number of samples necessary to minimize variability. |

[5] A related question is: What levels of successful silvery minnow spawning are needed to ensure survival and move on a trajectory towards recovery?

| Overarching critical uncertainty | Broad hypothesis | Potential management implications | What would be compelling evidence one way or the other to alter management? | How might this be tested? | Challenges in generating enough spatial/temporal contrast | Challenges in obtaining enough precision in monitoring |
|---|---|---|---|---|---|---|
| What is the spatial and temporal relationship of river drying to minnow population viability? | **M-2a:** Silvery minnow survival is directly related to the linear extent of river drying.<br>**M-2b**: There is a threshold effect of drying on RGSM viability at around 70 miles of drying.<br>**M-2c:** The minnow population can withstand considerable river drying, but need to determine limits.<br>**M-2d:** The effect of river drying on minnow survival and population viability can be mitigated with designed sanctuaries (small wetted areas kept wet through pumping or other means). | Use flow augmentation at certain times and places to keep fish alive during drying.<br>Use different management options (pumping, LFCC, etc.). | Reproduction/recruitment of minnow in other reaches not related to drying.<br>Convincing hypothesis tests from statistical analyses of monitoring data. | Develop and test prototype sanctuaries.<br>Use hatchery fish to reduce impacts on wild population, increase sample size, and improve survival estimates.<br>Monitor species composition in sanctuaries and survival of minnow for duration of drying. | May only be able to test one or two sanctuaries, limited test size.<br>Low numbers of minnow in area prior to drying. | Continued handling of fish in enclosed areas could affect survival.<br>Low numbers of minnow in area prior to drying. |
| Is an interconnected floodplain necessary for successful minnow spawning and recruitment? | **M-3:** In the Middle Rio Grande, silvery minnow do/do not require the channel to be connected to its floodplain for successful spawning, larval survival to become juveniles, and/or recruitment of young of year to age 1. | Outcome of hypothesis test affects the cost-effectiveness of different approaches for creating & maintaining each type of habitat, and appropriate flows associated with revised channel form to overcome channel incision and improve lateral connectivity. | Suitable in-channel and off-channel spawning habitat available in at least 5 different locations for 5 spawning seasons, and then at 3 or more of the locations, a majority of successful spawning is documented in the same type of habitat each of the 5 spawning seasons<br>Convincing hypothesis tests from statistical analyses of monitoring data (e.g., higher fall CPUE index in reaches and years where the channel was connected to the floodplain for more than X days). | Flow management to ensure suitable in-channel spawning habitat is available at each of 5 locations for all 5 years.<br>Mechanically create off-channel spawning habitat at 5 sites that will be wetted w/ rage of flows expected during 5 spawning seasons.<br>Monitor area of suitable habitat over time and space, and use as covariate to explain variation in recruitment. | Finding enough sites where available flows would wet off-channel sites long enough.<br>Influence of distinct river reaches and within-reach habitats on overall minnow population dynamics.<br>Distinguishing habitat contributions to spawning and minnow recruitment. | Minnow sampling – relating sampling numbers to total numbers at any given site; and knowing when spawning occurs such that capture location reflects spawning location. |
| What is the effect of propagation and salvage on minnow population viability in the MRG? | **M-4a:** Propagation and salvage do/do not benefit minnow population viability in the Middle Rio Grande.<br>**M-4b:** Propagation and salvage do/do not measurably affect genetic | Consider different rates and spatial allocation of propagation and salvage efforts; or may be able to curtail these activities. | Different survival rates of marked hatchery fish and marked wild fish over specified time and range of environmental conditions. | Evaluate survival and movement of marked released fish.<br>Use PVA models. | Marking salvaged fish can add stress and reduce immediate and latent survival.<br>Few marked fish are | Few marked released fish are recaptured.<br>Salvaged fish cannot be marked without |

| **Overarching critical uncertainty** | **Broad hypothesis** | **Potential management implications** | **What would be compelling evidence one way or the other to alter management?** | **How might this be tested?** | **Challenges in generating enough spatial/temporal contrast** | **Challenges in obtaining enough precision in monitoring** |
|---|---|---|---|---|---|---|
| | viability of the minnow population in the Middle Rio Grande. | | Convincing hypothesis tests from statistical analyses of monitoring data. | Use statistical power analysis to evaluate detection of change in allelic frequencies. | recaptured.<br>Need survival rates of released fish for PVA. | stress and reduced survival.<br>Difficulty assessing released fish reproduction and contribution to the population. |
| How will fish passage at San Acacia or other structures affect minnow population viability? | **M-5:** Fish passage at San Acacia and/or other structures will/will not affect silvery minnow population viability. | Create & maintain fish passage structures or modify existing structures for fish passage.<br>Re-evaluate priority for constructing fish passage structures. | Increased minnow population in reaches above passage structures as compared to pre-structure population.<br>Definitive minnow movement studies documenting sizeable portion of population (X%) with movement > Y miles.<br>Genetic evidence. | Construction of passage at San Acacia and at least one other structure (not reversible); *or* experimental movement of marked minnow or stocking of minnow above San Acacia*. | Limited number of locations where fish passage would be implemented. | Sampling approach for entire river reaches.<br>Detecting annual population response. |
| How does spatial/ temporal availability of food correspond with minnow diet? | **M-6:** Spatial/temporal availability of food in the MRG does/does not correspond to diet of minnow. | If flow alteration has affected specific food items of the minnow; other actions may be required to restore sufficient food availability. | Evidence indicating silvery minnow has/has not adapted to new environment existing conditions and food supply.<br>Evidence indicating that size at age is/is not unaffected by different diets available to silvery minnow in the MRG.<br>Convincing hypothesis tests from statistical analyses of monitoring data. | Assess size at age to determine if food may be limiting in certain reaches.<br>Conduct concurrent diet analysis of RGSM and food supply.<br>Use isotope analysis (e.g. $C^{13}$ and $N^{15}$) to evaluate diet and related minnow health factors.<br>Examine food composition and availability in response to water management including spring peak flows and summer drying. | Limited number of silvery minnow may be sacrificed for gut analysis.<br>Small stomach pumps have been used with other small cyprinids, but handling mortality is a concern.<br>Isotope analysis may be too coarse. | Size of guts from fish may be inadequate.<br>Food availability will vary greatly and require very large numbers of samples. |

* Second action is more reversible. Committing to fish passage may be more of a passive AM approach – agree to build passage structure, monitor, and see if results are as expected. Experimental movement or stocking is more reversible and may be more of an active AM approach. Consider passive vs. active tradeoffs for other uncertainties.

**Table 7.** Preliminary sample of critical uncertainties for Southwestern Willow Flycatcher, associated hypotheses, management implications, and strategies/challenges in testing hypotheses. The precise wording of the hypotheses will need to be further revised as the experimental design and monitoring methods are specified in greater detail in AM Plan Version 2.

| Overarching critical uncertainty | Broad hypothesis | Potential management implications | What would be compelling evidence one way or the other to alter management? | How might this be tested? | Challenges in generating enough spatial/temporal contrast | Challenges in obtaining enough precision in monitoring |
|---|---|---|---|---|---|---|
| Is flow augmentation for wetted breeding habitat needed to achieve flycatcher recovery? Exactly what flows are needed for overbank flooding in specific areas of potentially suitable habitat? | **F-1:** Flow augmentation *is/is not* required to create/maintain wetted breeding habitat for the flycatcher. | Consider modifying volume and timing of flows. | Positive trend in nesting and recruitment in areas with X wetted habitat characteristics (e.g., increased fledge ratio every year for 5 years at wetted habitat). | Minimum of 5 habitat restoration sites in more than one river reach.<br>Wetted by Program or natural flows.<br>Vegetation classification for finding suitable habitat and flow for determining river velocity for flooding suitable areas (or other models). | Limited extent of flycatcher utilization of MRG.<br>Length of time for productivity response.<br>Ability to manage flow across entire MRG – determining exact flow necessary for overbank flooding, flycatcher recruitment and nest success. | Determining factors that influence successful production.<br>Need to scale up bird monitoring efforts.<br>Distinguishing the role of tamarisk vs. native vegetation in supporting nesting territories and nest success. |
| Is habitat restoration in the San Acacia Reach (or other reaches) needed for flycatcher recovery in the MRG? | **F-2:** Flycatcher recovery in the MRG *requires/does not require* habitat restoration in the San Acacia Reach and/or other reaches. | Mechanical and/or flow-based habitat modification. | Increased population size and fledge ratio every year for 5 years on MRG (total). | Evaluation of vegetation suitability by reach and over time, including areas both with and w/out habitat restoration sites. | Extent of flycatcher utilization of MRG.<br>Length of time for productivity response. | Need to scale up bird monitoring efforts.<br>Long term effort. |
| Will created/restored habitat adjacent to existing territories be utilized? | **F-3:** Creation/restoration of habitat adjacent to existing territories *will/will not* be utilized. | Mechanical and/or flow-based habitat modification. | Establishment of nesting territories in adjacent habitat, and nest success once restored habitat is mature and suitable. | Restoration and control sites in close proximity to existing territories. | Extent of flycatcher utilization of MRG.<br>Length of time for productivity response. | Long term effort that needs consistency in monitoring and evaluation of suitable habitat. |
| What is the minimum distance from existing territories to create flycatcher habitat, and what is the minimum size of created habitat? | **F-4:** X distance from existing territories and Y patch size are required/not required for successful habitat creation. | Habitat restoration site selection, proximity requirements to existing habitat, and restoration site size. | Minimum distance evidence derived from statistical analysis of existing data. | Comparison between range-wide data and data on the Rio Grande related to territory habitat size and proximity or dispersal range across years. | Site fidelity and/or behavior characteristics may vary across flycatcher range. | Suitable habitat varies in vegetation composition throughout range. |
| How long does a territory last (based on changes to hydrology and/or succession of vegetation) in order to plan for when habitat creation/restoration | **F-5:** X timing of habitat creation and/or restoration is required/not required based on hydrology and/or succession of vegetation. | Habitat restoration site selection and timing of restoration projects. | Territory persistence evidence derived from statistical analysis of existing data. | Analyze the duration of time flycatchers occupied habitat, find the point in time where nest success and/or foliage in the canopy started to decline. Find the trigger – | Finding the source of habitat deprivation.<br>Site fidelity may indicate a patch of decadent vegetation still viable, but nest success analysis is | Numbers of examples with enough data to adequately estimate exact timing. |

| Overarching critical uncertainty | Broad hypothesis | Potential management implications | What would be compelling evidence one way or the other to alter management? | How might this be tested? | Challenges in generating enough spatial/temporal contrast | Challenges in obtaining enough precision in monitoring |
|---|---|---|---|---|---|---|
| is needed? | | | | over maturity, lack of water, duration of flooding, etc. | crucial. | |
| The saltcedar leaf beetle will likely be along the Rio Grande by the summer of 2012. What impact will the saltcedar leaf beetle have on existing flycatcher habitat? | **F-6:** The spread of the saltcedear leaf beetle in the MRG will have/not have X impacts on flycatcher habitat and territories. | Mechanical removal of dead saltcedar over time.<br>Invasive species management and native planting once dead saltcedar removed.<br>Soil amendments added to soil to decrease salinity.<br>Prioritization of habitat restoration sites selected and their design. | Increased/decreased fire potential.<br>Lack of native vegetation recruitment..<br>Changes in territory locations and nest success in areas in close proximity to saltcedar leaf beetle impacted plants. | Restoration and control sites once saltcedar is dead.<br>Model predicted beetle expansion and impact. Map saltcedar occurrence and flycatcher existing habitat (nesting and migratory), to determine expected or possible impact on flycatchers, and timing of that impact based on beetle dispersal rate. | Verifying flycatcher behavior in territory locations and nest success connected to beetle and not other factors (i.e., hydrological changes and/or succession of vegetation). | Length of time and consistency in monitoring. |

**Table 8.** Preliminary sample of critical uncertainties for the Middle Rio Grande system, associated hypotheses, management implications, and strategies/challenges in testing hypotheses. The precise wording of the hypotheses will need to be further revised and the remaining information filled in as the experimental design and monitoring methods are specified in greater detail in AM Plan Version 2.

| Overarching critical uncertainty | Broad hypothesis | Potential management implications | What would be compelling evidence one way or the other to alter management? | How might this be tested? | Challenges in generating enough spatial/temporal contrast | Challenges in obtaining enough precision in monitoring |
|---|---|---|---|---|---|---|
| Is flow augmentation needed to create river morphology and habitat quality/quantity favourable for the silvery minnow and the flycatcher? | **S-1:** Flow augmentation of varying magnitude, duration, frequency, timing, and rate of change from Cochiti Dam and other sources *will/will not* affect river morphology and habitat quantity/quality in MRG, including:<br>• Flows of X magnitude for duration of Y days at Z location on an annual or near-annual basis will provide spawning and recruitment habitat for the silvery minnow.<br>• Flows of X magnitude for a duration of Y days at Z location on an annual or near-annual basis will provide breeding habitat for the flycatcher. | Consider modifying volume and timing of flows. | *TBD by the Program* | *TBD by the Program* | *TBD by the Program* | *TBD by the Program* |
| Is sediment augmentation needed to create river habitat for the silvery minnow and the flycatcher? | **S-2:** Sediment augmentation and/or providing sediment movement through or around diversion structures *are/are not* required to maintain riverine habitat for the silvery minnow and the flycatcher. | Mechanical sediment augmentation or sediment transport through/around structures. | *TBD by the Program* | *TBD by the Program* | *TBD by the Program* | *TBD by the Program* |

## 1.4 Conceptual Models for the MRG System, Silvery Minnow, and Flycatcher

The conceptual models presented here are visual frameworks representing relationships between Program and member agency management actions, riverine processes, and responses of the silvery minnow, flycatcher, and the MRG system itself to those management actions. Because conceptual models are conjecture, uncertainty exists regarding linkages between the layers of the model. The most critical of these uncertainties should drive learning through implementation of the Program's AM Plan. As these uncertainties are explored and addressed, the Program's conceptual models can be updated and improved to represent the latest understanding of the relationships as knowledge builds.

Major uncertainties identified in the conceptual models in this section are stated as broad hypotheses in Section 1.3. In addition, the "Hypothesized Response Indicators" listed in the top line of the conceptual models are addressed in Section 1.2 as indicators linked to specific management objectives. These indicators thus form the basic set of metrics to assess the outcomes of testing specific hypotheses.

This section presents preliminary conceptual models:

**Figure 5 – Rio Grande silvery <u>minnow</u> (M):** This model includes potential management actions (as relevant to ongoing Program actions and the 2003 BO) and certain indicators of silvery minnow response to those actions. Some major uncertainties are noted in the model as **M0-M6** in the "Management Actions" and "Habitat Responses" rows, representing broad hypotheses which are explained in more detail in Section 1.5.

**Figure 6 – Southwestern Willow <u>Flycatcher</u> (F):** This model includes potential management actions (as relevant to ongoing Program actions and the 2003 BO) and certain indicators of flycatcher response to those actions. Some major uncertainties are noted in the model as **F1-F6** in the "Management Actions" row, representing broad hypotheses which are explained in more detail in Section 1.5.

**Figure 7 – Middle Rio Grande <u>system</u> (S):** This model includes potential management actions (as relevant to ongoing Program actions and the 2003 BO) and certain indicators of system response to those actions. Some major uncertainties are noted in the model as **S1-S2** in the "Management Actions" row, representing broad hypotheses which are explained in more detail in Section 1.5.

Each conceptual model is intended to be read from the bottom up. "Other Environmental Factors" in the brown row at the bottom influence all of the remaining rows above. Then, "Management Actions" have the potential to influence "Riverine Processes", which in turn can cause certain "Habitat Responses". Finally, "Hypothesized Response Indicators" can provide a link between the implementation of Program actions and the subsequent responses of the silvery minnow, flycatcher, and the MRG system as a whole.

The following is an explanation of the color-coded categories in each of these three figures:

Each model indicates the expected responses of the target species and the overall MRG system to **<u>various Program management actions</u>.** These are actions the Program will agree to take and will comprise the set of Program actions intended to result in positive species responses. This is shown in maroon-colored boxes in Figure 5, Figure 6 and Figure 7.

Implementation of these actions will result in certain **<u>riverine processes</u>** (restored, altered, or new). Riverine processes are natural processes on the Middle Rio Grande that determine channel characteristics, vegetation, and other habitat conditions. This is shown in blue-colored boxes in Figure 5, Figure 6 and Figure 7.

Riverine process will in turn result in **habitat responses**. These are habitat characteristics believed to be important to the silvery minnow and/or the flycatcher. This is shown in green colored boxes in Figure 5, Figure 6 and Figure 7.

The habitat response of Program management actions should be measures or evaluated using **indicators of hypothesized silvery minnow, flycatcher, or system responses.** This is shown in purple-colored boxes in Figure 5, Figure 6 and Figure 7.

**"Other environmental factors" in brown on the bottom row** are beyond the control of the Program but are likely to have significant effects on management actions, processes, responses, and species indicators. These 'other' factors will be operating concurrently with management actions generating cumulative and likely confounding effects that will often make it difficult to determine the relative importance of these factors and the management actions. To the extent possible, AM Plan experimental design and monitoring efforts will have to account for these factors and provide spatial and temporal controls to create contrast. This is shown in brown colored boxes in Figure 5, Figure 6 and Figure 7.

Refinements to these models may be warranted based on the results of the process described in Section 1.6 for identifying a set of actions to implement, and revised versions of the models should be provided in AM Plan Version 2.

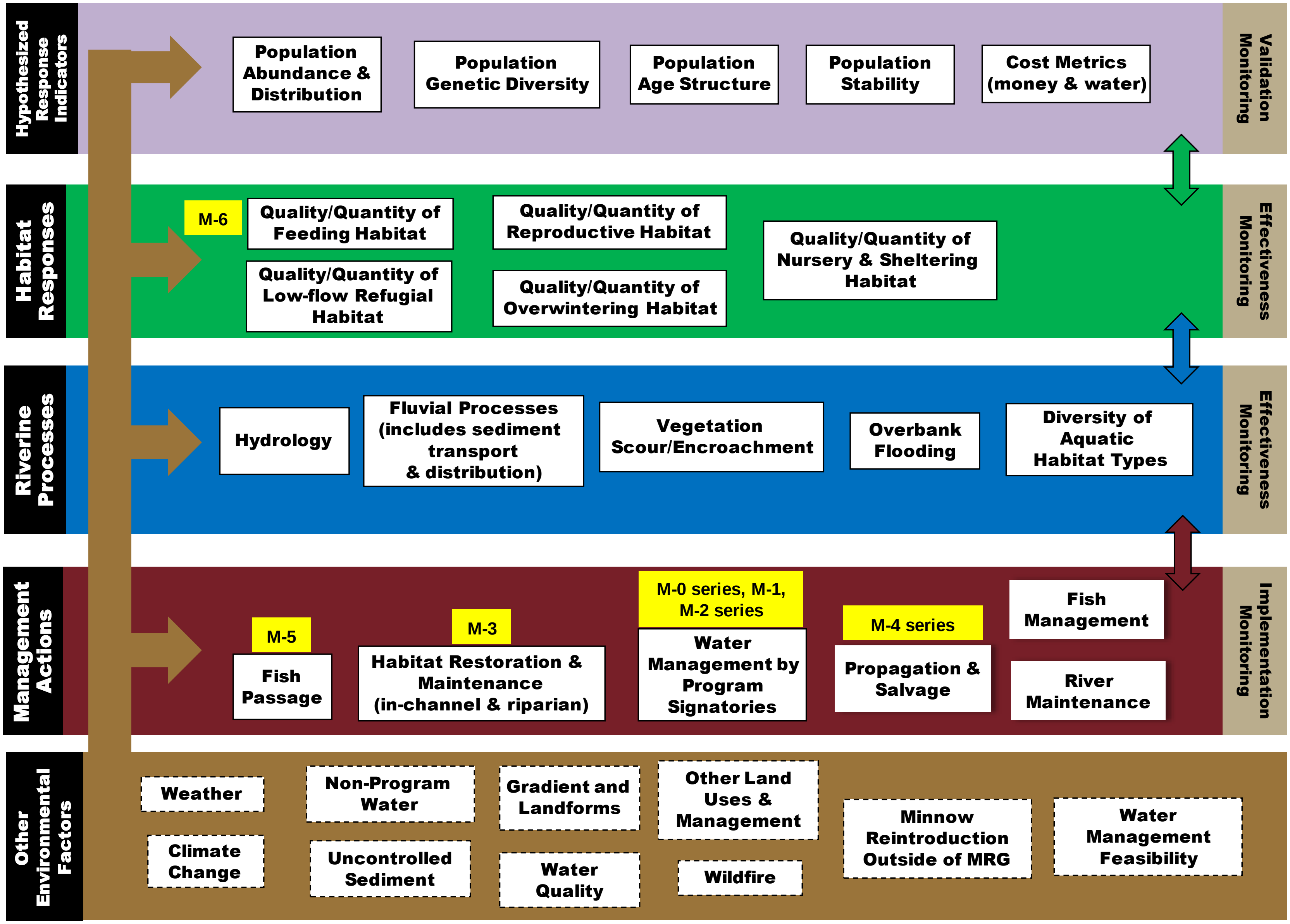



**Figure 5.** Conceptual model for the Rio Grande silvery minnow.

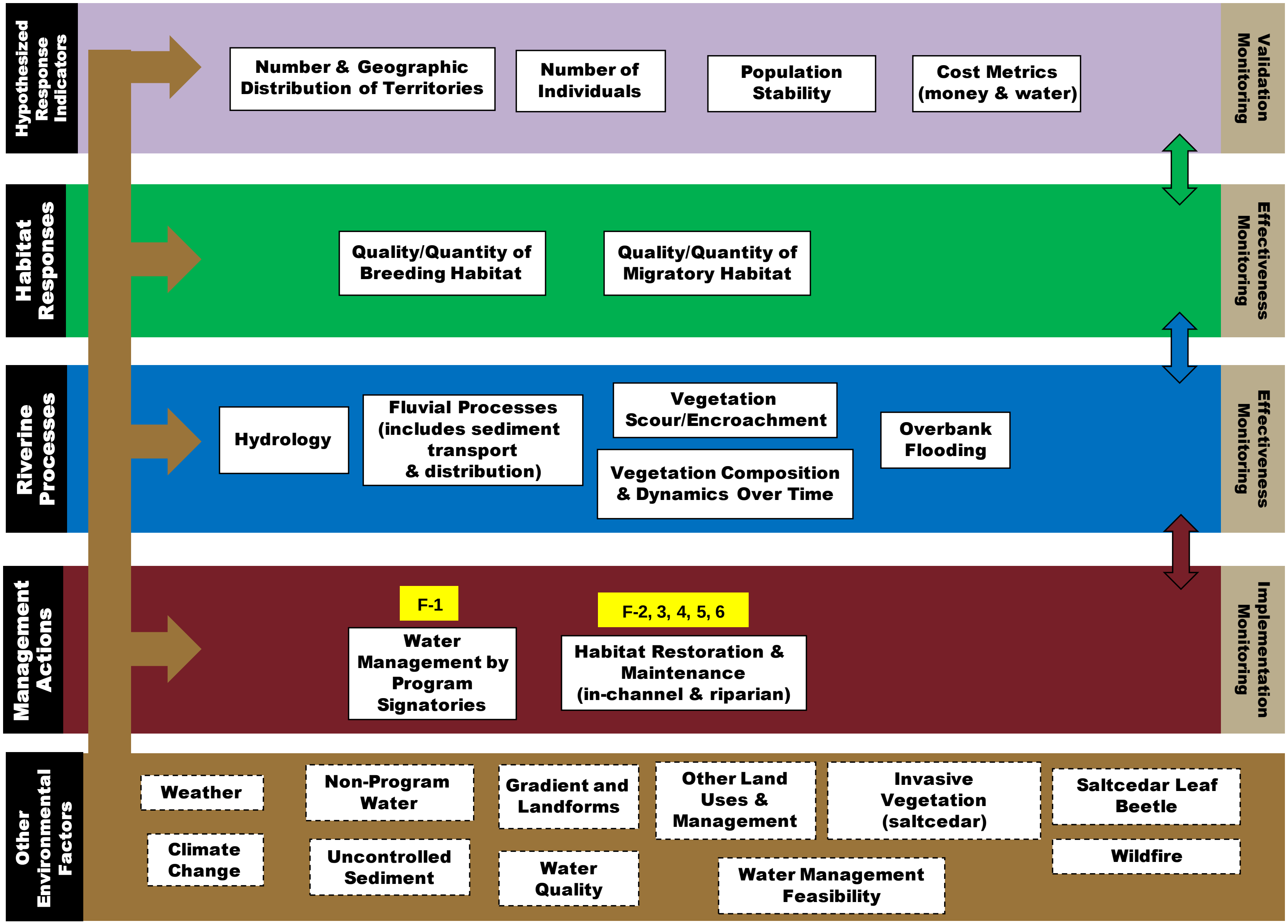



**Figure 6**. Conceptual model for the Southwestern Willow Flycatcher.

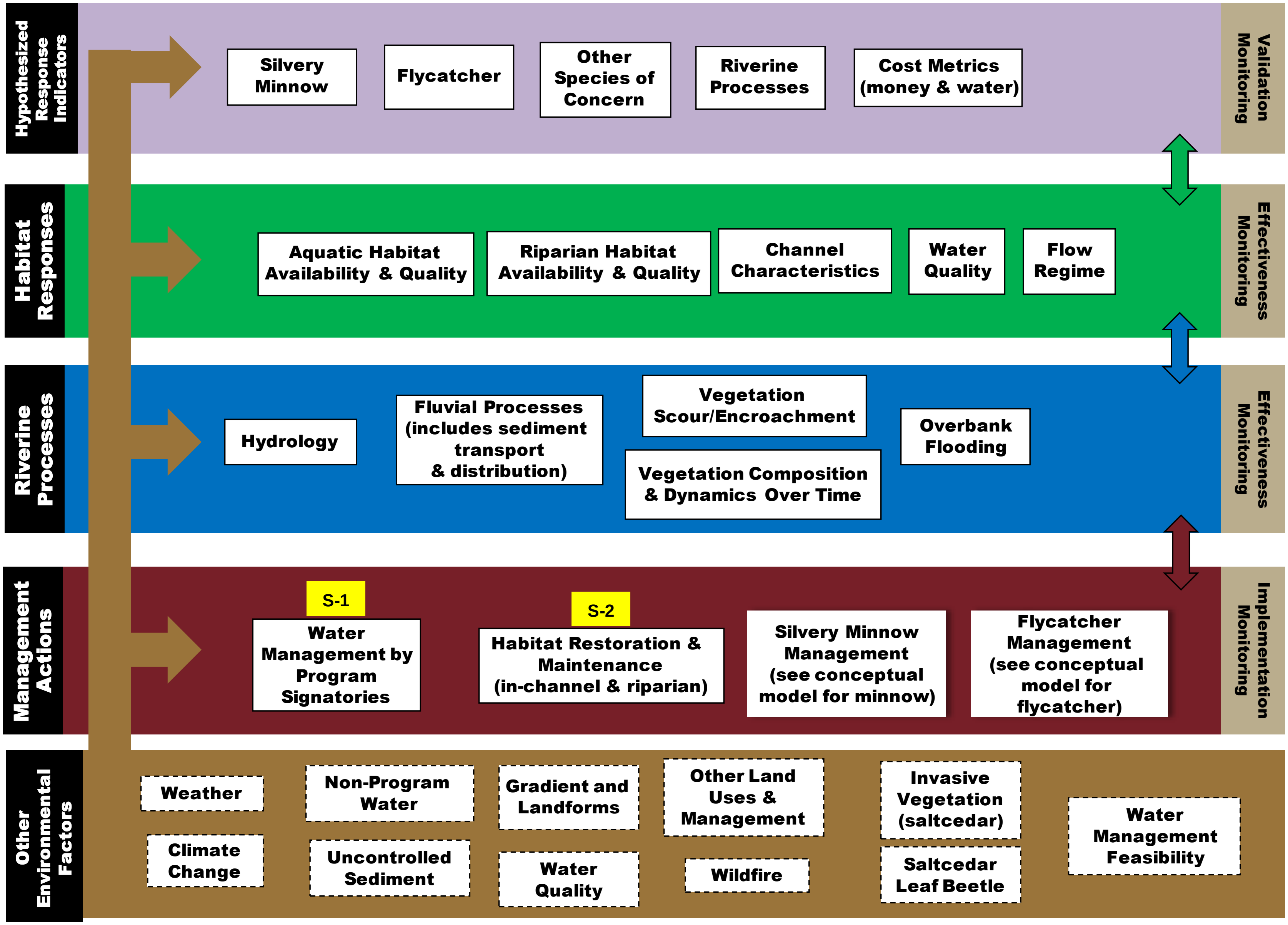



**Figure 7.** Conceptual model for the Middle Rio Grande system.

## 1.5 Hypotheses, Performance Measures & Benchmarks

Table 6, Table 7 and Table 8 in the previous section provided preliminary critical uncertainties and suggestions for broad hypotheses based on those uncertainties. Investigating critical uncertainties in the form of detailed alternative hypotheses facilitates the exploration of what is known and not known at a finer resolution. This enables the identification of next steps in the AM cycle. Specifically the design of management treatments in Step 2 allows for the development of research or monitoring to test the hypotheses. It requires substantial effort to zero in on the few critical hypotheses that truly affect management decisions. However, this effort is essential, as long 'laundry lists' of hypotheses are both overwhelming and unmanageable. Initial lists of hypotheses should be 'sequenced' to determine a small subset that is manageable and tightly focused on critical uncertainties. This approach can yield useful information in a time frame to be meaningfully tied back to Program management and policy decisions. The hypotheses should relate directly to the Program's management objectives as specified in Section 1.2, and be evaluated with performance measures developed for those management objectives.

It is understood that not all hypotheses can or will be addressed or investigated due to Program time constraints, physical limitations (there is only so much water and land), cost, or because they conflict with current policies or laws. Table 9 provides a framework (and examples for the flycatcher) of how hypotheses can be examined and sequenced, in order to prioritize next steps. Once the Program agrees to a set of critical uncertainties in Section 1.3 and refines the conceptual models in Section 1.4, the next step would be to brainstorm hypotheses for each uncertainty and compile the information in Table 9 for each hypothesis. That process should help Program managers and participants develop a smaller subset of hypotheses that could be addressed through Program implementation during the time period of the new BO.

The hypotheses presented in Table 9 are examples only and the information is intended to stimulate discussion about how to construct and sequence hypotheses, both for the silvery minnow and for the flycatcher. At this stage, hypotheses should be stated as precisely as possible, though they can be approximate in terms of specifying potential relationships between species and management actions. Phrasing of detailed hypotheses should include:

- The entity to be monitored (species, life stage, habitat features, flow, water quality, etc.)
- Location of the entity to be monitored
- Attribute of the entity (e.g., growth, residence)
- Expected change (increase, decrease, maintain) and amount of change expected
- Time expected for the change to occur
- Clear linkage to how hypothesis relates to management action

Once hypothesis sequencing is completed, the hypotheses rising to the top can be restated in these to ensure they are measurable and capture the metrics and monitoring techniques of most interest.

**Table 9.** Suggested format (and example content) for sequencing hypotheses. Hypotheses in this table should be specific, quantifiable, and provide direct links to performance measures that can be evaluated through the application of Program monitoring or research.

| Link to broad hypo-thesis | Broad Hypothesis | Alternative Hypothesis | Performance measures | Benchmarks | Time to detect response | Qualitative rating of the feasibility of testing the hypothesis (L,M,H) | Ballpark estimate of the cost of testing the hypothesis | Logical sequence |
|---|---|---|---|---|---|---|---|---|
| **F-1** | **SWFL-1:** Flow augmentation of ____cfs is required to create/maintain wetted breeding habitat for the flycatcher during breeding season. | SWFLs will persist in the absence of water as long as water is present within 50m of suitable habitat. | **Birds**<br># of resident SWFL.<br>Nest Success.<br>Nest location.<br>**Habitat**<br>Acres of suitable nesting habitat wet versus dry and distance to water. | Cfs required =?<br>SWFL recruitmen.t<br>Vegetation improvements (canopy cover/density/ etc.). | Cfs amount needed for overbank – at least 3 years for wet, average, dry conditions – then updated as conditions change (i.e. bank realign-ment, erosion, etc.).<br>Monitor SWFLs at least 5 consecutive years. | **High**<br>SWFL can be monitored for population size and fledge ratio.<br>Agency staff or contractors available to conduct monitoring and data analysis.<br>Flow2d model for determining cfs? | Would need at large scale – not just project related.<br>It would likely take several years to determine cfs needed at different conditions. | *TBD once more hypotheses are examined in this table, and there is a selection among which to sequence.* |
| **F-2** | **SWFL-2:** SWFL productivity will increase by 25% in all MRG reaches with Program habitat restoration sites. | SWFL population numbers are not affected by restoration efforts since habitat is not a limiting factor in the MRG. | **Birds**<br># of SWFL.<br>Fledge ratio.<br>Nest location.<br>**Habitat**<br>Acres of suitable nesting habitat. | Pop. # =?<br>Fledge ratio =?<br>Nest location =?<br>Acres =? | Expect annual response.<br>Need to detect response for 5 consecutive years. | **High**<br>SWFL can be monitored for population size and fledge ratio.<br>Agency staff or contractors available to conduct monitoring and data analysis. | Monitoring, data analysis, and reporting = $?/yr.<br>Habitat restoration and management = $?/yr. | *As above.* |
| **F-3** | **SWFL-3:** Proximity to existing territories is necessary for successful colonization of created/restored habitat by SWFLs. | Proximity to existing territories is not necessary for successful colonization of created/restored habitat by SWFLs if the new habitat patch is > ___ | **Birds**<br># of SWFL.<br>Fledge ratio.<br>Nest location (distance to nearest territory).<br>**Habitat**<br>Acres of suitable | Pop. # =?<br>Fledge ratio =?<br>Nest location =?<br>Distance to nearest | 5-10 years for restoration site's vegetation to reach maturity and attract SWFLs. | **High**<br>SWFL can be monitored for population size and fledge ratio.<br>GIS utilization for distance to nearest territory (or measuring tape if really close). | Long term monitoring, data analysis, and reporting = $?/yr.<br>Habitat restoration and management | *As above.* |

| Link to broad hypo-thesis | Broad Hypothesis | Alternative Hypothesis | Performance measures | Benchmarks | Time to detect response | Qualitative rating of the feasibility of testing the hypothesis (L,M,H) | Ballpark estimate of the cost of testing the hypothesis | Logical sequence |
|---|---|---|---|---|---|---|---|---|
| | | acres in size. | nesting habitat. | territory =? | | Agency staff or contractors available to conduct monitoring and data analysis. | = $?/yr. | |
| **F-4** | **SWFL-4:** Creating flycatcher habitat will have greater success when in close proximity to existing territories and with patch sizes at least ____ acres. | Patch size and proximity to existing territories will not have any effect on created habitat success. | Distance to existing territories.<br><br>Acres of currently occupied patch sizes and nest success rates. | Distance =?<br>Recruitment =?<br>Occupied Patch Size and Relation to Nest Success =? | N/A - Literature search past experiences. | **Medium**<br>A lot of these are data currently available, but may vary range-wide. | *TBD* | *As above.* |
| **F-5** | **SWFL-5:** Flycatcher habitat remains suitable for a short amount of time and re-creation and/or restoration with hydrology and/or successional growth considerations must be attempted in short timeframes. | Flycatcher habitat remains suitable over the long term and does not depend on hydrology and/or successional vegetation growth. Once good habitat is established, no maintenance necessary. | **<u>Birds</u>**<br># of SWFLs.<br>Fledge ratio/nest success.<br>Nest location.<br>**<u>Habitat</u>**<br>Acres of suitable nesting habitat<br>How long suitable (past data search).<br>Proximity to water.<br>Quantification of present vegetation over time (or review of past data). | Time suitable =?<br><br>Once suitability declines, how long do SWFLs stay (site fidelity & nest success) =?<br><br>Vegetation all one age class & height or successional stand? | N/A - Literature search past experiences. | **Medium**<br>A lot of these data are currently available, but may vary by circumstance (i.e. – removed water source for vegetation roots versus flooding year round). | *TBD* | *As above.* |
| **F-6** | **SWFL-6:** Because many flycatcher nests are physically located on saltcedar plants, the saltcedar leaf beetle will have an impact on flycatchers /flycatcher habitat. | Since flycatchers are found in mainly native stands of vegetation, the beetle will have little to no effect on flycatchers /flycatcher habitat. | *TBD* | *TBD* | *TBD* | *TBD* | *TBD* | *As above.* |

## 1.6 Management Actions

A key feature of AM is using contrasting actions to test priority hypotheses in order to address critical uncertainties. A challenge is finding the opportunities for creating these contrasts within the existing rules for water, physical system and species management actions, and in a way that will not result in jeopardy to either the silvery minnow or the flycatcher.

As described in the Introduction, the actions have yet to be identified, and this section suggests a collaborative process for doing so. It is based on the two-function organizational structure presented in Figure 3: a policy group comprised of policy and management representatives and a technical group comprised of scientists in various disciplines who work together to iteratively *simulate the entire AM process before deciding which actions to implement***.** This is the safest way to explore different options and converge on a set of actions that the Program intends to implement under the AM Plan.

Figure 8 illustrates a suggested process for the Program to use simulations to iteratively explore hypotheses to test and actions to test them, along with how these would be monitored and evaluated. What might happen if you implement different actions – what effects would you expect? What you would monitor and how? How well might this accurately detect the expected effects? What might you change based on what you would learn? Simulating different actions and conditions using formal tools and procedures that apply critical thinking and current scientific knowledge before taking any action on the ground provides the rigor necessary for successful (and lower-risk) AM design, particularly in large systems such as the MRG. The results of these iterations would help the Program:

- Further develop and refine the preliminary critical uncertainties, conceptual models and hypotheses in the previous sub-sections of this AM Plan Version 1.
- Explore actions to test these hypotheses, implementation and monitoring designs for these actions, how the results would be evaluated, and what would be adjusted, using the examples and guidance in the subsequent sections of this AM Plan Version 1.
- Move towards an accepted and scientifically defensible set of AM actions to implement.

The refined uncertainties, hypotheses and actions, along with how they will be implemented, monitored and evaluated would then be detailed in Version 2 of the AM Plan. At that point concrete adjustment options can also be outlined.

The simulation process in Figure 8 is based on four overarching and sequential questions that together represent the challenge facing the Program each year as well as key considerations when exploring the feasibility and advisability of potential management actions:

1. What pattern of inflows, sediment and temperature can we expect throughout the MRG system? (What conditions might nature give us in different years?)
2. How do we manage water, habitat, salvage activities and hatcheries? (What as managers do we have control over, and what could we do that we have not yet tried?)
3. What are the <u>expected</u> effects on minnow, flycatcher, and water uses? (How might what nature provides us, and the management actions we take, affect achievement of our Program goals? If we tried particular new things, what might the outcomes be in different years? What new functional relationships, insights and alternative hypotheses are emerging from recent data analyses?)
4. What are the <u>observable</u> effects on the minnow and flycatcher, and our ability to learn which actions are most effective in meeting Program objectives, and to what degree they are effective?

(How well can we monitor? Will we be able to measure outcomes accurately enough to learn what actually happens to minnows and flycatchers when we try different management actions?)

The Program would address these questions using simulation models and other tools in order to explore what might happen if different management actions were tested, and iteratively hone in on a set of actions that would provide the best opportunities for learning within acceptable levels of risk. Table 10 describes some of the tools that can be used for each of the four questions; some of these tools exist and some do not.

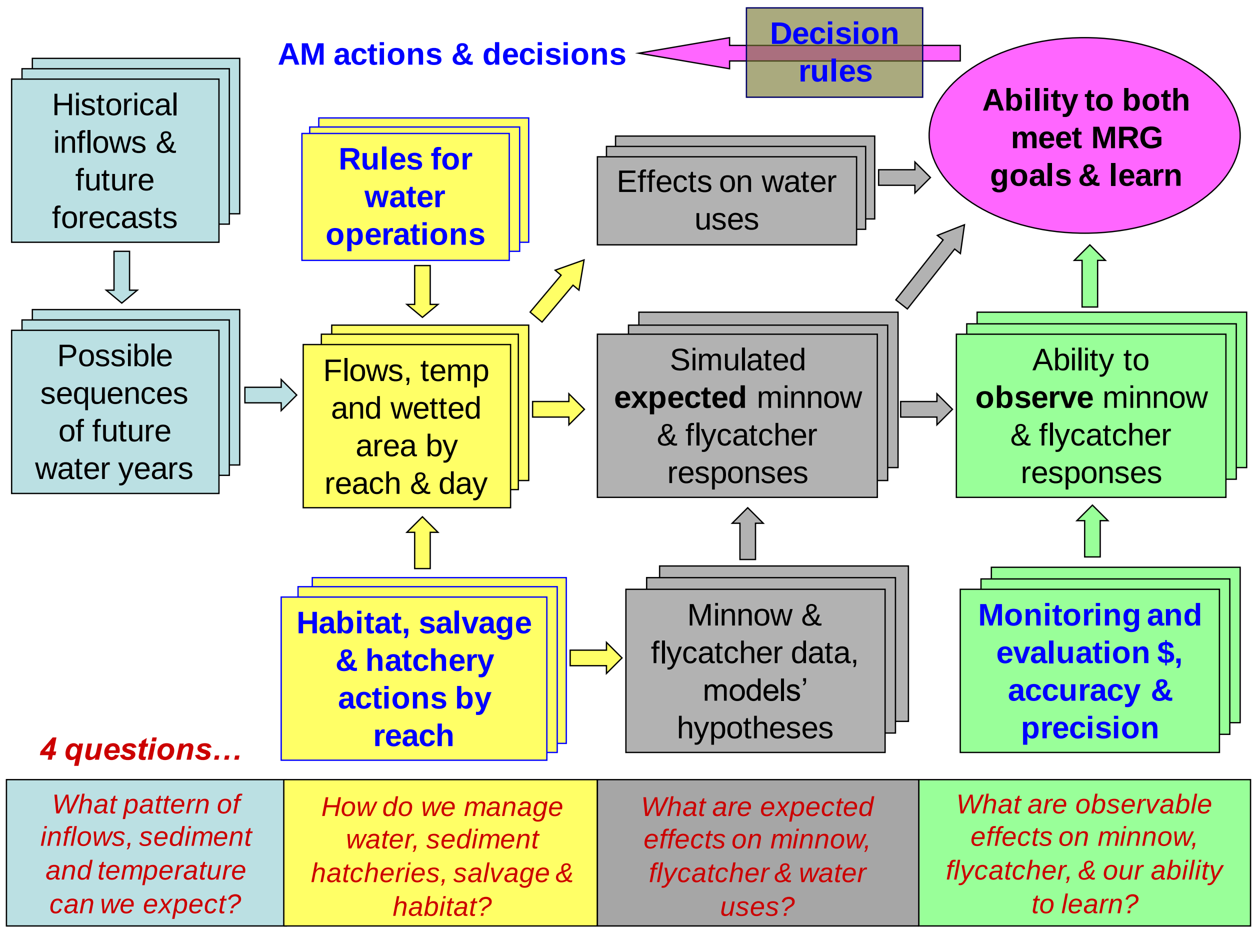
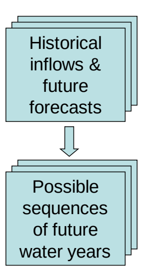
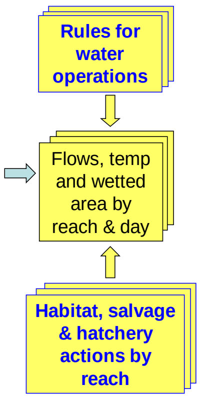



**Figure 8.** Illustration of suggested process for simulating the AM cycle to explore AM actions and design.

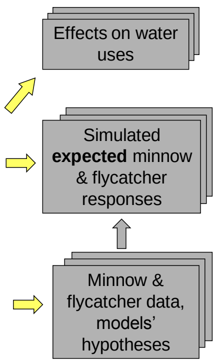
The following paragraphs describe this process step by step.



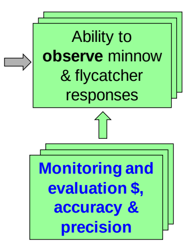

The process would begin by identifying what range of variation in inflows, sediment and temperature would be expected in the future. This involves examining historical flow and sediment data and simulating a range of potential future inflows and sediment transport conditions. The results of this portion of the process would provide a range of water year sequences for subsequent links in the modeling chain.




The policy/management group (with advice from the technical group) would propose the next set of water, sediment, hatchery, salvage and channel rehabilitation actions based on what Program participants believe would concurrently meet Program goals and reduce critical management uncertainties. These actions would attempt to create meaningful contrasts over space and/or time to test priority hypotheses, while also meeting Program goals and operating within the rules that govern water operations. Physical models would be used to simulate the resulting flows, water temperature and wetted area under each set of actions, for each sequence of water years. Iterations through this process would be made for each proposed combination of actions to compare simulated results.




Simulate the *expected* effect of these flows, temperature and wetted area on water uses in the MRG and on the minnow and the flycatcher, given various hypotheses about their direct or indirect responses to flows, water temperature and wetted area.




Simulate the range of responses that the Program could *expect to be able to observe*, given the level of investment in monitoring. This is an important distinction from the expected responses in the grey boxes. The ability to reliably detect actual responses and distinguish among key alternative hypotheses within an acceptable period of time will depend on the intensity of monitoring, and the level of natural variation in flow conditions (more variation is better). Including this monitoring and evaluation component in the simulations provides valuable information about the tradeoffs between cost and accuracy in decision making (Alexander et al. 2006; CSMEP, 2007a and 2007b).

**Table 10.** Potential tools for addressing the four questions in Figure 8.

| Questions | Potential Tools |
|---|---|
| *1. What pattern of inflows, sediment and temperatures can we expect throughout the MRG system?* | **Inflows.** The Bureau of Reclamation has developed a set of 10-yr hydrologic sequences that represent 10, 30, 50, 70, and 90 percentiles of flow in a 640-year paleohydrologic history determined from tree-ring records. Each of these five10-yr sequences could be used to represent possible sequences of inflows. Downscaled projections from Global Circulation Models may provide further insights into the relative probability of different water year sequences. Using Global Circulation Models to weight the selection of 10-yr sequences may be valuable as future conditions may be outside of the range of observed historical variation.<br>**Temperatures.** Air temperatures affect the water balance and water temperatures. Since fish gonadal development for reproduction is primarily dependent on photoperiod (constant from year to year) and water temperature (e.g., cumulative degree days is often a good predictor of spawning timing), it is important to be able to predict when silvery minnow are ready to spawn physiologically, and how spawning timing varies from year to year. If flows are low, then water temperatures could vary considerably with flow. Monitoring water temperature, turbidity, and flow may help to further improve understanding of the triggers for |

| Questions | Potential Tools |
|---|---|
| | spawning, and lead to models predicting the likelihood of spawning. Temperature is however not normally a manageable element of the Rio Grande system.<br>**Sediment.** Sediment transport needs to be modeled, since it affects both channel form and habitat attributes of the river and its floodplain. |
| *2. How do we manage water, sediment, physical structure, and species?* | **Water.** The Upper Rio Grande Water Operations Model (URGWOM) can be used to simulate alternative rules for water operations, and determine the impacts of those rule changes on flows in different reaches.<br>**Physical structure.** Curves showing the wetted areas at different flows (Figure 18), or other models (FLO2D and SRH-2D) can be used to simulate how wetted area changes with different channel cross-sections (reflecting different levels of investment in channel reconfiguration and habitat rehabilitation).<br>**Species.** Existing information on capacities of the various hatcheries (ABQ Biopark, Los Lunas, Rio Grande Bosque) can be used to estimate a range of feasible stocking rates for each reach. Existing data can also be used to evaluate success of stocking hatchery fish. Salvage actions also need to be evaluated.<br>**Sediment.** Sediment augmentation is often used below dams to rectify sediment deficits, as in the Trinity, Sacramento and Platte Rivers. Sediment augmentation is a potential management action below Cochiti Dam, particularly for the degraded Angostura reach, and possibly the more northern parts of the Isleta reach. Flow, channel rehabilitation and sediment management actions all need to be closely coordinated. |
| *3. What are expected effects on the silvery minnow and flycatcher?* | Silvery minnow population models developed by the PVA work group, with some further work, can be used to generate estimates of the expected responses to flow, habitat and hatchery actions, for a range of hypotheses. The PVA work group could also develop flycatcher population models, or build off existing models, but predicted flycatcher responses to habitat changes can also be modeled using simple spreadsheet tools that Program participants can develop jointly. The two silvery minnow PVA models currently active within the PVA work group (Norris et al., 2008, Goodman pers. comm.) use different modeling frameworks. With multiple modeling frameworks it is generally difficult to determine the causes of differences in model output (i.e., different outcomes could be caused by differences in input data, functional relationships, parameter values in these relationships, different forms of output and/or other aspects of the model structures). To make progress, it would be best to embed both models in **one** analytical framework, so that it is straightforward to clearly compare the consequences of alternative actions under different hypotheses, parameter values and water years, and to perform sensitivity analyses. If however different modeling frameworks are used with the intent to compare results, they should also use completely consistent implementations of management actions, input data streams, spatial and temporal stratification, and comparable outputs. |
| *4. What are observable effects on the silvery minnow and flycatcher, and our ability to learn?* | Analyses of existing data suggest that there can be very high variation in the sampled abundance of silvery minnow with replicate sampling (Figure 4 in Goodman, 2011). So we need to understand how well various monitoring protocols estimate key population attributes like abundance and survival. Tools to address this need include observation models which simulate the sampling process and power analyses which generate estimates of the level of precision obtainable for different levels of sampling effort. Such tools can be used to simulate the ability to learn, that is, to revise estimates of the probability of hypotheses or population parameters which affect the selection of preferred management actions (e.g., Paulsen and Hinrichsen, 2002, Alexander et al., 2006). We understand from conversations with some Program scientists that these models and power analyses do not yet exist for the MRG; if that is indeed the case then they certainly should be developed. Flycatcher monitoring can be continued on an annual basis with high precision and accuracy. Habitat metrics can be easily calculated using analyses of LiDAR and aerial photography data (collected frequently enough to capture major changes). |

The process of building linked models that meet management needs deserves careful consideration. Based on our experience with this over the last three decades, we recommend the following steps:

a) The technical and policy groups meet to jointly establish a core set of objectives and associated performance measures which will be evaluated for any simulated management action, and to sketch out the range of potential management actions. This discussion should build on the content of Sections 1.1 through 1.5, and also be informed by the *example* actions and performance measures in Sections 2 and 4 of this Version 1 of the AM Plan. The modeled performance measures must relate to the objectives, but may in some cases be different from what is monitored in the field, or may be proxies for what would ideally be examined given the limitations of existing models (e.g., a habitat model may generate wetted area by reach rather than a more precise forecast of the area of suitable spawning habitat which meets multiple attributes).

b) The technical and policy groups also jointly review the spatial extent of actions and objectives (e.g., just the MRG area, or all the way from Colorado to Mexico), and the time horizon of interest, which should be long enough to observe the outcomes of all actions for all objectives. The actions, performance measures, spatial extent, and time horizon will help bound the scope of the linked set of models.

c) The technical group works together to clearly establish linkages between all submodels through a Looking Outward Matrix which specifies what information gets passed between submodels and the associated units, and the spatial and temporal resolution of this information. A template is shown in Table 11. Information is also required regarding what would be needed to properly implement each suite of management actions being modeled (including the level of investment in monitoring), and to incorporate a consistent set of driving variables (e.g., water years and associated temperatures). Each submodel is responsible for a given set of performance measures. The observation submodel simulates *observed* values of the performance measures in other submodels considering the sampling and measurement errors associated with a given level of investment in monitoring. The shaded diagonal cells of the matrix serve as a reminder that this step is a looking outward exercise, and is not focused on factors internal to each submodel.

   It is usually best to start the looking outward procedure with one set of candidate actions, and then consider how such actions would be simulated, working *backwards* from the biological submodels to the habitat submodels to the physical submodels. This counter-intuitive approach helps to keep modelers focused on the ultimate endpoints.

d) After completing steps a) through c), the modeling subgroups work in parallel to get their submodels operational.

e) Once the submodels are all working (or appear to be), conduct a pilot test to ensure that all the linkages work. Output files from one submodel will need to be processed into the appropriate format to become input files for the next submodel in the chain, and this conversion step must be automated. These linkage issues can be worked out through a pilot test. Inevitably, errors will appear which will require revisions and retesting.

f) Once pilot testing is complete, the suite of models can be applied to a wider range of management actions. Ideally, all of the information describing scenarios and model outputs should be stored in a relational database which permits rapid review and comparison of alternative scenarios.

The approach illustrated in Figure 3 and Figure 8 is based on our experience with other processes for water management decisions (e.g., Province of British Columbia, 1998; Marmorek and Peters, 2001; Peters and Marmorek, 2001; Peters et al., 2001; BC Hydro, 2003; Gregory et al., 2006), and various technical approaches for evaluating alternative AM experiments (e.g., Paulsen and Hinrichsen, 2002; Alexander et al., 2006). A summary of the process and outputs used for the Bridge River project in British Columbia, a multi-objective water use planning effort which developed an adaptive management plan, is provided in Appendix A. This project used methods very similar to what we envision for the Program to get from Version 1 to Version 2, although the organizational structure would need to be designed to fit the situation and entities in the MRG.

**Table 11.** Looking Outward Matrix template for articulating inputs and outputs between submodels. Each cell would list what exact information the submodel represented by the column requires from the submodel represented by the row in order to generate its assigned set of performance measures ( $PM_1$ to $PM_6$ in the second row).

| To ⇒ / From ⇓ | Hydrology Submodel | Habitat Submodel | Biology Submodel | Observation Submodel |
|---|---|---|---|---|
| Performance Measures | $PM_1$, $PM_2$ | $PM_3$, $PM_4$ | $PM_5$, $PM_6$ | $PM_{4*}$, $PM_{5*}$, $PM_{6*}$ |
| **Hydrology Submodel** | | *Specific hydrology submodel outputs needed as inputs to habitat submodel; TBD.* | *Specific hydrology submodel outputs needed as inputs to biology submodel; TBD.* | *Specific hydrology submodel outputs needed as inputs by observation submodel; TBD.* |
| **Habitat Submodel** | *Specific habitat submodel outputs needed as inputs to hydrology submodel; TBD.* | | *Specific habitat submodel outputs needed as inputs to biology submodel; TBD.* | *Specific habitat submodel outputs needed as inputs by observation submodel; TBD.* |
| **Biology Submodel** | *Etc., TBD.* | *Etc., TBD.* | | *Etc., TBD.* |
| **Observation Submodel** | *Etc., TBD.* | *Etc., TBD.* | *Etc., TBD.* | |

## 1.7 Spatial and Temporal Bounds

The spatial extent of the Program is the Rio Grande and its tributaries from the Colorado/New Mexico state line to the elevation of the spillway crest at the headwaters of the Elephant Butte Reservoir, comprising roughly 300 miles of mainstem river (Figure 9). The Program goals include supporting self-sustaining populations, and Program actions have historically included some efforts outside the MRG that serve to benefit the MRG (e.g., in Big Bend for the experimental minnow population). Therefore this should also be the spatial bounds for the AM Plan, with any AM actions that are designed, implemented and monitored under the AM Plan occurring somewhere within the same spatial area in which the Program conducts its actions. Ultimately however the spatial extent of the AM Plan will depend on the area needed to implement the actions the Program agrees to undertake in order to test the priority hypotheses. These hypotheses and actions have not yet been identified or agreed to (as explained in Sections 1.3, 1.5 and 1.6), but should be clear by the end of the process described in Figure 8. Any refinements to the special bounds based on those results should be articulated in AM Plan Version 2.

The temporal horizon of the AM Plan is less obvious, but will greatly affect how hypotheses are sequenced and will bound design and implementation of actions under the AM Plan based on how long it will take to reliably detect the responses of valued ecosystem and socio-cultural components (and their habitats) to Program actions. For example, the response-time of the silvery minnow to variations in flows may facilitate rapid learning, with multiple iterations of action and response within a few years. On the other hand, challenges in reliably monitoring minnow reproduction, and naturally high year-to-year fluctuations in recruitment, may require longer time periods to draw sound inferences on action effectiveness. Program management actions and monitoring activities will have to be sequenced to maximize learning within a reasonable time period, relying on faster-responding interim indicators (e.g., the area of suitable habitat available during critical periods of the year, the persistence of these habitat features from year to year) to complement information on biological responses.

The 2013 BO is expected to include actions to alleviate jeopardy for listed species and adverse modification of critical habitat for the coming years, and as such will set boundaries to what adaptive management actions may be undertaken in order to not risk jeopardizing the species or adversely modifying critical habitat. Other constraints also exist in the MRG basin (e.g., Rio Grande Compact, state and federal laws and regulations, existing agreements) and thereby also limit the range of actions that could be explored through AM. Therefore the temporal horizon for the AM Plan should be bounded by the amount of time it will take to test priority hypotheses with the chosen actions (yet to be defined, as discussed in Sections 1.3, 1.5 and 1.6).

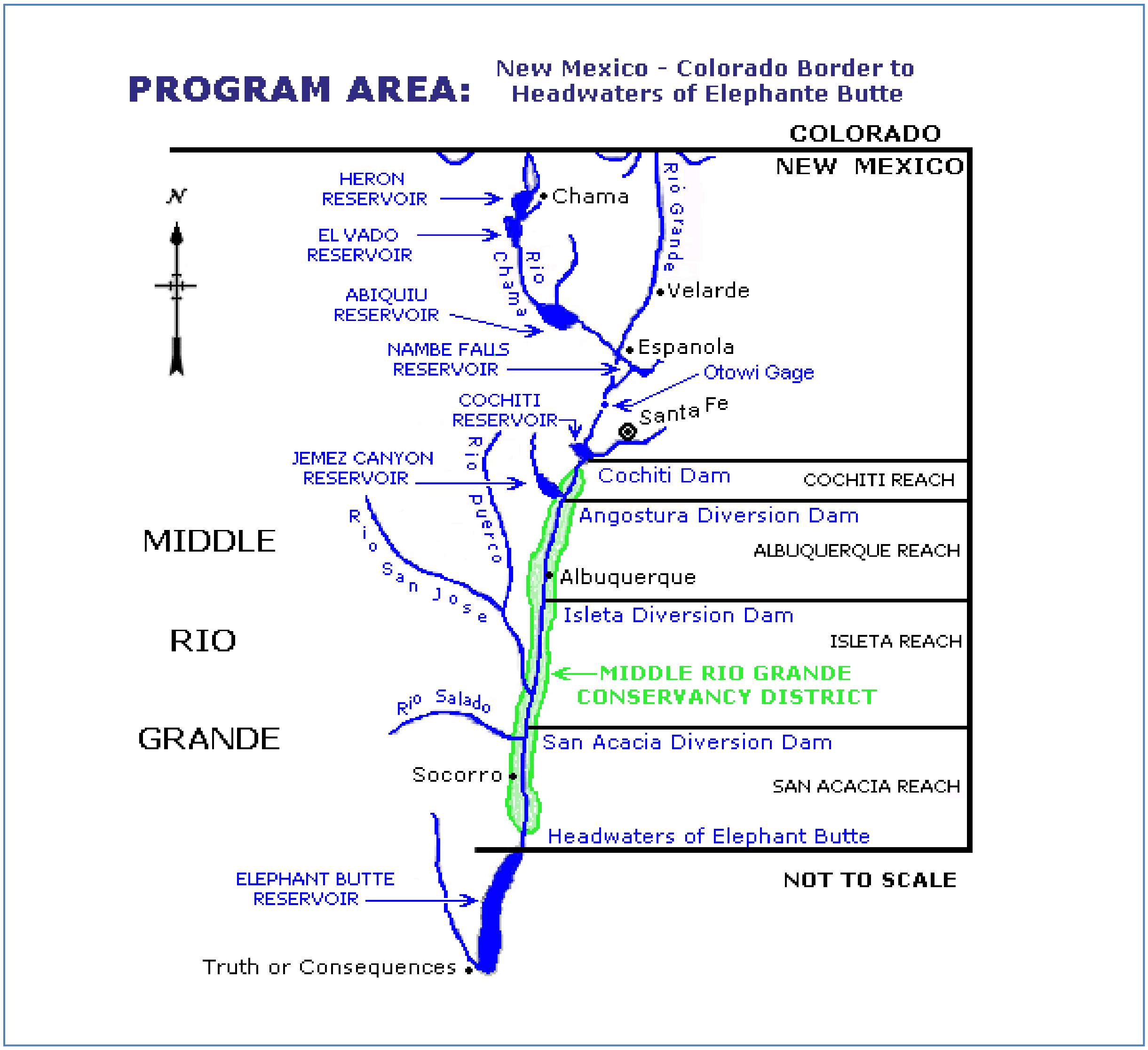



**Figure 9.** The Program area. The map is not to scale. Source: Program website http://www.mrgesa.com/.

# 2.0 AM Cycle Step 2 – Design

An AM design should include all aspects of good experimental design, including contrasts[6], controls and replication. However in a natural system the number and complexity of hypotheses being tested, the variability in the system and the logistical limitations to true randomization of actions often make it very difficult to implement an ideal experimental design. It is crucial to invest time up front to simplify the problem and develop a manageable design. This is usually a lengthy iterative process such as that shown in Figure 8 which uses a variety of tools for making probabilistic estimates of anticipated outcomes of various action alternatives, exploring which alternatives are most likely to resolve the most critical uncertainties, determining the feasibility of being able to adequately monitor the outcomes, and analyzing costs versus benefits and other tradeoffs.

For reasons explained in the Introduction, the Program has not yet selected AM actions. Therefore **this section describes *example* AM actions** that could be considered to address a set of hypotheses that participants identified as being high priority. The purpose of these example actions is threefold: to convey what AM for the MRG could look like, to illustrate the remaining steps in the AM cycle, and to provide a catalyst for thinking about design options and the whole AM process when developing Version 2 of the AM Plan. The design section of AM Plan Version 2 may or may not contain elements of the example described here.

A key question facing the Program seems to be, "how can we achieve the Program goals with even less water than we have had in the past few years, as drier years are expected to become more common, and improve the physical system over which the water flows?" This is what we believe is worrying water managers, who face even greater challenges with less runoff expected in the future (Bureau of Reclamation, 2011a). This increases both the pressure on them to make the 'right' decisions about water and habitat management, and the importance to them of being fairly certain what the 'right' decisions are – i.e., that the management actions they take really are going to help achieve the multiple Program goals (for minnow, flycatcher, and existing and future water uses). The design examples described in this section focus on some of these water management uncertainties. The ability to test alternative actions will depend on the level of contrast in those actions, and the level of investment in monitoring and evaluation.

## 2.1 Principles for Designing AM Actions

The design of actions must carefully consider the natural variability of the system, the complexity of the ecosystem, and the complexity of the water management infrastructure and operational rules and constraints. It must also consider a range of other factors including the risks associated with management of endangered species and the need for 'safe-fail' precautions, such as early warning indicators or significant decline triggers (an example from the Columbia Basin is provided in Appendix D). Box 1 presents these considerations as a list of principles that should be followed when designing the AM actions.

[6] Using contrasting treatments means taking an active AM approach, rather than a passive one. In active AM two or more carefully chosen alternatives are tested to see which best meets management objectives. Learning can occur more quickly if the different treatments can be done concurrently in different places, although this won't be possible for some types of actions. For example, different mechanical habitat actions could be tested in different river reaches in the same year (concurrent spatial contrasts), whereas different flow operations would need to be tested in different years (temporal contrasts). Simply put, contrasts facilitate learning: the bigger the contrasts are between alternative treatments, the easier it is to detect and distinguish if and how the outcomes differ.

**Box 1.** Principles for Designing AM Actions for the Middle Rio Grande. The four main principles are listed in order of priority. There are tradeoffs amongst some of the design attributes under Principle 3, which need to be assessed through the process outlined in Figure 8.

1. Meet the Program goals of:
    a. Alleviating jeopardy to the listed species in the Program area.
    b. Conserving and contributing to the recovery of the listed species.
    c. Protecting existing and future water uses.
2. Include measurable triggers, safeguards and emergency actions to ensure jeopardy is avoided for silvery minnow and flycatcher.
3. Design actions to achieve as many of the following attributes as possible (all important, not in order of priority), within the constraints created by principles 1 and 2:
    a. Anticipate factors beyond management control.
    b. Recognize ecosystem variability (e.g., Figure 10, Figure 11, Figure 12) and complexity, working in harmony with species' life histories (e.g., Figure 13, Figure 14).
    c. Be well integrated (e.g., flow and habitat actions work well together; also look for actions that benefit both species).
    d. Move the river system towards a well-articulated, desired state.
    e. Reflect recent advances in scientific understanding affecting the recruitment and survival of silvery minnow and flycatcher.
    f. Deliberately use contrasting actions (over space and time), monitoring and evaluation to reduce key uncertainties affecting management decisions.
    g. Focus on 'need-to-know' uncertainties from the perspective of decision-makers.
    h. Be feasible (to implement as well as monitor), with an estimate of the implementation uncertainty and clearly identified constraints and potential confounding factors.
    i. Be cost-effective and sustainable, using water as efficiently as possible and ensure protection of existing water rights.
    j. Test out new approaches incrementally through demonstration of proof-of-concept, pilots and safe-fail methods.
    k. Be reversible or adjustable if shown to be ineffective (not always possible).
    l. Involve both policy and technical participants in the design (e.g., Figure 3, Table 2).
    m. Clearly allocate responsibilities for implementing each part of an integrated set of actions.
4. Communicate progress and results throughout the design process, ensuring all participants and stakeholders are kept informed about the emerging design.

Principle 3b addresses several aspects of the MRG. These include highly variable hydrologic conditions (illustrated by the range in timing and magnitude of flows at Otowi in Figure 10) and tightly constrained management options (e.g., under the 2003 BO and the Rio Grande Compact), which lend complexity to the exploration of flow management actions. Flow is affected by the sequence of recent water years, current water year inflows and precipitation, dam operations, water withdrawals, and physical channel conditions (which are in turn affected by flow). These factors affect the storage conditions, which in turn affect the degree of flexibility that water managers have to change operations. For example: dry conditions can decrease the usable water for the Middle Rio Grande Project available in Elephant Butte Reservoir below the 400,000 acre-ft threshold for Article VII, leading to storage restrictions in upstream dams; insufficient water for non-Indians in El Vado reservoir could put the District into 'run of the river' operations, which could result in drying in the Albuquerque reach; and the counter-intuitive consequences of inter-state rules where wet year conditions can result in water debits under the Rio Grande Compact that must made up in non-wet years (D. Llewellyn, BOR, pers. comm.).

Minnow densities are also subject to considerable variability (both across and within sampling sites as shown in Figure 11 and Figure 12 respectively). This high variability is not surprising given the high reproductive potential of the minnow. Flycatcher numbers (individuals and nests) in the MRG are less variable within study reaches, with each reach showing either constant, decreasing or increasing trends over the past 10 years, although numbers of individuals and nests vary greatly between study reaches.

Consideration of the complexity of the ecosystem also includes understanding how the life history of the species relates to the hydrograph (Figure 13 and Figure 14).

Principle 3b also implies working with the natural variability in year-to-year flows to achieve different kinds of outcomes in different types of water years. For example, the Trinity River Restoration Program has a different flow schedule for each kind of water year (Figure 15), and different expectations of what will be accomplished with these flows. The flow and temperature recommendations for the Flaming Gorge Dam in the upper Colorado River basin provide another example of adjusting dam releases to accommodate different runoff and inflows to the reservoir to meet ESA needs (Muth et al., 2000).

Principle 3f emphasizes the importance of contrasts – comparing outcomes of different actions. This means designing management actions to deliberately create contrasting conditions where appropriate, or take advantage of already existing variability in hydrologic and habitat conditions, and monitoring the responses of the silvery minnow and flycatcher across that variation. Melis et al. (2005) discussed three different options for creating contrasting treatments in the Colorado River as part of the Glen Canyon Adaptive Management Program: 1) *Titration* - progressively more expensive options, 2) *Reverse Titration* - invest heavily in specific flow or non-flow treatments and then back off to see what worked, and 3) *Factorial* - comparison of treatment combinations using a multi-year, blocked approach. Though none of these options was formally adopted in the Glen Canyon AM Program, the concepts are still worthy of consideration in any AM approach. However, deliberately creating large flow contrasts is currently not feasible in the MRG Program; there is much less managerial control of flow than at the Glen Canyon Dam. The MRG Program must rely on natural variability to provide large contrasts in flow (passive AM) with smaller magnitude manipulations piggybacked on top of these natural flows (e.g., the Cochiti deviation; changes in the magnitude or timing of inflows, withdrawals or return flows throughout the MRG system). The potential magnitude and level of contrast in active flow actions depends on the amount of available water, water management decisions and legal constraints.

Principle 3g is a reminder that ‘need-to-know’ uncertainties from the perspective of decision-makers may differ from the uncertainties of great interest to scientists. It would be exceedingly impractical and unrealistically costly to attempt to design adaptive management actions to address all of the questions and hypotheses listed in Appendix C.

Principle 3h may require the development of an approach to resolve differences between policy-makers and scientists on acceptable degrees of implementation uncertainty for desired actions. Such an approach would likely also touch on Principle 3j, as ’safe fail’ pilot tests allow learning to occur while minimizing risks.

Some participants have concerns about the species’ recovery criteria, which are determined by the Service in the species’ recovery plans. Annual progress toward recovery will be assessed with interim criteria, yet to be developed. Those interim criteria are important for principle 3j and the identification of triggers for safe-fail contingencies or ‘stopping rules’.

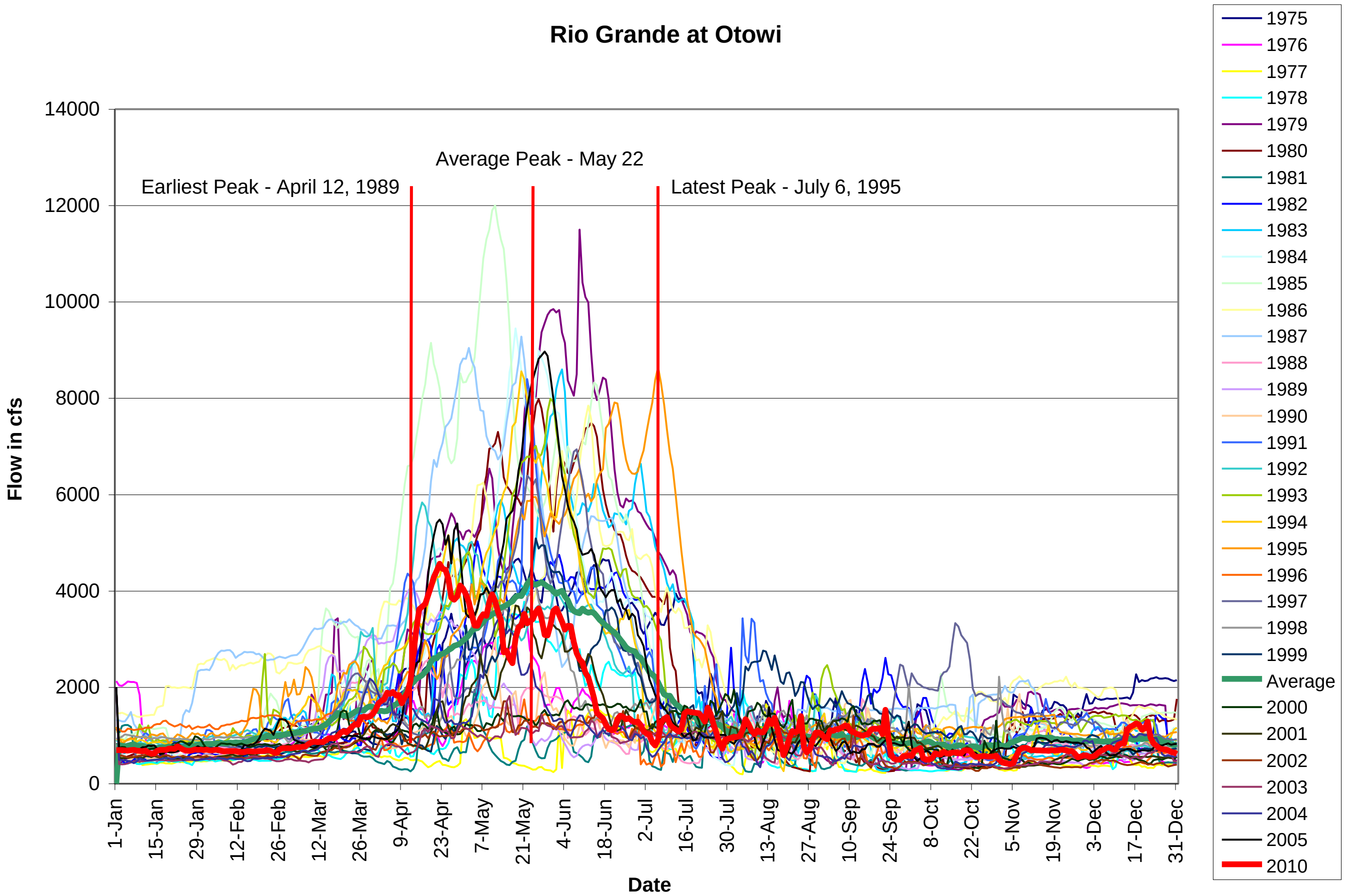



**Figure 10.** Variation in flows, and the timing of flows at Otowi (the upstream delivery point to the Rio Grande Compact), 1975 - 2007. Source: Marc Sidlow, U. S. Army Corps of Engineers.

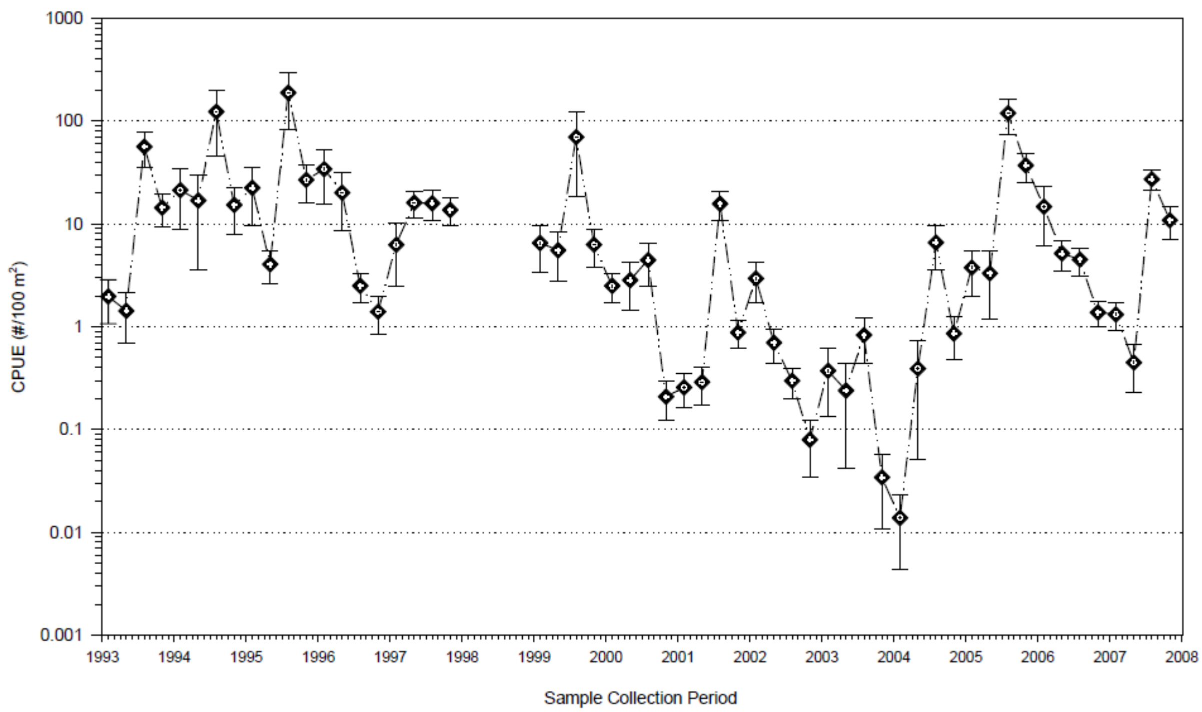



**Figure 11.** Variation in quarterly Rio Grande silvery minnow densities (1993-1997, 1999-2007) at population monitoring program collection sites (shown in Figure 22). Source: Figure 8 in Dudley and Platania (2008). Hollow diamonds indicate sample means for each survey and capped-bars represent the standard error. High year to year variability (note the log scale on the y-axis) is characteristic of this species in response to year to year changes in river conditions. Dotted horizontal lines represent different orders of magnitude.

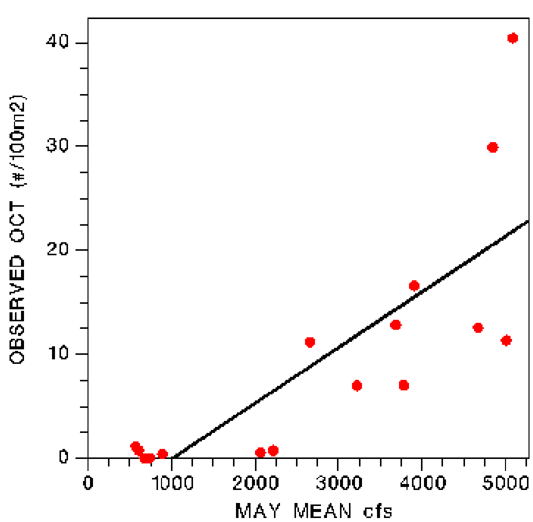



**Figure 12.** Observed recruits (October census) vs. May mean flow (cfs) at Albuquerque. Reproduced from Figure 5 in Goodman (2011). Underlying data from Dudley and Platania (2008). This figure illustrates both the high variability (in observed recruits and in May mean flow) as well as the correlation between May mean flows and fall recruitment. Correlation is 0.790; jackknife cross-validation $R^2$ is 0.4703; n=16; there are 5 years in the cluster < 1000 cfs. The high outlier is 2005.

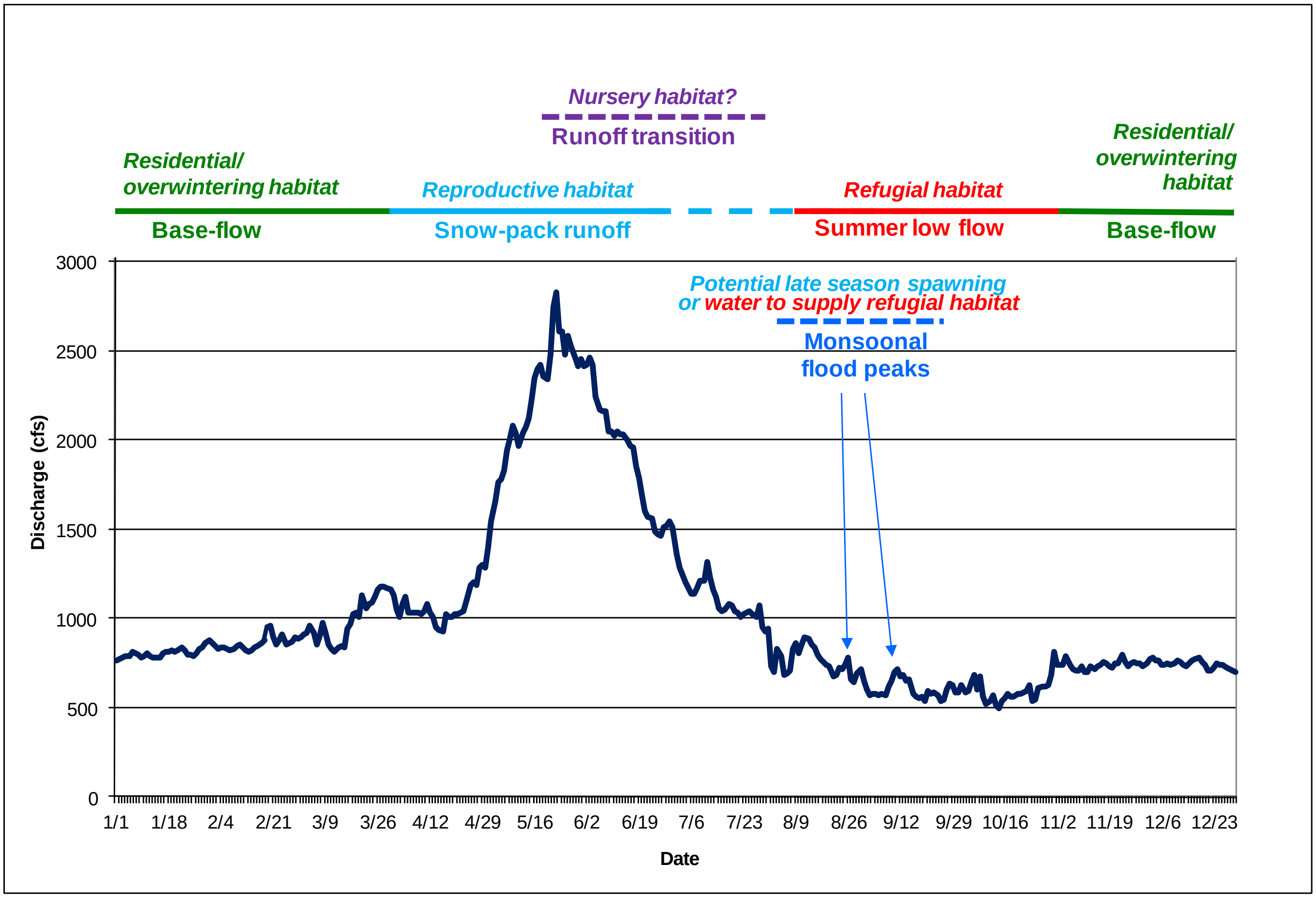



**Figure 13.** Mean flows at the stream gage at Central Avenue in Albuquerque, and the general timing of habitat availability for silvery minnow life-history activities. Source: Adapted from a figure provided by Anders Lundahl, NMISC.

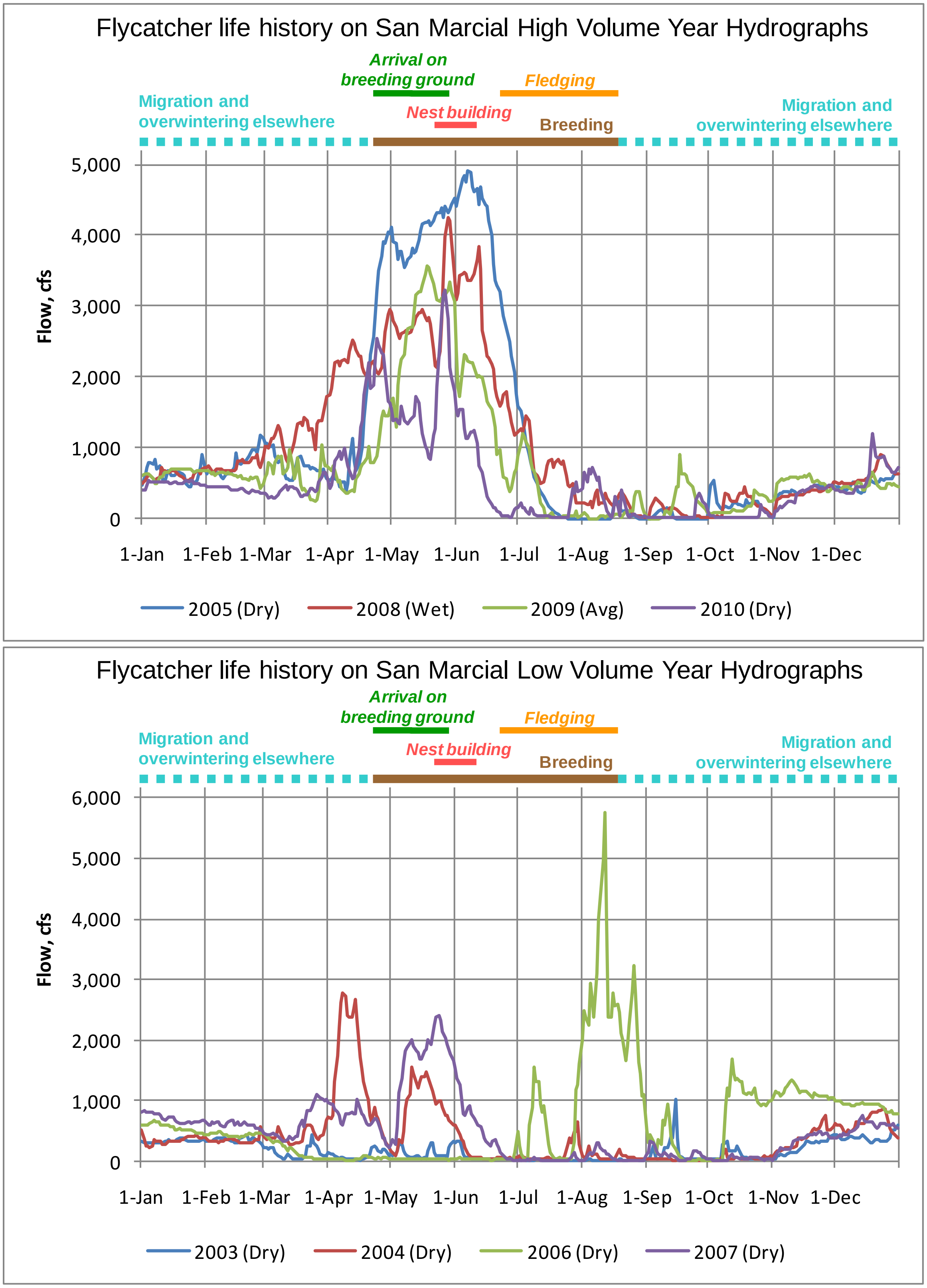



**Figure 14.** High and low flows at San Marcial, and the general timing of flycatcher life history stages. Source: Hydrographs from the Bureau of Reclamation.

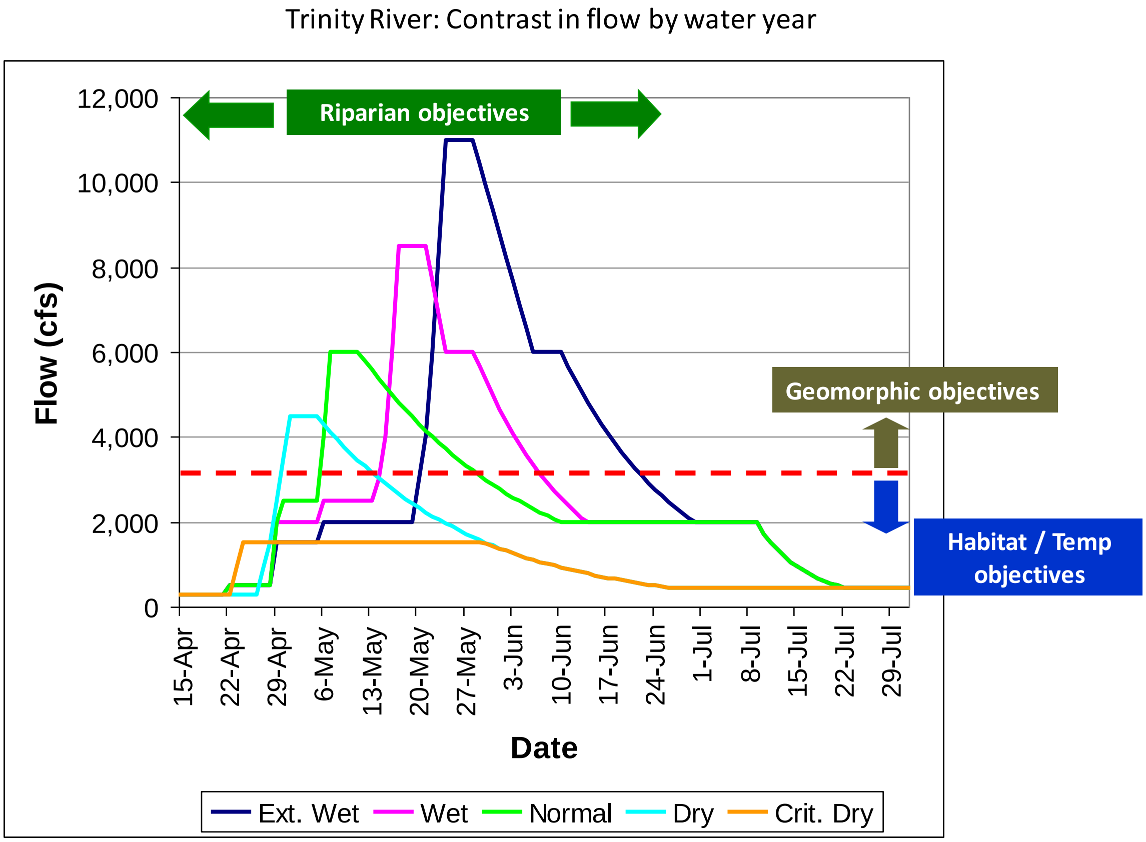



**Figure 15.** Example of working with the natural variability in year-to-year flows: flows applied to the Trinity River in each of five different kinds of water years: extremely wet, wet, normal, dry and critically dry. Source: U.S. Dept of Interior (2000). In years when flows are below 3,000 cfs, the focus is on achieving objectives relating to habitat and temperature: keeping critical habitats sufficiently wet and cool. In years when flows are above 3,000 cfs, the focus is on achieving objectives relating to geomorphic processes. Riparian objectives are relevant to all water years.

## 2.2 Example AM Actions for the Program

In this section we suggest example actions to catalyze thinking through the entire AM process. They are based on a variety of inputs (workshop and planning session discussions, background reports, other material, and the key questions, uncertainties and hypotheses from Section 1.3). The example actions are listed in Table 12. The flow and habitat components of the Table 12 example are illustrated graphically in Figure 16. **This is only one example set of actions; many sets of actions should be evaluated through the process illustrated in Figure 8 for moving from Version 1 to Version 2 of the AM Plan.** We stress that the process of moving towards Version 2 of the plan should be openly creative, and include the exploration and evaluation of any alternatives suggested by the policy group. This could include various options for water storage, water release, water diversion/return and water use, while meeting water use requirements and keeping the species on a trajectory toward recovery. These options might include on-farm efficiencies, overall irrigation system efficiencies, overall river and reservoir management opportunities, and other conservation and conjunctive use opportunities.

**Table 12.** Example AM actions to test some of the preliminary hypotheses from Section 1.3. These are only examples; many sets of actions should be evaluated.

| Hypothesis | System Attribute | Example AM Action to test the hypotheses |
|---|---|---|
| M-1, M-3 | 1. Spawning spike/flow | Sufficient flow must be provided during the spring period for successful spawning and recruitment, which appears to set the carrying capacity for reproduction (Figure 12). The timing and magnitude of the hydrograph peak is highly variable (Figure 10) and largely determined by nature rather than Program actions, although efforts such as the Cochiti deviation can help to tweak the hydrograph. Current practice is that a spawning flow release is timed to coincide with the natural spring flow peak in each year. Flow management actions, analyses and evaluations could focus on tradeoffs between the *duration* of the spring peak and the actual *peak* cfs levels reached, determining what combinations provide the maximum benefit to the silvery minnow (Figure 17). This would involve a mixture of passive AM (relying on natural year to year variability) and active AM approaches (deliberate tweaks to hydrograph). Use cross-section improvements to increase the area inundated (e.g., Figure 18) and associated data analyses (e.g., Figure 19) to ensure that there will be sufficient wetted area for at least 7 to 10 days after spawning in a sufficient proportion of spawning areas and water years to keep the population on a recovery trajectory. |
| M-2 series | 2. Continuous flow | Allow some areas to go dry for certain periods, while maintaining wetted refugia in key sub-reaches. These periods should avoid times when silvery minnows are spawning or larvae are drifting. Strategies for keeping sub-reaches wet would need to be determined through more detailed analyses which incorporate habitat enhancements. These strategies would vary by water year, region and time period; dry year strategies would emphasize using water for successful spawning. The strategy post-spawning would be to allow the river to dry in various sections following the spring period flows in dry and average water years, but to maintain a wetted channel in key refugial areas to try to improve silvery minnow recruitment above current levels. This would be accomplished through optimal use of irrigation return flows and other methods (e.g., maintenance of groundwater-fed refugia in Isleta Reach, pumping of groundwater to maintain backwaters and refugia) to maintain survival during the post-spawning period. Areas of 'drying' would be interspersed with designated sanctuary or refugium habitats that will be kept wetted, based on hydrology or manmade inputs, and will serve as known source areas for repopulating the river. Wasteways in Isleta Reach could potentially provide additional water to support potential refugia, provided that water quality meets criteria for minnow use. Predation on refugia is also a concern, so tests of this strategy would best be done in a phased pilot approach. |
| M-1, M-3 | 3. Overbank flooding & channel rehabilitation | Implement increased amounts of channel rehabilitation and habitat restoration (relative to current levels of activity) to allow more wetted area during springtime spawning period, under a wide range of flows, promoting greater levels of overbank flooding, higher spawning success, and retaining eggs and larval fish near their spawning locations (Figure 18). Refugial habitat would also be constructed for dry periods. Rehabilitation sites would be chosen based on criteria (to be determined) such as physical and vegetation characteristics, depth, edge-to-area ratio, vegetation height/density, degree of mixing/lateral connectivity to the river (number of inlets), and proximity to the key refugial areas described in row 2 above.<br><br>For flycatchers, consider flow releases to provide wetted breeding habitat and to stimulate growth of cottonwoods and willows. Implement a habitat restoration project near the largest current population of flycatchers at Elephant Butte Reservoir to determine if population re-distribution is possible. This could include creating off-channel wet areas near nesting locations to provide a foraging area for nesting flycatchers. |
| M-1, M-3 | 4. Hatchery actions | Deliberately stock tagged hatchery fish in the vicinity of particular channel rehabilitation sites, as well as in reference or control areas, to determine silvery minnow utilization of different spawning habitats. |

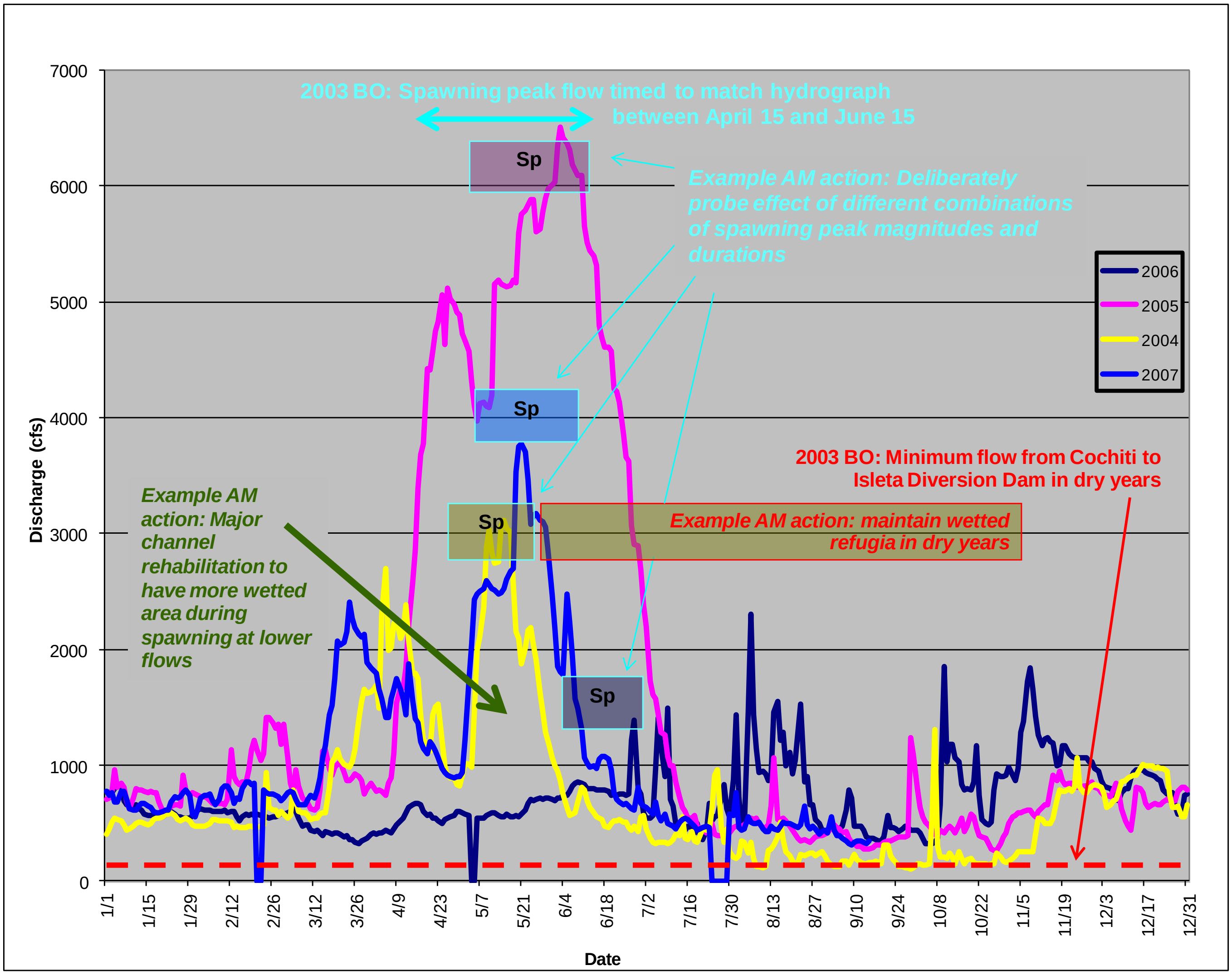



**Figure 16.** Illustration of the example AM actions described in Table 12**.** The hydrographs show Central Avenue flows from 2004-2007. Adapted from a figure provided by Anders Lundahl, NMISC.

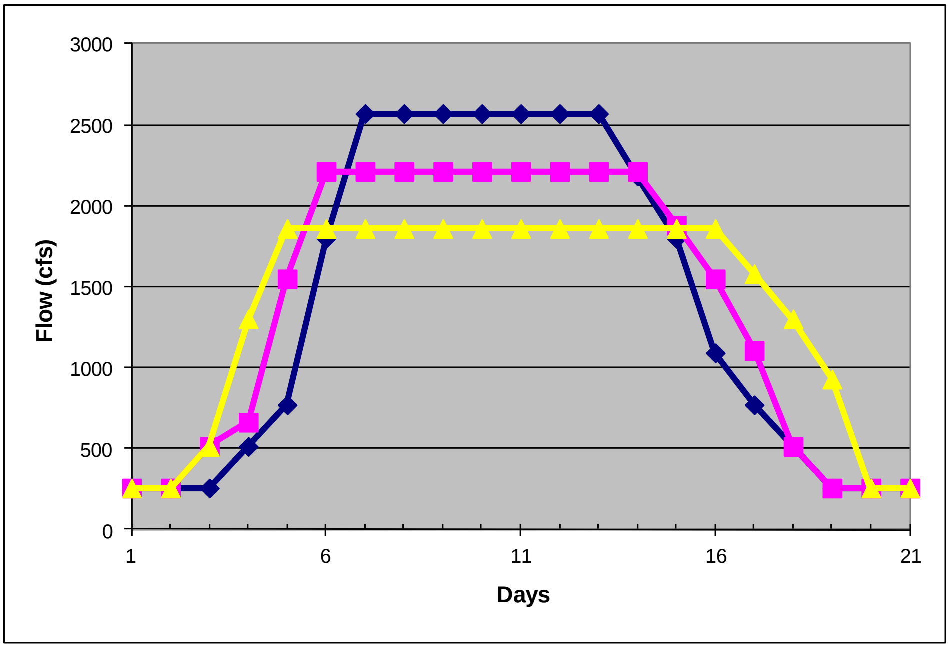



**Figure 17.** Hypothetical example of the tradeoff between flow magnitude and duration for a fixed volume of water during the peak spawning period. The three curves each distribute 57,500 a-ft of water over 21 days with peak flows of different magnitudes (2570, 2210 and 1860 cfs) for different durations (7, 9 or 12 days respectively). The relative effectiveness of options like these for supporting silvery minnow recruitment will depend on the channel cross-section, spawning habitat attributes, and the rate of development of silvery minnow eggs and larvae. Actual hydrographs would show far more variability in flow than shown here (i.e., more like the actual data in Figure 16). This variability will necessitate careful analysis to characterize the attributes of each year's hydrograph (e.g., flow magnitude peak, duration above a certain threshold, wetted area), and to determine how silvery minnow recruitment success relates to these attributes. Previous analyses have relied on aggregated measures of flow such as May mean flow (Figure 12).

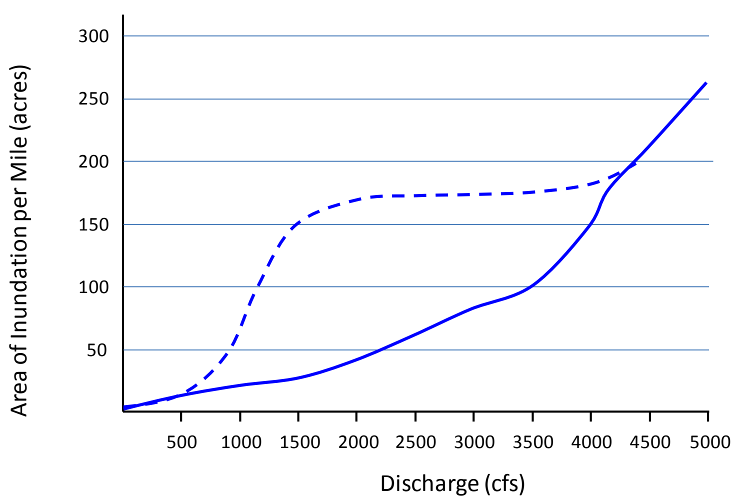



**Figure 18.** Hypothetical floodplain inundation curve before and after modification of the channel cross-section. The solid blue line is a hypothetical representation of the increase in inundated area in a given subreach across a range of flows prior to any channel rehabilitation. The hatched blue line shows how the curve might look in the same subreach across the same range of flows after substantial modifications to the channel cross-section to increase wetted area.

The example AM actions in Table 12 comprise a mix of comparisons that can be made in space and time. An important part of the design step is to identify: (1) all of the components of a particular action, (2) the range of feasible levels for each component, and (3) the spatial and temporal scale at which each action is implemented. Possible uncontrollable confounding factors such as water year should also be identified. Finally, the dependent variable(s) of interest must be described including the spatial and temporal scale at which they can be measured. Given these pieces, the implications of various design permutations and combinations – such as how many replicates might be needed, or how long it will take to learn the outcome of the alternatives being tested – can be examined. Preliminary design considerations are provided below for the spawning, continuous flow and channel rehabilitation aspects of the AM example.

***Spawning Flow and Channel Rehabilitation Actions***

The first row in the table of AM actions suggests deliberately varying the magnitude and duration of the spawning flow to determine what combination is optimal for the minnow. In this example, the management action is spawning flow which can be manipulated in three ways: timing, magnitude, and duration. Each of these components could be set to a variety of levels. If we considered only two settings for each of these three components, $2^3$=8 years would be the absolute minimum required to be able to estimate each of the effects and their potential interactions. This doubles to 16 years if one replicate is added to increase the power to detect effects. Now consider the uncontrollable confounding factor 'water year type' and the combinations increase 3 fold, and even without replication may take much longer than 8x3=24 years unless that period comprises exactly 8 dry years, 8 average years and 8 wet years. Step back at this stage and re-evaluate the critical uncertainties and feasibility of various actions. Which components are you most uncertain about – is there sufficient knowledge or are there sufficient data from past research to narrow down what really requires further experimentation? Consider what you would do with the information if you had it. Would you change your management action? In this example current management practice already times the spawning flow to coincide with spring runoff and this component is not the subject of the uncertainty, reducing the treatment components to just magnitude and duration. Focusing the design on these two components means that an un-replicated full factorial design (i.e., all treatment combinations) can be achieved in a minimum of $2^2$=4 years. Accounting for water year would require a minimum of 4x3=12 years, which would double to 24 years by adding one replication to increase the power to detect effects. Table 13 shows what this might mean for water managers (how much water, when and for how long) in each type of water year (dry, average, wet) if two levels of magnitude and duration are being tested. Table 14 breaks these options down into specific combinations that would need to be tested in each water year.

One way to reduce potential confounding due to water year would be to manipulate the system so that the fish experience the same conditions in wet and average years, or average and dry years. For example, two different levels for the magnitude of peak flow are tested, but they are the same regardless of water year[7]. For thoroughness all components should be described but it may not be necessary to manipulate all possible components in the design.

[7] It may not be feasible to match the peak flows between dry and average or between average and wet water years in the MRG, but the idea is offered to stimulate thinking about how to minimize confounding thereby reducing the number of years necessary to estimate effects.

**Table 13.** Example options for water managers for the spawning flow action in Table 12.

| | Dry year (D) | Average year (A) | Wet year (W) |
|---|---|---|---|
| Timing | As per current management – start at the natural spring flow peak that year. | As per current management – start at the natural spring flow peak that year. | As per current management – start at the natural spring flow peak that year. |
| Duration | ___ days (TBD; one of two durations being tested in dry years, Dd1 and Dd2). | ___ days (TBD; one of two durations being tested in average years, Ad1 and Ad2). | ___ days (TBD; one of two durations being tested in wet years, Wd1 and Wd2). |
| Magnitude | ___ cfs (TBD); one of two magnitudes being tested in dry years, Dm1 and Dm2). | ___ cfs (TBD); one of two magnitudes being tested in average years, Am1 and Am2). | ___ cfs (TBD); one of two magnitudes being tested in wet years, Wm1 and Wm2). |

**Table 14.** Combinations of duration and magnitude from Table 13 that would need to be tested in each water year.

| | Dry year (D) | | | | Average year (A) | | | | Wet year (W) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dry yr1 | Dry yr2 | Dry yr3 | Dry yr4 | Ave yr1 | Ave yr2 | Ave yr3 | Ave yr4 | Wet yr1 | Wet yr2 | Wet yr3 | Wet yr4 |
| Duration | Dd1 | Dd1 | Dd2 | Dd2 | Ad1 | Ad1 | Ad2 | Ad2 | Wd1 | Wd1 | Wd2 | Wd2 |
| Magnitude | Dm1 | Dm2 | Dm1 | Dm2 | Am1 | Am2 | Am1 | Am2 | Wm1 | Wm2 | Wm1 | Wm2 |

The flow magnitude and duration will depend on flows necessary to keep important downstream spawning habitats in each reach wetted for the desired duration given the current channel form, and will be among the design aspects to explore when moving from Version 1 to Version 2 of the AM Plan. Storage limitations in Cochiti Reservoir will affect the degree of flow tweaking that is possible. Crosshair graphs for different locations such as that shown in Figure 19 can help with this design effort. These graphs are helpful for determining in what percent of years a given location will have how many days of continuous flow above a certain magnitude, which together with Figure 18 (and possible channel reconfigurations) can be used to estimate areas that will be wetted for at least 30 days – a duration considered sufficient for recruitment of the silvery minnow.

To complete this example, as per the third row in Table 12 the design must also consider mechanical channel rehabilitation to increase the area inundated by the available flows. The spawning flow actions are temporal contrasts that occur annually at the scale of the entire system. It is not possible to test two different spawning flows in the same year; they must be tested in different years. The channel rehabilitation actions provide spatial contrasts. The components of this management action include determining *what* habitat rehabilitation to do, *when* and *where* – and should be coordinated with other ongoing or planned habitat restoration projects.  The spatial scale of this management action is smaller than the system scale, so multiple replicates of this action may be initiated each year.  As a result of the smaller spatial scale of these actions, there are additional uncontrollable confounding factors such as: position upstream versus downstream, tributary influence, local geomorphic characteristics, etc. These spatial confounding factors may affect the success of the rehabilitation actions but are too numerous to control for. This is a typical problem encountered with rivers.  The best strategy is to ensure replication of actions to determine which work under the broadest set of conditions.

In order to make use of these within year replicates the response variable must be on the same scale as the actions. Is it possible to estimate the response variable(s) at the scale of the rehabilitation site thus comparing rehabilitation sites to non-rehabilitations sites within each year? Given this limitation it may be sensible to use an easier response variable such as area of overbank habitat for comparison within a year, while still using a biological response variable for comparison across years.

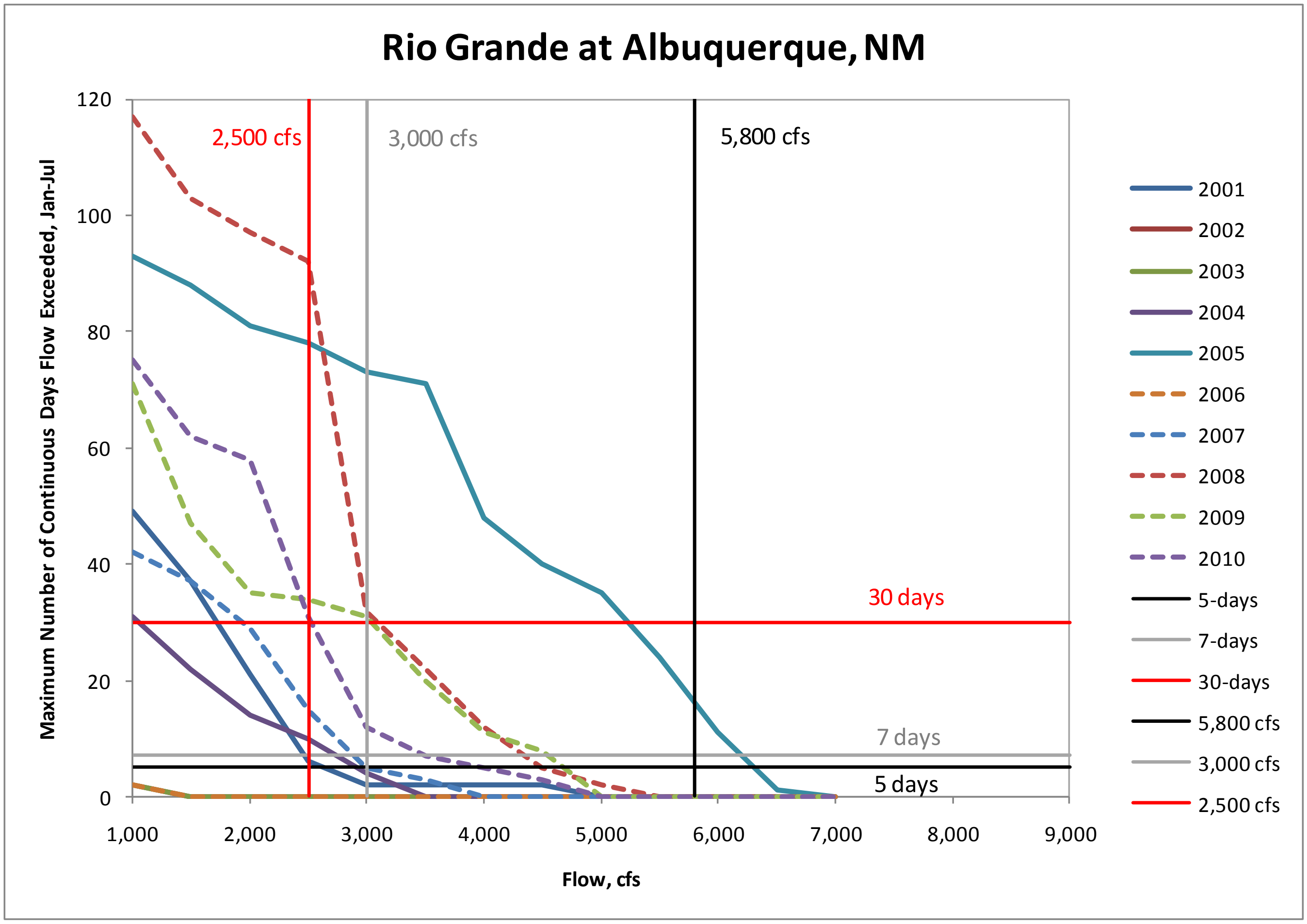



**Figure 19.** 'Cross-hair' analyses for the Rio Grande at Albuquerque, NM. Source: Bureau of Reclamation. The y-axis shows the maximum number of continuous days that the flow on the x-axis was exceeded, during the January to July period (though peak flows are generally between April and June). Examples of flow magnitudes which persisted for 30 continuous days at this location: 5,300 cfs in 2005; 3,000 cfs in 2008 and 2009; 2,500 cfs in 2010; and 1,000 cfs in 2004.

### *Continuous Flow and Refugium Actions*

The continuous flow AM action in the second row of Table 12 also includes both temporal and spatial aspects. In this example there are two main flow options for water managers in each type of water year: (1) operations so as to maintain continuous flows, and (2) the alternative of letting some areas dry while maintaining wetted refugia. Spatial decisions need to be made about where to place the refugia, but the refugia sites can only be tested during an Option 2 flow year.

Table 15 shows what these options might mean for water managers (how much water, when and for how long) in each type of water year (dry, average, wet). Not conveyed in the table is the need to select refugia sites and develop methods for keeping them wet. Irrigation infrastructure wasteways, existing wetted features inside the levees such as old oxbows and marshy areas, areas of groundwater accretion, and groundwater pumping are among the potential opportunities to be explored to maintain wetted refugia.

**Table 15.** Example options for the continuous flow actions in Table 12.

| | Dry year | | Average year | | Wet year | |
|---|---|---|---|---|---|---|
| | Option 1 (D1) | Option 2 (D2) | Option 1 (A1) | Option 2 (A2) | Option 1 (W1) | Option 2 (W2) |
| Locations of temporary drying* | None; continuous, as per current management. | Sub-reach A___ (TBD).<br>Sub-reach B___ (TBD).<br>Sub-reach C___ (TBD).<br>Etc. | None; continuous, as per current management. | Sub-reach A___ (TBD).<br>Sub-reach B___ (TBD).<br>Sub-reach C___ (TBD).<br>Etc. | None; continuous, as per current management. | Sub-reach A___ (TBD).<br>Sub-reach B___ (TBD).<br>Sub-reach C___ (TBD).<br>Etc. |
| Timing and duration of drying | Not applicable. | Sub-reach A: starting ___ (date TBD) to dry for ___ days (TBD).<br>Etc. | Not applicable. | Sub-reach A: starting ___ (date TBD) to dry for ___ days (TBD).<br>Etc.… | Not applicable. | Sub-reach A: starting ___ (date TBD) to dry for ___ days (TBD).<br>Etc. |
| Refugia maintenance (keeping them wet) | Not applicable. | Refugia X: starting ___ (date TBD) for ___ days (TBD).<br>Refugia Y: starting ___ (date TBD) for ___ days (TBD).<br>Etc. | Not applicable. | Refugia X: starting ___ (date TBD) for ___ days (TBD).<br>Refugia Y: starting ___ (date TBD) for ___ days (TBD).<br>Etc. | Not applicable. | Refugia X: starting ___ (date TBD) for ___ days (TBD).<br>Refugia Y: starting ___ (date TBD) for ___ days (TBD).<br>Etc. |

* These locations (sub-reaches A, B, C, etc.) must be chosen carefully in concert with the refugia locations (X, Y, etc.).

### *Preliminary Experimental Design Considerations for these Actions*

In a typical experimental design, several management actions of interest are identified. For each management action the components (or factors) that may be manipulated are identified. For example the management action of "spring flow" comprises three factors: timing, duration and magnitude. The range of plausible levels is then described for each factor (e.g., magnitude of spring peak flows of 100-7,000 cfs based on data over the past 25 years at Otowi). The most basic design requires one replicate for each combination of factors/levels. For example, if there were 3 factors each with 2 levels, this would require a minimum of $2^3$ or eight replicates. The number of replicates required can quickly become unmanageable, and as a result it is common to start with only two levels for a given factor with levels that are far apart (i.e., highly contrasted). For example, if no difference is detected between a flow of 200 cfs and a flow of 2,000 cfs, it is unlikely that a difference would be detected between 200 cfs and 400 cfs. Often a simple 'low' versus 'high' categorical level is used. When the number of factors is large, there are several approaches for simplifying the design and reducing the number of replicates required.

At first glance the AM example appears to have many factors (spring flow, spawning habitat, summer flow, refugia), each with many possible levels. However, this is when viewing the options from the perspective of *conditions managers can manipulate* (e.g., when to release flow, how much, and for how long; how much habitat rehabilitation to do, where, when and how; how many refugia to create, where, how, and for how long). As discussed at the beginning of Section 2, MRG managers have less ability to manipulate flows than in other river systems such as the Colorado. When exploring operational experimental designs where the actions (e.g., flow releases) indirectly affect the outcome of interest (e.g., amount of wetted habitat) viewing the options from the perspective of *conditions the minnows experience* can greatly simplify the experimental design. The design process therefore first needs to determine what spring flow peaks and magnitudes, plus channel rehabilitation actions appear to be optimal for minnow spawning in different water years, and whether refugia are adequate for summer survival and recruitment compared to continuous flow. If these analyses do in fact show that some alternative options appear to be better than (or just as good as) the 2003 BO RPAs, then it may be worth implementing follow up experiments to (a) test alternative levels of key attributes (i.e., flow magnitude and duration, channel rehabilitation flow refugia), and (b) assess the most cost effective way to achieve those levels.

Another way to simplify the design is to focus on the factors where there is the greatest uncertainty. In many cases previous research or scientific knowledge is sufficient to determine a reasonable setting for the management action. It is also good practice to ask ‘what you would do differently if you had the data?’ If it is not feasible or practical to manipulate the factor then why focus on learning about that factor? For example, it might be interesting to also explore the significance of maximum safe project release levels, but first ask the following: Are these levels fixed by safety of dam concerns, or potentially changeable? If there is some flexibility, would such levels be expected to have any influence on biological outcomes? And if there is some biological and management justification, would it make sense to deliberately vary maximum safe project release levels as part of an AM strategy?

In addition to the factors of interest (i.e., under management control), uncontrollable noise factors should also be identified. It is common to include a year effect in the design and analysis either as a random effect or grouped by year type as in the example shown above. More complex design structures (e.g., randomized block, split plot, nested etc.) may be necessary depending on the nature of the uncontrollable factors.

Finally, when all efforts to simplify the design into something manageable have been completed, there are formal statistical recommendations for how to reduce the number of replicates while minimizing the confounding of factors. These designs are known as fractional factorial designs (Montgomery, 1997).

Therefore the number of factors and levels (both within and outside of management control), as well as the ability to have spatial replicates (versus temporal ones) and comparable response variable(s) should be considered as AM actions are examined in more detail. This detailed examination would be part of the process depicted in Figure 8 for moving from Version 1 to Version 2 of the AM Plan, and will have implications for the complexity and temporal horizon of the experimental design. Randomization of treatments to experimental units within a well-constructed experimental design is required to show cause and effect relationships. Factorial designs and fractional factorial designs are the most efficient designs for evaluating both additive and multiplicative relationships (Montgomery, 1997). Contrasting conditions are vital to detect the effects of management actions, regardless of the analytical methods used to detect those effects against a background of natural variability (e.g., multiple regression approaches, other multivariate statistical techniques, non-linear parameter estimation for PVA models).

**What this section should contain in AM Plan Version 2:**

At the end of the process depicted in Figure 8, the Program will have thoroughly explored, examined and selected which hypotheses to test and what actions it intends to take to test them. A design for those actions would be clearly described in Version 2 of the AM Plan, specifying spatial and temporal details and experimental design elements including contrasts and replicates, controls and stratification.

# 3.0 AM Cycle Step 3 – Implement

## 3.1 Implementation of MRG Management Actions

The design example presented in Section 2 focuses on the exploration of varied forms of spawning flows, and periods of continuous flow in conjunction with habitat restoration projects and summer refugia to create and/or maintain habitat for the target species (silvery minnow and flycatcher). Flow releases closer to the upper end of the Program area, such as the Cochiti deviation (which could be used to facilitate the spawning flows under the AM example), will affect the Middle Rio Grande at the system scale. Habitat restoration projects and development of silvery minnow refugia occur at a site-specific scale. As a combined AM experiment, species' responses to these flow and habitat actions will largely have to be assessed on a reach-by-reach basis to speed and expand the learning that can occur. Spatial and temporal contrasts between reaches will provide quicker and more direct evaluation of species responses, more data for modeling input, and greater opportunities for exploring differences in the design of restoration projects and the ability to provide habitat under varying hydrological conditions.

Figure 20 and the associated notes in Box 2 provide a sample flowchart of activities for implementation of these flow and habitat actions. Flow and habitat actions can share an action diagram due to the current nature of the channel and limited flexibility in water releases. Most flow actions will be based on river flows as dictated by the conditions of the water year, with some tweaking via the Cochiti deviation and other actions. Channel rehabilitation actions will have to be designed and constructed in a way to take advantage of a variety of water conditions and not with the expectation that managed or natural flows alone can create and/or maintain species habitat. Figure 20 is a draft diagram and can be modified as more is learned about the relationship between water, habitat, and species response and the suite of actions available to the Program.

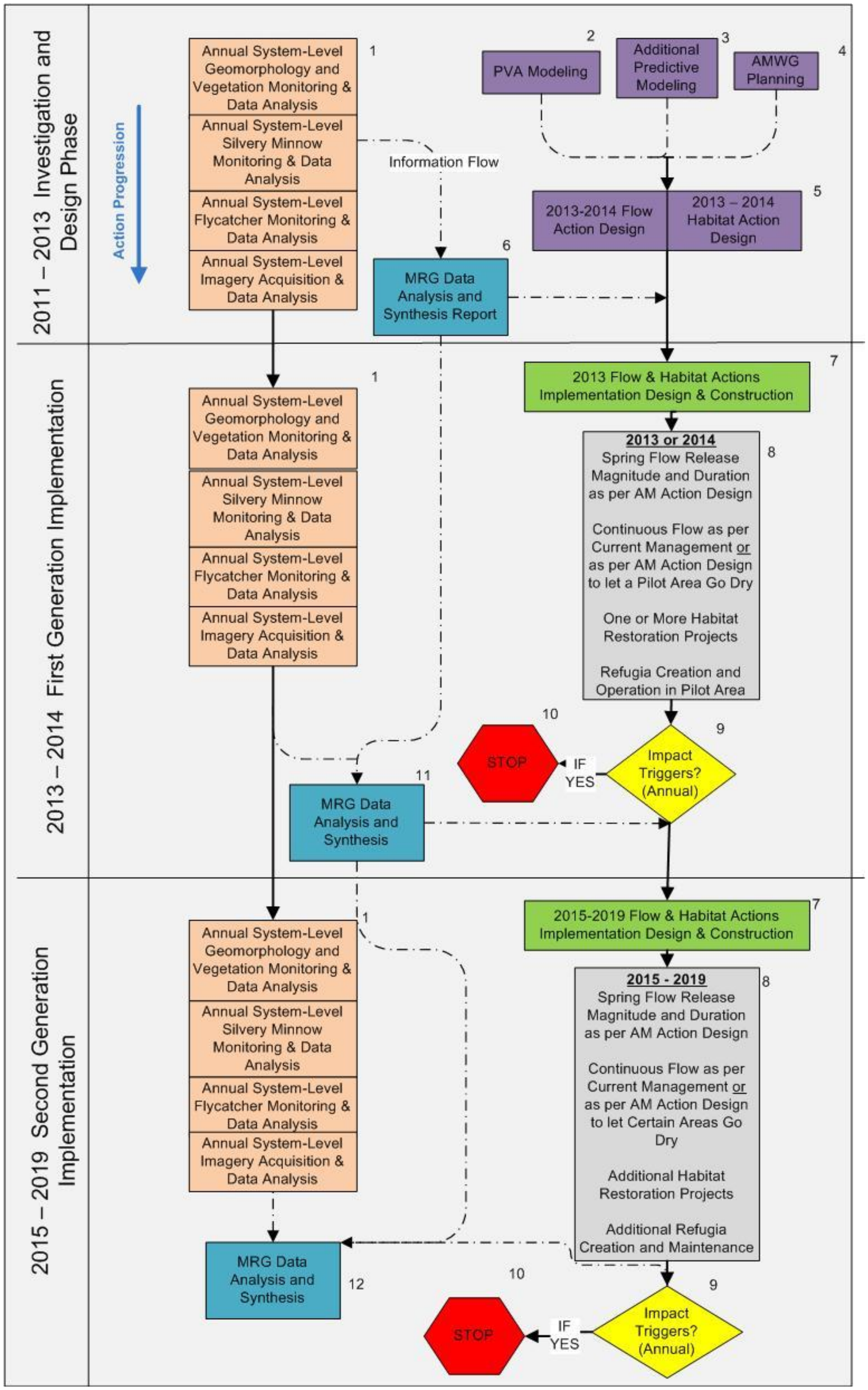



**Figure 20.** Sample implementation flowchart for the activities in the AM example from Section 2.

**Box 2.** Explanation of the steps in the implementation flowchart for the activities in the AM example.

1. Compilation of baseline data as well as system-level effectiveness and validation monitoring and data analysis. Monitoring will be systematic observational study through time and will be implemented by Program staff, partners, or contractors based on Program-established protocols. Geomorphology and vegetation monitoring should be based on a series of constant and rotating anchor points along the entire Middle Rio Grande. Data collection includes topographic data, material sampling, green line elevation, vegetation species occurrence, percent cover by species, etc. This can be paired with acquisition of annual aerial photography and LiDAR data to serve as a primary data source for evaluating the Program's ability to create and/or maintain habitat on a system scale. Silvery minnow monitoring should focus on the most significant performance measures related to population viability and agreed-upon priority hypotheses for the Program. Flycatcher monitoring can continue largely as the current BOR annual effort. Monitoring protocols should include both species and habitat data of relevance. Annual monitoring reports with Program-requested data analyses should be generated and made available to Program staff and partners on an established timeline.
2. Complete ongoing PVA modeling efforts. Unify models to generate commonly-understood output.
3. Consider additional modeling efforts (e.g. development of simple Excel tools) to match potential habitat creation/maintenance outcomes with expected species response. When combined with the final PVA model, this will allow the Program to predict what silvery minnows and flycatchers might do in response to particular habitat or flow actions and then compare these predictions to real data collected through monitoring protocols.
4. The AM technical group (e.g., a new AM Work Group or however the Program assigns the AM 'technical group' roles described in the Introduction) should establish minimum design criteria for habitat projects (what is silvery minnow and flycatcher "habitat"), and think through the best experimental design (spatial and temporal contrasts, what river reaches to work in and when, type of habitat restoration projects, flow management actions, etc.).
5. The AM technical group, in conjunction with other Program Work Groups, should develop conceptual designs for how to put flow and habitat restoration actions on the ground. This includes temporal and spatial contrast, timing in the first phase of implementation, the plan for monitoring and evaluation, and how the results will be synthesized and reported. This may include initiation of feasibility studies or other tools to specify and rank alternatives and evaluate potential impacts (on irrigation infrastructure, water supply, etc.). Existing Analysis and Recommendations reports already complete for some sub-reaches may be helpful as well.
6. In this phase, the Program should complete retrospective analyses of existing data and combine it with new data collected under annual monitoring protocols to answer any key questions and help to screen action alternatives, monitoring and evaluation techniques, and refine critical uncertainties that should be guiding overall AM implementation. This first "Synthesis Report" should be written in a way that pulls together all existing information, relates it to critical uncertainties, and can be transmitted to and translated for the Executive Committee.
7. Development of integrated construction, monitoring, and assessment design for the first generation implementation of flow and habitat restoration actions. Impact triggers will be established as part of the monitoring and evaluation portion of the design effort and analysis of monitoring data will be conducted annually and compared to impact triggers to determine if negative impacts are occurring.
8. First- and second-generation management actions to test the relationships and expected outcomes relevant to silvery minnow and flycatcher hypotheses.
9. Determine whether or not annual analyses of monitoring data indicate that an impact trigger has been surpassed. 'Impact triggers' are thresholds for certain performance measures utilized to assist in identifying potential negative effects of management actions on adjacent property owners. These triggers can be used to help determine if a management action should be stopped or modified.
10. Suspend flow releases and any associated actions tied to negative impact triggers. Mitigate and revise operations to avoid future impacts. If mitigation is not possible, the management action(s) will end.
11. Analysis at this stage will include annual analysis of monitoring data but also a synthesis of data collected through annual monitoring as well as action-specific monitoring. Results of this effort will help to determine action design, monitoring, and assessment in the next phase.
12. This version of the Synthesis Report will encapsulate several years of monitoring data and evaluation and will be aimed at an overall performance evaluation of this set of Program actions in terms of species responses.

## 3.2 Project Oversight, Management, and Reporting

An example of AM Plan implementation responsibilities and a general implementation schedule for preparing for the first phase of management actions is presented in Figure 21. Under this example:

- Certain actions such as the Cochiti deviation and refugia maintenance may occur in Year 1 as other projects are developed and administrative processes are completed. Special attention should be paid to how actions such as these are monitored so that data can be evaluated later in conjunction with data from implementation of a broader suite of actions.
- AM technical group planning efforts for actions in 2013 and beyond should begin immediately. The scientific and technical details of that planning effort must feed into the project and administrative oversight processes described in the green circle.
- The U.S. Fish and Wildlife Service and Bureau of Reclamation will continue to make water management decisions each year. In the future, those decisions should link to management action needs of the AM Plan to ensure all water commitments are being met while allowing for some flexibility in water management related to testing species responses to management actions.
- The Coordination Committee should begin to evaluate potential properties (sites) for habitat restoration projects and build management agreements or an acquisition process to ensure those properties are available for consideration in the design process.
- Silvery minnow and flycatcher ESA section 10a permits need to be secured from the U.S. Fish and Wildlife Service by qualified personnel to ensure necessary data can be collected. The permitting process may take up to 6 months. For example, this includes permits for tagging, capturing, collecting, and handling silvery minnow and surveying and banding flycatchers.
- The Program should begin to build "out-year budgets"[8] and coordinate with the Bureau of Reclamation on future federal funding requests to ensure funds are available for implementation, monitoring, evaluation, land and water acquisition (if necessary), and staffing in the long term.
- The Program should establish an independent science review panel now, comprised of areas of expertise most relevant and important to the Program. At this stage, the independent science panel can help assess the results of retrospective analyses, approaches to implementing the AM Plan, and provide feedback on experimental design.
- Fieldwork will generally start in the spring of each year and continue into early fall. Monitoring reports and data analysis should be completed as quickly as possible at the conclusion of fieldwork to ensure as much lead time as possible for Program evaluation.
- The Program should conduct an annual AM Plan symposium each winter, bringing together Program staff, partners, contractors, the independent science panel, and decision-makers to discuss the results of annual data evaluation, the progress of implementation, and an assessment of success/failure and next steps (including what should be adjusted based on what has been learned – see Section 6).
- Results of annual monitoring should be used as input into Program models to refine those models. This is also an opportunity to assess the accuracy and precision of data collection and to consider additional monitoring, research, or methodology changes that need to be implemented.

This example provides a draft roadmap through time-sensitive actions that must be accomplished for implementation to proceed smoothly, both in terms of starting up and from year to year. As the figure and description suggest, successful implementation will require a focused effort on coordination and

[8] Out-year budgeting means budgeting long-term, years beyond the current fiscal year. Generally these are estimates. For example, the Platte River Program has budget estimates through 2019.

communication, and specific scientific and technical activities outlined in Figure 20 will have to be merged with the activities in the figure below to enable efficient administration, oversight, and synthesis.

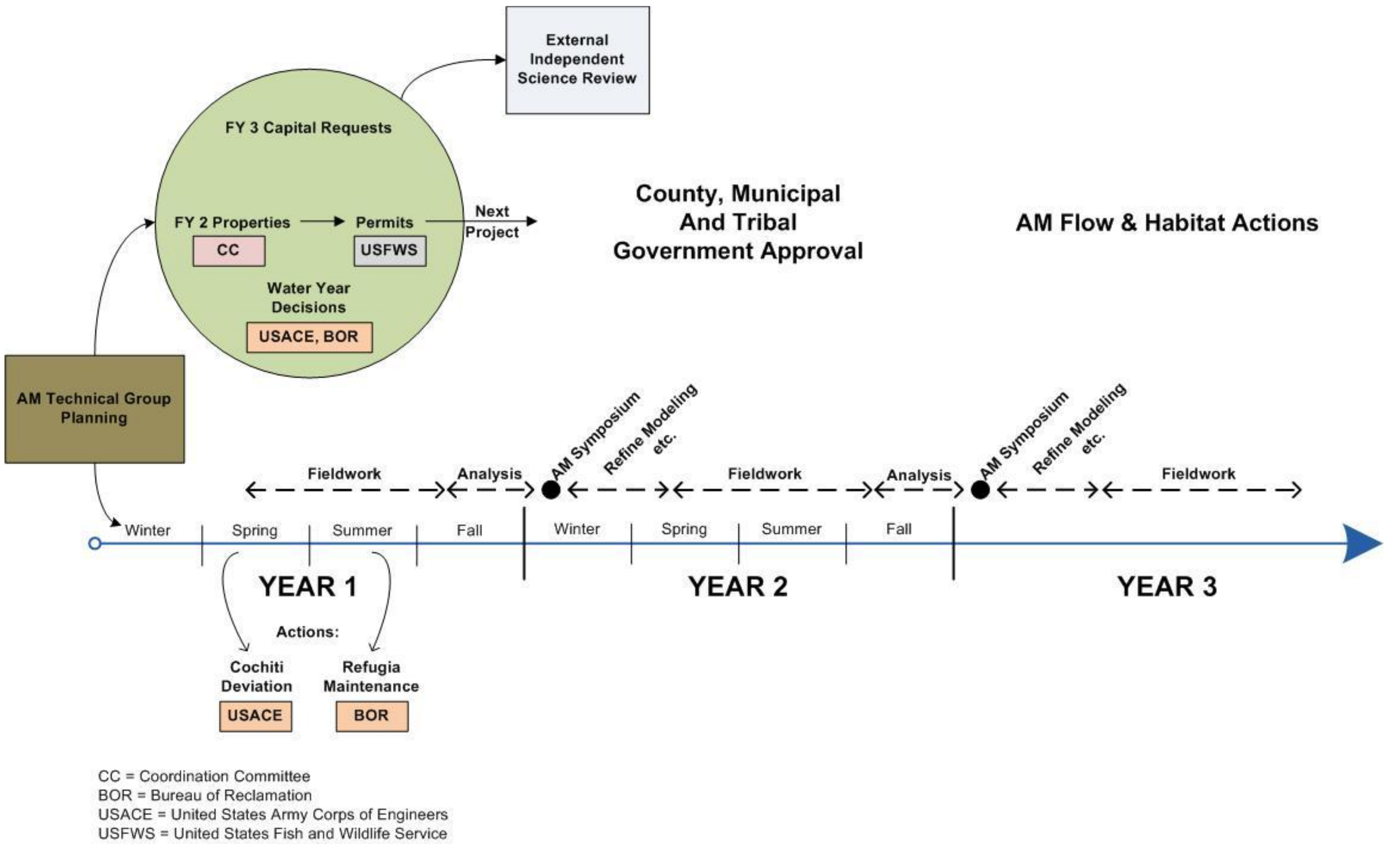



**Figure 21.** Draft AM implementation and oversight flowchart for the Program.

## 3.3 Implementation Guidance from another River Recovery Program

Each program will have a unique approach to implementation based on its decision-making structure, staffing structure, priority projects, and other considerations. However, certain principles apply broadly and can help the MRG Program develop a clear path for project implementation, application of associated monitoring and research, and data analysis and synthesis.

The Platte River Recovery Implementation Program recently completed a full Implementation Plan for its Adaptive Management Plan (PRRIP, 2006). As guidance for the Program, a few key points from the Platte River Implementation Plan are provided below:

***Implementation Planning Prerequisites***

- Critical uncertainties to be addressed (hypotheses)
- Identification of necessary research, monitoring and management experiments at a conceptual level
- Implementation period of the AM Plan

- Water, land, and cash contributions from signatories; stakeholder roles, responsibilities, and decision-making process

***Implementation Plan Development***

- Assign a staff person to champion the planning effort and give him or her a significant block of time to work through the progression of actions/activities necessary to implement AM. This champion should be someone who has a general knowledge of target species ecology and important physical processes (hydrology and hydraulics) as well as an understanding of how information is (or could be) integrated across disciplines to address uncertainties. Project planning/management experience is also helpful in identifying appropriate timelines for project planning and implementation.
- Consider conforming actions/activities to the steps of the AM cycle. This ensures that activities are not orphaned from the AM process. If activities do not conform to a step of the AM cycle, they may not be necessary or useful.
- Directed research and investigations may be necessary as extensions to the assessment step of the AM cycle. They often do not appear to fit neatly into an AM cycle step but are necessary to generate information/data that are needed to focus management experiment implementation design.
- When developing and organizing implementation actions/activities, it is useful to think in terms of both action progressions and information flow. Identifying information flow between actions and over time provides a reminder that data collection and synthesis needs to be consistent and compatible across disciplines and between projects.
- Focus on identifying actions/activities that will be undertaken as part of the first AM cycle. Provide action/activity and schedule placeholders for subsequent cycles but do not worry about identifying specific objectives as the outcomes from the first management experiment cycle will drive the objectives of subsequent cycles. However, it is important to at least include placeholders as it conveys the expectation that management actions will be adjusted and learning will continue into the future.
- Explicitly identify points during implementation where all research, monitoring, and management experiment performance data will be aggregated and synthesized to determine progress toward addressing critical management uncertainties. This reinforces the expectation that data will be synthesized and given to policymakers in support of high-level decision-making.
- Explicitly identify critical decision points where different research or management experiment outcomes will alter subsequent actions and identify the possible subsequent action/activity progressions. Identifying future actions under a range of possible outcomes can reduce reluctance to draw conclusions and make decisions.
- Keep the plan as simple as possible and provide links (or otherwise direct readers) to other documents that contain more detailed information about objectives, uncertainties, and actions/activities. Implementation plans are intended to be living documents that are regularly updated. Flow charts with links to protocols, reports and other documents are easily updated and provide the reader a way to drill down into more detailed information if they choose to do so.

**What this section should contain in AM Plan Version 2:**

Implementation details for the AM design specified in Section 2 of AM Plan Version 2, using guidance from the examples provided above.

# 4.0 AM Cycle Step 4 – Monitor

Key outputs from the Assess Step in the AM cycle, including measurable objectives, critical uncertainties, hypotheses, and the AM actions selected to test these hypotheses, together with the results of the Design Step in the AM cycle, will all determine what is monitored, when monitoring occurs, where monitoring occurs, how monitoring is undertaken, and the type and role of focused investigations.

Monitoring is vital for providing important information to MRG decision-makers. Determining the biological response of the silvery minnow and flycatcher to management actions should be at the heart of the monitoring design, and is the need-to-know information managers require to improve management decisions. This requires statistically valid monitoring data collected in a well-focused approach to evaluate Program critical uncertainties and hypotheses related to the performance of management actions. Monitoring must document trends in indicators of target species and their habitats in relation to measured variables (or covariates) that can impact those trends. This is essential both for accurately assessing the status and trends of target species, and also to gain a better understanding of factors outside management control that affect those trends.

Program monitoring should be designed to provide reliable estimates of species and habitat indicators over space and time, and with sufficient accuracy and precision to inform key decisions (e.g., EPA (2006) describes a decision-driven process for determining data quality objectives). Management decisions for improving ESA species status and making progress toward recovery requires reliable information on population status and trends, and flow/habitat/hatchery management decisions require feedback on action effectiveness. Monitoring generally falls into three categories:

- **Implementation monitoring** – Monitoring to determine if management actions are being implemented according to design requirements and standards.
- **Effectiveness monitoring** – Monitoring of physical habitat indicators to determine if management actions are achieving habitat performance criteria.
- **Validation monitoring** – Monitoring of silvery minnow and flycatcher to determine species' responses to management actions, critical cause-effect linkages between actions and species' responses, habitat conditions, and overall progress towards the Program's biological objectives.

Monitoring data can be gathered (and analyzed) at multiple spatial scales, including the entire MRG, individual reaches, mesohabitats within reaches, dry vs. wetted areas within a reach, habitat restoration areas of specific interest, and individual sampling units. The appropriate scale, and the population variables and covariates to monitor, will vary with the specific hypothesis or question being addressed (Section 1.3 and Section 1.5). This section describes a monitoring approach for two silvery minnow hypotheses from Table 6, M-1 and M-3 which could be tested trough the example spawning flow and channel rehabilitation actions described in Section 2. It also describes a monitoring approach for two flycatcher hypotheses from Table 7, F-1 and F-3, which are most closely associated with potential flycatcher responses to variations in flow magnitude and duration.

The accuracy and precision of monitoring, which provides the data that will be analyzed according to population performance measures, will have a large effect on the ability to reliably evaluate the consequences of different management actions (and to test related hypotheses) in a reasonable length of time. Thus, it is essential to have power analyses showing how many years it would take to reliably detect various levels of change in the abundance of silvery minnow and flycatcher.

All monitoring will be conducted by following detailed protocols. Each protocol should be developed by the Program, either written specifically for a certain Program need or by adopting and modifying existing protocols to ensure collected data will address the questions at hand. Each protocol should be independently peer reviewed, approved by the Executive Committee, and ultimately incorporated in final form into the AM Plan and any associated implementation work plans. Contractors or others implementing the protocols will be expected to closely follow all protocols, as well as applicable regulatory requirements (e.g., permitting).

In developing and revising sampling designs and monitoring protocols, the Program needs to assess the costs and benefits of alternative approaches, given the ultimate decisions to be made, and the analyses planned to feed those decisions. This assessment of costs and benefits (part of the process of moving from Version 1 to Version 2) should explore the tradeoffs between cost, the level of reliability in decisions, and the risks of drawing the wrong conclusions (e.g., CSMEP, 2007a; CSMEP, 2007b). In making their approvals of specific monitoring protocols, the Executive Committee needs to be presented with a summary of the above assessment and consider several criteria: the costs and benefits of alternative approaches; how the monitoring data will be analyzed to feed decisions; and the risks of decision errors. Decision errors include, for example, concluding that a set of actions are sufficient to ensure survival and recovery when in fact they are not (a conservation and potential legal risk), as well as concluding that a set of actions are insufficient for survival and recovery when in fact they are (an economic risk).

A substantial amount of Program monitoring is currently underway. It is essential that past monitoring data be evaluated for its ability to provide data for critical uncertainties and hypotheses, associated protocols be modified as necessary (while ensuring that long term time series are maintained), and (as described above) each existing protocol be rigorously assessed, peer reviewed and approved by the Executive Committee. Analyses of past monitoring data have been an ongoing activity in the PVA Work Group. Monitoring should use the same protocols to assess the effectiveness of all management measures, whether implemented under the AM Plan, the Long Term Plan, or the 2013 BO.

## 4.1 Silvery Minnow

Key performance measures for the silvery minnow should be monitored across a range of conditions over the MRG (Figure 22), using contrasts over space and time to help evaluate the outcomes of testing key hypotheses (Table 6).

Table 16 extracts two of the hypotheses from Table 6, M-1 and M-3, which serve to guide the discussion of monitoring examples in this section and evaluation examples in Section 5. Hypotheses M-1 and M-3 would be tested through the following actions, previously discussed in Section 2 on design:

1. Create contrasts in spawning peak flow and magnitudes through the use of both natural year to year variation in flows (passive AM) and deliberate tweaking of the hydrograph (active AM).

2. Implement substantial habitat restoration to allow more wetted area during springtime spawning period, under a wide range of flows, promoting greater levels of overbank flooding, higher spawning success, and retaining eggs and larval fish near their spawning locations.

These two sets of actions need to be designed to operate in harmony across a range of water years.

**Table 16.** Two rows from Table 6 to illustrate monitoring design.

| Overarching critical uncertainty | **Broad hypothesis** | Potential management implications | What would be compelling evidence one way or the other to alter management? | How might this be tested? | Challenges in generating enough spatial / temporal contrast | Challenges in obtaining enough precision in monitoring |
|---|---|---|---|---|---|---|
| What magnitude and duration of flows are required for successful silvery minnow spawning and recruitment, and population viability? | **M-1:** Spring spawning peak of at least W cfs at days X1 to X2, followed by maintenance of Y cfs for Z days after spawning for successful silvery minnow recruitment.<br>Alternative hypotheses have different values for W and Y (e.g., peak spawning flows of 3000 cfs), X1 and X2 (hydrograph driven vs. fixed dates), and Z (e.g., 30 days).<br>Hypotheses M-1 and M-3 are closely linked, as flow and habitat actions need to be designed to work together. | Consider modifying volume and timing of flows from current rules expressed in 2003 BO.<br>Use Cochiti deviation to create desired contrasts. | Increased area of floodplain inundation by reach, and evidence of sufficient contribution of those areas to species spawning, recruitment, and population viability.<br>Larger numbers of eggs/larvae.<br>Larger numbers of young from monthly catch per unit effort (CPUE) monitoring.<br>Higher October CPUEs than years of low flow. | Cochiti Deviation.<br>Establish sample design to monitor and evaluate flow, timing, floodplain inundation, egg/larval abundance, Oct CPUE (by reach; during and after peak flow); analysis of all years with spring hydrograph and silvery minnow CPUE. | Looking at Oct CPUE alone does not account for intermediate effects on minnow survival.<br>Must monitor before/after flow, and monthly to follow survival (CPUE already being done 9 months of the year). | Need robust sampling design to account for sampling and resource variability in CPUE.<br>If not already completed, perform power analysis to determine sample strategy and number of samples necessary to minimize variability. |
| Is an interconnected floodplain necessary for successful minnow spawning and recruitment? | **M-3:** In the Middle Rio Grande, silvery minnow do/do not require the channel to be connected to its floodplain for successful spawning, larval survival to become juveniles, and/or recruitment of young of year to age 1. | Outcome of hypothesis test affects the cost-effectiveness of different approaches for creating & maintaining each type of habitat, and appropriate flows associated with revised channel form to overcome channel incision and improve lateral connectivity. | Suitable in-channel and off-channel spawning habitat available in at least 5 different locations for 5 spawning seasons, and then at 3 or more of the locations, a majority of successful spawning is documented in the same type of habitat each of the 5 spawning seasons<br>Convincing hypothesis tests from statistical analyses of monitoring data (e.g., higher fall CPUE index in reaches and years where the channel was connected to the floodplain for more than X days). | Flow management to ensure suitable in-channel spawning habitat is available at each of 5 locations for all 5 years.<br>Mechanically create off-channel spawning habitat at 5 sites that will be wetted w/ rage of flows expected during 5 spawning seasons.<br>Monitor area of suitable habitat over time and space, and use as covariate to explain variation in recruitment. | Finding enough sites where available flows would wet off-channel sites long enough.<br>Influence of distinct river reaches and within-reach habitats on overall minnow population dynamics.<br>Distinguishing habitat contributions to spawning and minnow recruitment. | Minnow sampling – relating sampling numbers to total numbers at any given site; and knowing when spawning occurs such that capture location reflects spawning location. |

There are four general categories of performance measures which should receive primary attention:

1. *The area of suitable habitats over time*. The area (and in some cases volume) of suitable habitats for silvery minnow provides a useful measure of the effectiveness of efforts to provide overbank flows for spawning (M-1) and to rehabilitate the channel (M-3). Aerial orthophotos during peak spawning flows may be a simple and accurate way to estimate the area of wetted habitats in each reach. Frequent orthophotographs of priority habitats during the peak spawning period can be used to build hydraulic model predictions of wetted area; once these models are well tested for priority habitats, their outputs can be used to generate this performance measure. Defining the attributes of suitable habitat generally requires confirmatory estimates of habitat utilization, taking into account the available density of animals to colonize such habitat, and is not a trivial effort (see #3 below). Reviews of past studies (e.g., Dudley and Platania, 1997) can help to define the attributes of suitable habitat. However, animals may utilize different habitats than what has been observed previously, and the Program's definition of suitable habitat in the MRG may well evolve over time, as it has in the Platte River Program (ISAC, 2011). Improvements in the area of suitable habitat are a necessary but not sufficient sign of action effectiveness. First, newly created habitats may also be used by species that compete with silvery minnow (e.g., common carp (*Cyprinus carpio*), Hatch and Gonzales, 2008).[9] Second, improved recruitment at a given level of flow (e.g., Figure 25 in Section 5) is a more meaningful measure of the ultimate effectiveness of combined flow and habitat actions.

2. *CPUE index of population density*. It is important to continue the catch per unit effort (CPUE) index of silvery minnow density (see Figure 22 for sampling locations and Dudley and Platania (2008), as well as earlier reports by ASIR, for more details). This index provides a measure of relative (not absolute) abundance across both space (Albuquerque, Isleta, San Acacia reaches) and time (monthly), which is essential to assessing population status and trends, estimating recruitment, developing PVA models, and helping to evaluate hypotheses M-1 and M-3 (as well as other hypotheses in Table 6). There are occasional very high outliers in these density estimates, and replicate sampling in 2009 showed a high level of variation (see Figures 3 and 4 in Goodman (2011), presumably based on work by ASIR though no reference is provided). It is important to ensure continuity of the long-term time series with consistent methods, but perhaps other features could be added to the sampling design or monitoring protocols to improve accuracy and precision (e.g., estimating density in terms of the number per unit volume as well as the number per unit area). Efforts are currently underway to develop a numerical population estimate for silvery minnow to supplement the CPUE density index, and to evaluate the gear types used for fish sampling through a gear evaluation study funded by the Program.

3. *Relatively precise estimates of the abundance, distribution and/or movement of tagged fish to test the effectiveness of actions related to flow and channel rehabilitation (hypotheses M-1 and M-3).* This monitoring is required to determine silvery minnow utilization of different spawning habitats, particularly in the vicinity of areas subject to channel rehabilitation, relative to nearby reference areas. Understanding the effects on habitat utilization, survival and minnow recruitment of different flow patterns (i.e., changes in spawning flow magnitude and duration to test hypothesis M-1) will provide feedback the hydrograph attributes that are required for successful utilization and recruitment in each reach.

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[9] The Program might also consider exploring hypotheses that consider the role of non-native fishes in the decline of silvery minnow. Hoagstrom et al. (2010) report that *a non-native population of plains minnow Hybognathus placitus in the Pecos River, New Mexico, USA, replaced the endemic, ecologically similar Rio Grande silvery minnow Hybognathus amarus in less than 10 years*.

For testing hypotheses M-1 and M-3 it is worth considering using tagged fish, which can be deliberately placed in the vicinity of particular channel rehabilitation sites, as well as in reference or control areas, to monitor habitat utilization, survival, and movement. Given the longevity of the silvery minnow, these would likely need to be early age-1 fish stocked soon after Jan 1 or young-of-year fish stocked in the year hatched. Hatchery fish stocked prior to the spring flow peak for purposes of tracking their spawning that year will need to be reared under similar photoperiod and temperature conditions as occur in the river so that gonadal development mimics wild fish. Alternatively, young-of-year fish could be stocked in their first fall (age-0) and sexually mature while overwintering in the river. This will alleviate the need to mimic environmental conditions in the hatchery, but the tradeoff is it increases mortality and emigration the longer they are in the river before spawning. Which option is implemented depends on how many fish can be propagated and held in hatcheries and then tagged before releasing. If knowledge is lacking on the survival of young-of-year silvery minnow stocked in the fall, both approaches could be tried as an experiment to examine differential survival and spawning success of each.

VIE tags have been widely used in the MRG hatchery program, and have the benefit of large sample sizes which improve precision. Other tag technologies (e.g., PIT-tags, shown by Remshardt et al. (2008) as feasible, and being implemented to evaluate movement of silvery minnow) have the benefits that individual fish can be tracked should it be necessary to know individual versus group responses. PIT-tags also cost more per tagged fish than the standard VIE tags currently applied to hatchery fish. The cost-benefit tradeoffs associated with various tagging technologies (including VIE, immersion, coded wire, and PIT-tags) need to be carefully assessed for these two hypotheses, building on past evaluations for silvery minnow and other similar small fish

4. *Covariates which are helpful in explaining biological responses.* Modeling floodplain wetted area by reach over a range of river discharges/stages is needed to test hypothesis M3. In addition to floodplain and in-channel wetted areas, physical variables such as water temperature (including cumulative degree days)[10], turbidity, depth, velocity, and flow can help to refine our understanding of the triggers for silvery minnow movement and spawning. In addition to these variables, oxygen and other water quality constituents may help to explain variation in survival through other life history stages.

[10] It is becoming much more informative to measure cumulative thermal units as it is a major factor dictating when riverine fishes spawn (it strongly relates to rate of gonadal development) and is much more accurate than just stream temperature. Recording thermistors make it easy to estimate cumulative thermal units (Falke et al., 2010).

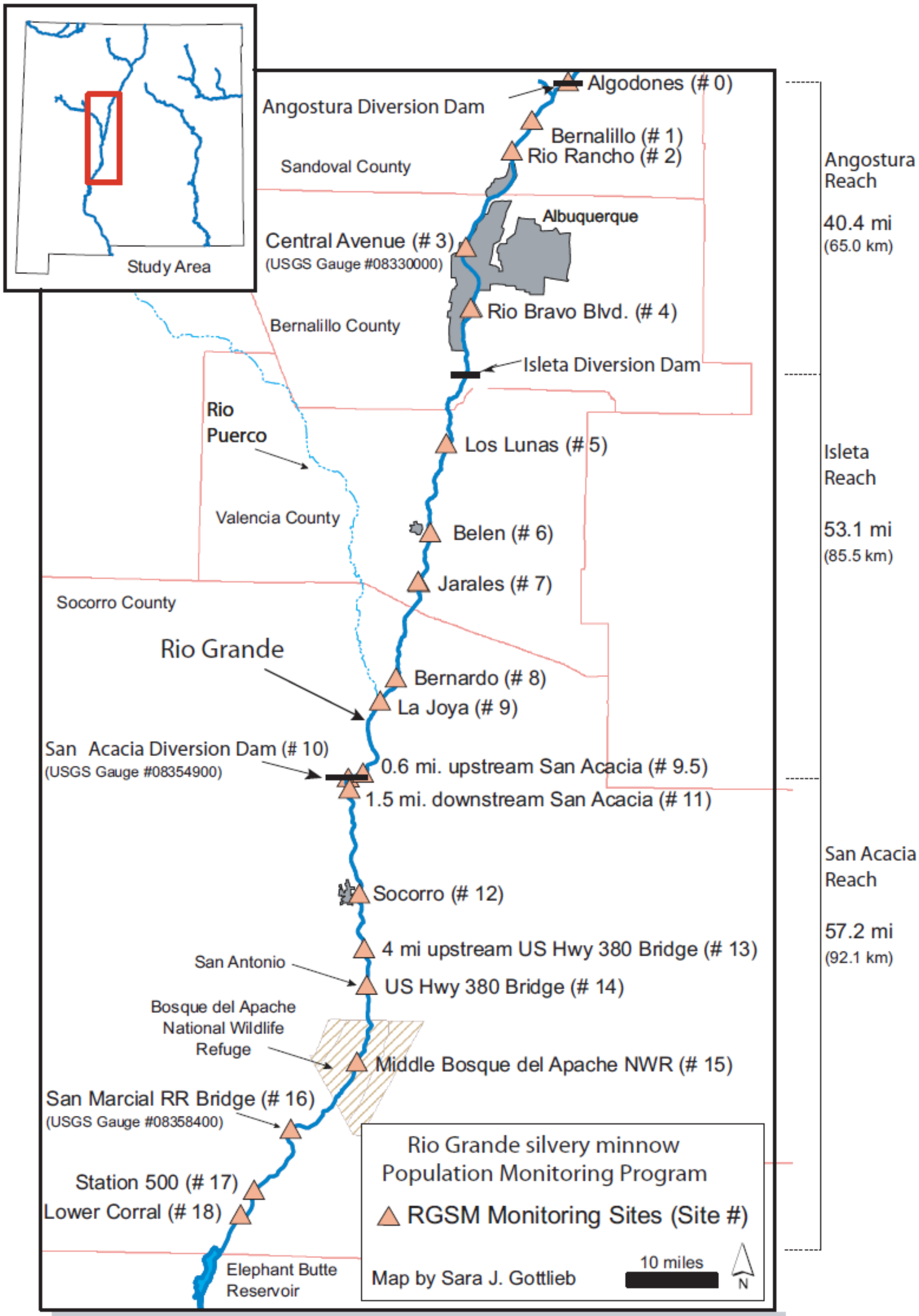


**Figure 22.** Map of minnow sampling localities (numbered) for the December 2006 to October 2007 Rio Grande silvery minnow population monitoring program. Source: Dudley and Platania (2008).

## 4.2 Flycatcher

Monitoring of flycatchers is designed to annually gather information on flycatcher abundance, use, and productivity on MRG habitat territories as well as characteristics of that habitat. Specific monitoring objectives include:

- Contribute to baseline data regarding the population status, distribution, and habitat requirements of the flycatcher in the MRG basin.
- Monitor flycatcher nests to determine productivity, parasitism and predation rates, population recruitment, and identify limiting factors.
- Determine relationships between flycatcher nesting and hydrologic parameters.
- Assess habitat availability and utilization by breeding flycatchers.

Currently, this monitoring is conducted annually by the Bureau of Reclamation (Moore and Ahlers, 2011) and includes the area from Los Lunas to Elephant Butte Reservoir **(**Figure 23**)**. Specific nest monitoring methodologies are implemented according to the Southwestern Willow Flycatcher Nest Monitoring Protocol developed by the Arizona Game and Fish Department (Rourke et al., 1999). Hydrology monitoring occurred in 2004-2010 through 19 hydrostations in the headwaters of Elephant Butte Reservoir and 4 hydrostations (only 2 now in operation) in newly occupied habitat in 2008 (Moore and Ahlers, 2011). Habitat metrics have been measured over time through various studies including vegetation quantification, a habitat suitability model, aerial photography, and photostations (Moore and Ahlers, 2011).

Key performance measures for the flycatcher should be monitored across a range of conditions over the study area (Figure 23), using contrasts over space and time to help evaluate the outcomes of testing critical hypotheses (Table 7).

Table 17 extracts two of the hypotheses from Table 7, F-1 and F-3, which serves to guide the discussion of monitoring examples (this section) and evaluation examples (section 5). Hypotheses F-1 and F-3 would be tested through the following actions, previously discussed in Section 2 on design:

1. Create contrasts in peak flow and magnitudes through the use of both natural year to year variation in flows (passive AM) and deliberate tweaking of the hydrograph (active AM).

2. Implement flycatcher nesting habitat restoration near the largest existing territories (focus on areas just north of Elephant Butte) to potentially provide a large range of nesting habitat and begin to re-distribute the Elephant Butte population further north along the Middle Rio Grande.

These two sets of actions need to be designed to operate in harmony across a range of water years.

**Table 17.** Two rows from Table 7 to illustrate monitoring design.

| Overarching critical uncertainty | **Broad hypothesis** | Potential management implications | What would be compelling evidence one way or the other to alter management? | How might this be tested? | Challenges in generating enough spatial / temporal contrast | Challenges in obtaining enough precision in monitoring |
|---|---|---|---|---|---|---|
| Is flow augmentation for wetted breeding habitat needed to achieve flycatcher recovery? Exactly what flows are needed for overbank flooding in specific areas of potentially suitable habitat? | **F-1:** Flow augmentation *is/is not* required to create/maintain wetted breeding habitat for the flycatcher. | Consider modifying volume and timing of flows. | Positive trend in nesting and recruitment in areas with X wetted habitat characteristics (e.g., increased fledge ratio every year for 5 years at wetted habitat). | Minimum of 5 habitat restoration sites in more than one river reach.<br>Wetted by Program or natural flows.<br>Vegetation classification for finding suitable habitat and flow for determining river velocity for flooding suitable areas (or other models). | Limited extent of flycatcher utilization of MRG.<br>Length of time for productivity response.<br>Ability to manage flow across entire MRG – determining exact flow necessary for overbank flooding, flycatcher recruitment and nest success. | Determining factors that influence successful production.<br>Need to scale up bird monitoring efforts.<br>Distinguishing the role of tamarisk vs. native vegetation in supporting nesting territories and nest success. |
| Will created/restored habitat adjacent to existing territories be utilized? | **F-3:** Creation/restoration of habitat adjacent to existing territories *will/will not* be utilized. | Mechanical and/or flow-based habitat modification. | Establishment of nesting territories in adjacent habitat, and nest success once restored habitat is mature and suitable. | Restoration and control sites in close proximity to existing territories. | Extent of flycatcher utilization of MRG.<br>Length of time for productivity response. | Long term effort that needs consistency in monitoring and evaluation of suitable habitat. |

To address these critical uncertainties and hypotheses, the following performance measures should be measured and evaluated on an annual basis using consistent protocols:

- Habitat performance measures
  - Acres of suitable[11] nesting habitat (wet versus dry)
  - Distance of habitat to water
  - Composition of the habitat soil
  - Number of territories supported by the habitat (tied to aspects such as the prey base supported by the habitat)
  - Relationship of river channel to territories
- A full habitat availability analysis (based on aerial photos, LiDAR, and habitat data) at three scales
  - All possible habitat (includes all available habitat Program lands, partner lands, and private land if possible
  - Habitat meeting Program suitability criteria
  - Habitat actually utilized by flycatchers

[11] Use of the term "suitable" assumes that the Program concurs with the definition of suitable habitat for the flycatcher as defined in the flycatcher Recovery Plan and the Primary Constituent Elements (PCEs) of flycatcher critical habitat.

- Population performance measures
  - # of resident flycatchers
  - Nest success
  - Fledge ratio
  - Nest location (note: specific nest location information is typically protected)
- Account for dynamic nature of flycatcher habitat – it is dynamic over time; change of composition and vegetative succession over time is important; include not just habitat presently available, but when that habitat will no longer serve as flycatcher habitat and what areas are now maturing into suitable habitat (and when).


* Please note: The length of the survey site reaches from North to South along the Rio are exact, whereas the width from West to East is exaggerated for viewing purposes. Most survey sites are within 1 mile (either East or West) of the Rio Grande. Gray shading in territory boxes represent reaches funded by BOR Albuquerque Area Office and yellow shading represents reaches funded by MRG Endangered Species Collaborative Program.

**Figure 23.** General location of BOR flycatcher surveys in 2010. Source: Moore and Ahlers (2011).

To guide this monitoring effort, the Program should develop a specific monitoring protocol that encompasses the full Middle Rio Grande Program area, to ensure consistent, accurate and precise collection of all bird- and habitat-related metrics from year to year. Methodologies will likely include a mix of imagery acquisition, nest monitoring, acquisition of specific habitat measurements at nest and territory locations, and calculation of population indicators such as fledge ratios. The Program should also consider acquiring permit authorization for qualified personnel to band flycatchers in the MRG to better determine flycatcher occurrence, recurrence, and movements.

## 4.3 Monitoring Responsibilities & Tasks

Monitoring will be conducted by Program staff, partners, and/or contractors based on priorities and funding availability. Field monitoring activities will closely follow Program-approved protocols. Annual implementation of a monitoring protocol will be followed by submission of an annual monitoring report from the implementing entity that will include an explanation of methodology, raw results, and data analysis as directed by the Program. Critical to continued learning are annual symposia at which analyses and evaluations of monitoring data are presented, organized around the critical uncertainties and hypotheses.

## 4.4 Data Issues

The Program is currently developing a comprehensive database management system. When completed, the Program's database management system should serve as central storage for all Program data and enable users to store, modify, and extract information as needed – with the appropriate protections for sensitive data such as specific flycatcher locations. This type of system will allow rigorous quality assurance/quality control of all data, will standardize data collection and reporting, and can be utilized to generate basic analyses quickly and with repetition during cycles of implementation. The system should be constructed in a way to safely store Program data in the long term and ensure more complete and accurate annual reports.

**What this section should contain in AM Plan Version 2:**

Once critical uncertainties, hypotheses and AM actions are selected, this section should include details on the following:

- What monitoring protocols will be used (protocols should be approved by the Program, peer reviewed, and included in the final AM Plan)
- What measurement accuracy and precision of performance measures are attainable with the protocols
- What methods will be used for data management, analysis and reporting
- What the size of river and species' responses to management actions are expected to be, including the detectability and expected timing of responses

# 5.0 AM Cycle Step 5 – Evaluate

Evaluation of hypothesis-testing actions will be used to build a path from data to management decision-making. Annual analysis and reporting, and annual and longer-term synthesis of monitoring data will provide the information needed to assess performance and help decision-makers close the AM cycle and adjust on-going management actions. Evaluation includes both analysis of collected data and synthesis of numerous analyses to draw more comprehensive inferences regarding critical uncertainties related to management actions and the associated responses of the silvery minnow and the flycatcher.

It is vital that alternative actions to test hypotheses be designed to deliberately create contrasting conditions or use natural variability in hydrologic and habitat conditions, and that the responses of the silvery minnow and flycatcher are monitored across that variation. The evaluation strategy would be to use those contrasting conditions across both space (i.e., Cochiti, Albuquerque, Isleta and San Acacia reaches, as well as finer scale examinations of particular habitat areas) and time (i.e., across water years and seasonal differences within years) to estimate various performance measures and parameters that reflect silvery minnow and flycatcher responses to AM actions, and to evaluate the outcomes of tests of specific hypotheses related to critical uncertainties as outlined in this AM Plan (Table 6, Table 7 and Table 8). The critical uncertainties are:

1. How silvery minnow abundance, reproduction, survival and spatial distribution varies as a function of various hydrological and habitat parameters (including wetted habitat area during spawning and rearing periods, spring spawning peak flows, summer flows, flows during fall and winter, and the coincidence in timing of spawning with water temperatures and hydrologic peaks)
2. The form of the spawning-recruitment relationship (i.e., what levels of spawning are required to maintain recruitment in different water years, and how does this relationship vary by reach?)
3. Response of the population age structure and genetic diversity to AM treatments
4. The implications of 1, 2 and 3 for estimates of the probability of extinction and probability of recovery
5. How flycatcher habitat use, nest success, fledge ratio, and nest location vary as a function of various hydrological and habitat parameters (including amount of suitable habitat available during the migratory and breeding season, distance of the habitat to water, and the persistence of wetted habitat during the nesting season)

Sections 5.1 and 5.2 present examples of mock data and graphs to illustrate the types of evaluations which could be undertaken to evaluate flow and channel rehabilitation actions (related to hypothesis M-1 and M-3 for the silvery minnow and F-1 and F-3 for the flycatcher). In Version 2 of the AM Plan, Program participants should develop a full complement of such mock data and graphs according to all hypotheses to be tested in order to guide the development of analysis and synthesis techniques.

## 5.1 Silvery Minnow

Evaluations of silvery minnow responses for hypotheses M-1 and M-3 should use a variety of methods, including empirical analyses (similar to those in Goodman (2011), but exploring a range of non-linear fits to data), detailed analyses of specific habitat restoration actions (e.g., Before-After-Control-Impact approaches), discharge-wetted floodplain area models, and simulation models such as those being used by the PVA Work Group. The evaluation approaches discussed here should be simulated (and refined) during the process of moving from Version 1 to Version 2 of the AM Plan as illustrated in Figure 8.

The contrasts of greatest interest for evaluating hypotheses M-1 and M-3 are illustrated in Table 18. The flow contrasts are likely to be largely generated by nature, with some tweaking by water managers, while the contrasts in floodplain connectivity will be determined by both current conditions and channel rehabilitation actions. Though shown in tabular form in Table 18 as though the flow actions were separate treatments, in reality the hydrograph attributes will be continuous variables monitored over multiple peak spawning periods in different years and locations. Floodplain connectivity could be a binary variable (i.e., yes/no), or measured in terms of total wetted area. The flow and channel covariates in Table 18 could be combined into a habitat performance measure of “wetted floodplain area x days” (in units of acres x days) to reflect both the area of floodplain wetted and the duration of that flooding.

**Table 18.** Contrasts which will be helpful for evaluating hypotheses M-1 and M-3 within each reach of the MRG. The flow conditions are continuous variables, not discrete classes, as shown in this simplified example.

| Flow Condition (M-1 contrasts) | | Channel Condition (M-3 contrasts) | |
|---|---|---|---|
| **Flow Magnitude** | **Flow Duration** | **Floodplain Connected at Spawning Flow?** | |
| Low | Short | yes | no |
| Low | Medium | yes | no |
| Low | Long | yes | no |
| Medium | Short | yes | no |
| Medium | Medium | yes | no |
| Medium | Long | yes | no |
| High | Short | yes | no |
| High | Medium | yes | no |
| High | Long | yes | no |

### *Graphical Approaches to Evaluation*

The monitoring data described in Section 4 could be evaluated using simple graphs to assess both action effectiveness and the relative level of support for alternative hypotheses. Hypothetical examples are shown in Figure 24.

Figure 25 (adapted from Figure 12) illustrates hypothetical outcomes which would be indicative of successful habitat restoration actions (i.e., higher levels of silvery minnow recruitment at low flows). While this graph is for all three reaches combined, one could also look at individual reaches (e.g., Figure 7 in Goodman, 2011). Similar analyses should be done for each reach.

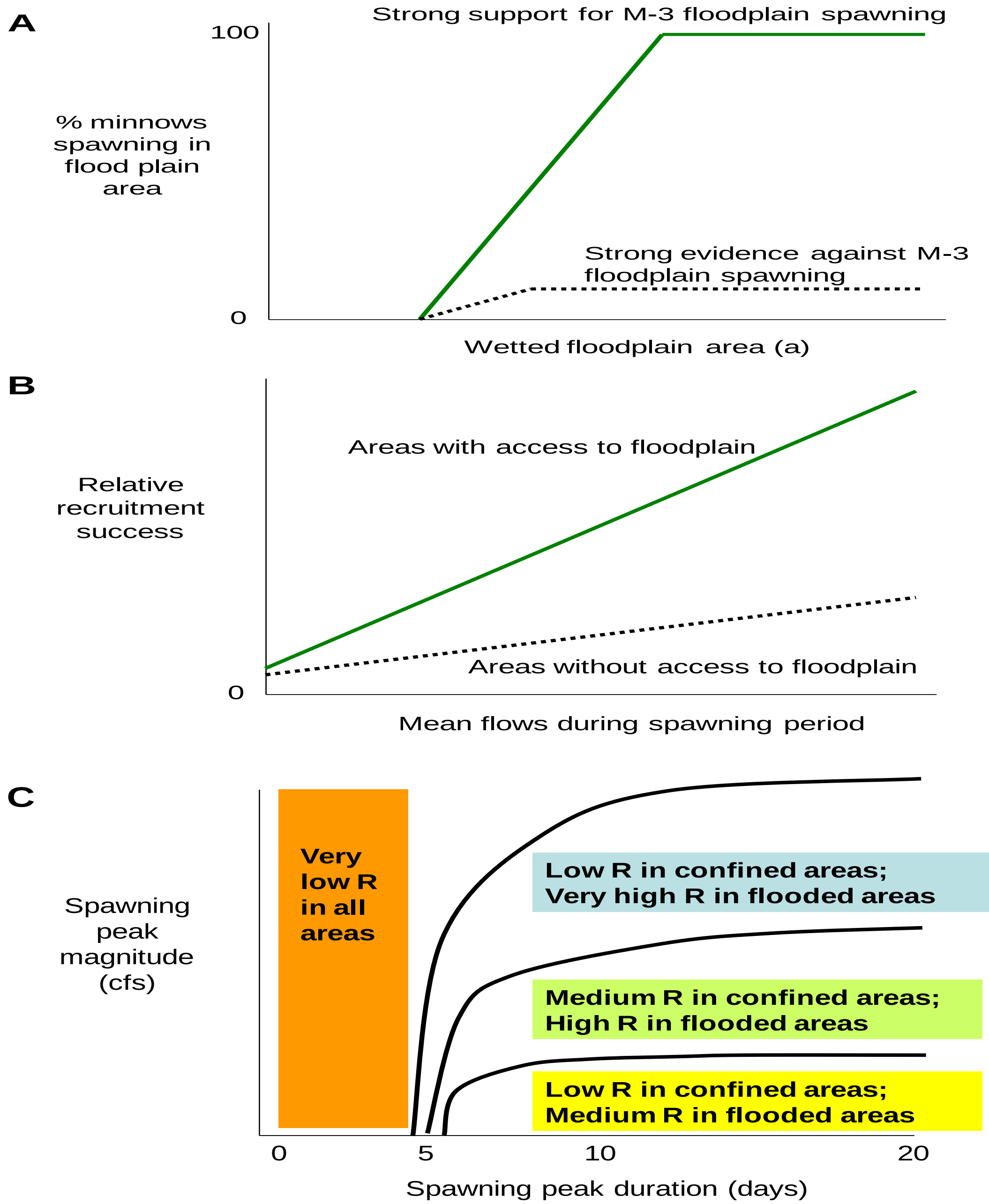


**Figure 24.** Hypothetical graphs of possible outcomes of AM actions. A. The upper solid line shows the percentage of silvery minnow spawning in floodplain areas increasing with the area of wetted floodplain area, consistent with the floodplain spawning variant of hypothesis M-3; the lower dashed line provides evidence against this variant of hypothesis M-3. Percent of minnows spawning in the floodplain area might be indexed by counting obviously gravid females or measuring total length of fish collected during inundation (e.g., > mean length of first spawning females). B. This graph shows outcomes consistent with the variant of hypothesis M-3 that recruitment is higher when minnows have access to the floodplain. If silvery minnows with access to floodplains showed the same relative level of recruitment as minnows in areas without access to floodplains (e.g., both areas followed the dashed line), that would provide evidence against this variant of hypothesis M-3. C. Examination of relative levels of recruitment (R) under different combinations of flow magnitude and duration, and regions with or without floodplain access. This hypothetical graph assumes that the duration of the spawning peak period must be at least five days to allow eggs to mature into larvae and that timing of the spawning peak coincides with optimal spawning temperatures.

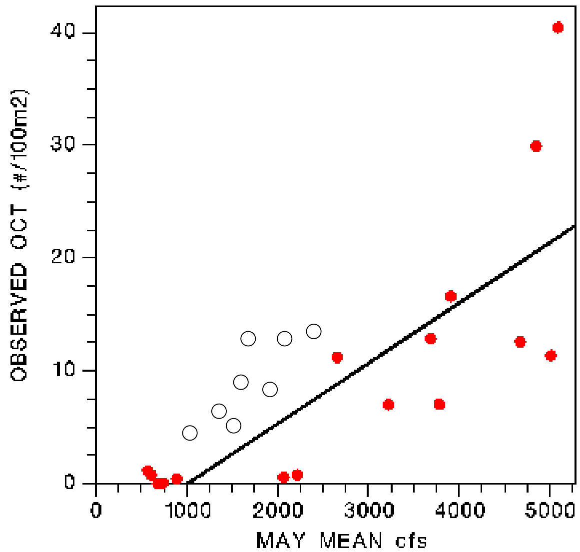


**Figure 25.** Hypothetical data following habitat restoration (open circles) compared to actual data (solid circles) which suggests that habitat restoration efforts to improve minnow spawning and recruitment at low flows had been successful. Adapted from Figure 5 in Goodman (2011). Underlying data from Dudley and Platania (2008).

### *Statistical Approaches*

Statistical analyses are complementary to graphical explorations. Within a given reach (or reach subsection), the flow conditions (magnitude, duration, timing, wetted area) and channel attributes (floodplain connected or unconnected during the spawning period, floodplain vegetation state) could be used as covariates in multiple regression equations (both linear and non-linear) to predict habitat utilization (index of spawner densities) and spawning success (index of larval CPUE or densities). Multivariate analyses are probably more possible although less robust. Recruitment (fall CPUE) could also be predicted on either a reach or sub-reach scale using a mix of these covariates. Other covariates (e.g., densities of competitors or predators) may also be helpful in explaining the observed variation in habitat utilization, spawning success, and recruitment. Examining the goodness of fit and relative ability of alternative models to explain the variability in fish response measures (i.e., AIC scores) is a common statistical approach to hypothesis testing (e.g., Burnham and Anderson, 1998; Deriso et al., 2001; Petrosky and Schaller, 2010).

Functional regression analysis differs from classical regression in that the regression coefficient is actually a function. In classical regression the covariates and the response variable have the same dimension. That is, if there is one measure of minnow recruitment per year, then we need a corresponding data point for each covariate of interest (e.g., mean May flow, as in Figure 25). In reality many physical covariates such as flow and temperature are measured on a much finer temporal scale. Functional data analysis enables the covariate to be incorporated at a finer scale by letting the parameter (i.e., regression coefficient) be a function rather than a fixed value. This approach may better capture the underlying behavior that relates to the response variable (e.g., habitat utilization, spawning success, recruitment). Ainsworth and Routledge (2011) describe how functional data analysis may be applied for this specific purpose. Additionally, occupancy analysis is becoming more widely used to estimate spawning phenology, habitat use, and detectability for larvae of threatened stream fishes (e.g., Falke et al., 2010)

## 5.2 Flycatcher

Flycatcher responses to increased habitat availability could be modeled through development of simple tools in Excel to help predict changes in fledge ratios, number of adult pairs, or other metrics as “suitable habitat” amounts increase over time, by reach, and by other factors. Predictions from these models could then be tested with field data.

Associations between nesting pair, fledge ratios, and other flycatcher productivity measures and habitat improvements could be developed using productivity and habitat monitoring types of protocols and standard statistical analysis procedures. Figure 26 illustrates a hypothesized positive association between nesting pair number and wetted area with habitat availability. Figure 27 illustrates a hypothesized positive association between nesting pair number and habitat patch size, and negative association between nesting pair number and the distance that habitat creation or restoration occurs from existing nesting habitat (i.e., fewer nesting pairs the further their nest locations are from created or restored habitat).

The relationship between physical (e.g., flood irrigation, cottonwood and willow regeneration, saltcedar removal, etc.) and biological (e.g., saltcedar leaf beetle) habitat alterations and habitat availability and suitability are dependent on succession and may result in temporary declines in the availability of suitable nesting habitat until cottonwood and willow trees regenerate and canopy cover at all levels increases. As such, understanding associations between habitat restoration, availability, and suitability and bird response will require long-term monitoring.

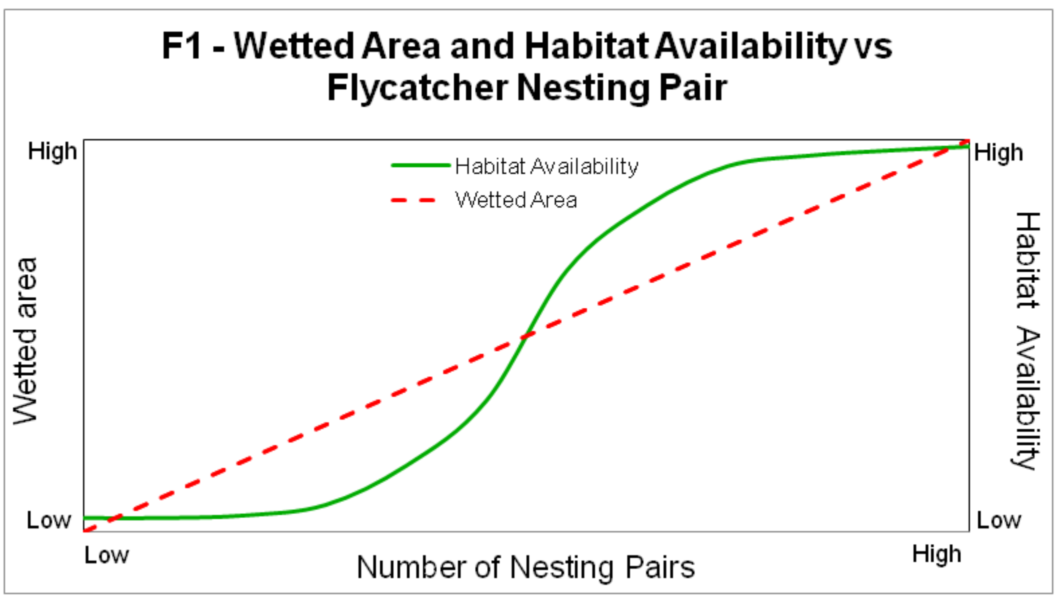


**Figure 26.** Hypothesized (F1) positive and logistic relationships between wetted area within suitable nesting habitat and habitat availability and number of flycatcher nesting pairs, respectively. Similar positive relationships could exist with flycatcher fledge ratios as well.

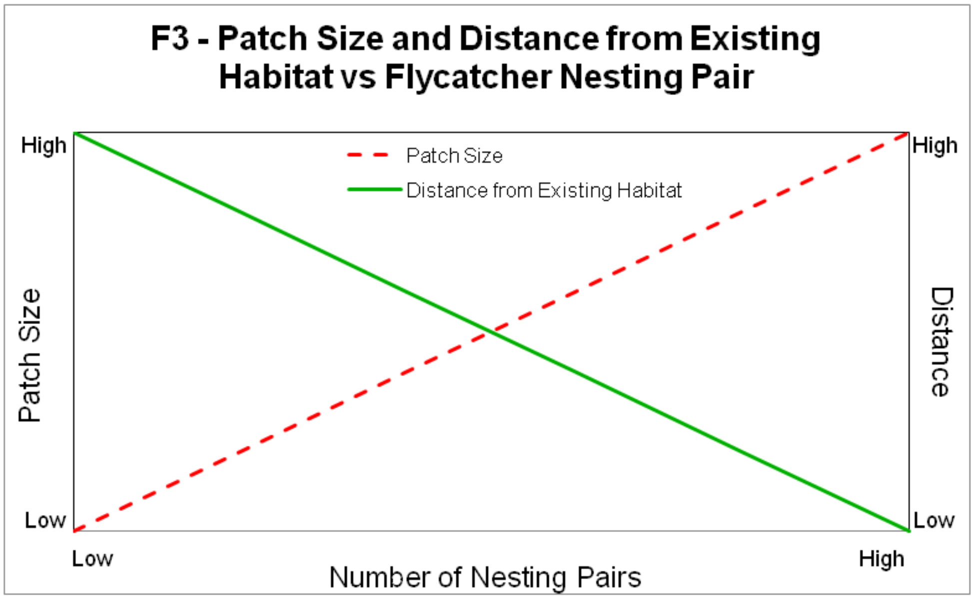


**Figure 27.** Hypothesized (F3) positive and negative relationship between patch size and distance from existing suitable nesting habitat and number of flycatcher nesting pairs, respectively.

## 5.3 Analysis, Reporting, & Synthesis

Analysis methods will be driven by evaluation needs: what information needs to be conveyed to decision-makers, and how that information will be presented. Each monitoring protocol should outline appropriate analysis procedures to ensure data can be compared from year to year, in the same format as the mock graphs in Section 5.2 above, and provide the most illustrative representation of species' responses to management actions. Analysis methods will vary and the Program should consider developing a Data Analysis Plan that provides the scientific and technical detail of how information from each monitoring protocol will be analyzed, how those analyses will be compared, and the best way to comprehensively report that information.

Annual monitoring reports should be completed by the entities implementing the protocols and should include basic analysis as directed by the Program. This reporting will be coordinated by Program staff and will be reviewed by Program work groups and the Program's independent science committee. These reports will contain all of the traditional sections found in scientific reports such as an introduction, methods, results, and discussion, but should also include Program-specific content such as:

- Summary of management actions taken
- Discussion of any unexpected treatments or management and impacts on results
- Discussion of how the results address critical uncertainties and hypotheses

The next step is to synthesize information from individual monitoring protocols to provide a more holistic picture of how the Program is progressing toward addressing management objectives and goals. Synthesis is the role of Program staff and, to facilitate timely decision-making, should occur annually and also across a range of years (for example, a complete synthesis report every 4 or 5 years). Program staff will work with contractors, work groups, the independent science committee, and others to develop and refine synthesis reports, and the Executive Committee will be engaged to ensure that each synthesis report contains the information they expect to have to help with decision-making. The Program will host an annual AM Plan symposium that will bring together all Program contractors, participants, decision-makers, and the independent science committee to present the results of monitoring and research and discuss next steps for synthesis.

## 5.4 Independent Science Review

The design, monitoring and evaluation approaches should all have independent science review, which has proven to be valuable in many other large scale AM programs (e.g., Trinity, Platte, Glen Canyon, Columbia). Independent scientists can be involved in either of two distinct roles: 1) as arms-length reviewers of products and symposia presentations; or 2) as independent experts who roll up their sleeves and work with technical scientists to help them develop approaches to challenging problems. Each of these roles is helpful, but must be filled by different people (e.g., Marmorek and Peters, 2001).

An independent science committee will help ensure scientific integrity and quality in the Program by providing an independent review of AM design, implementation, and evaluation. The committee should be comprised of scientists from areas of expertise most significant to the Program. The purpose of this committee would be to provide the Program with an independent opinion on issues such as experimental design, associated monitoring and research, and how to evaluate the results of management actions and monitoring. The committee would report directly to the Executive Committee and would be coordinated by Program staff.

Independent experts could also be engaged by the Program to assist with special topics and actually work closely with Program staff and work groups on design, implementation, and evaluation issues. A third level of independent science review would be assembling peer review panels to review all Program monitoring protocols and products such as study reports.

**What this section should contain in AM Plan Version 2:**

A full set of mock graphs to clearly illustrate the intended analyses of the hypotheses the Program chooses to test using AM.

Complete discussion of Program analysis methodologies, or a link to a separately-developed Data Analysis Plan.

Additional guidance on how to integrate independent science into the Program, based on how the Program decides to handle independent science review.

# 6.0 AM Cycle Step 6 – Adjust

Step 6 represents what is often described as ‘closing the loop’, by using what has been learned to make better, more effective decisions. This requires decision-makers to be *informed* about what has been learned. Communication is an enormously important aspect of AM at all steps in the cycle, but is particularly critical in Step 6. Ideally decision-makers have participated in previous steps (particularly in Step 1 where their ‘big questions’ have driven the selection and sequencing of hypotheses to test) and have remained involved in or at least aware of actions and progress throughout Steps 2 through 5.

Adaptation and adjustment of management actions for the example AM actions described in Step 2 (Section 2) would occur on three time scales:

1. **Within a season**, based on changes in precipitation and evaporation, with the goal of maintaining both legal obligations and target water flows/refugia, as described for the selected AM action, and consistent with plans for different water conditions made well in advance. For the AM example, adjustments will need to be made to spring spawning flow releases to achieve the desired flow magnitudes and durations (dry, average and wet year treatments in Table 13 and Table 14) or to flow management to allow some non-refugial areas to go dry (treatments D2, A2 or W2 in Table 15) without compromising other water delivery obligations, or methods to maintain wetted refugia may need to be adjusted during the summer to prevent the refugia from drying out. These within-season adjustments will be based on agreed upon procedures in the annual plan, rather than *ad-hoc* changes.

2. **Annual** adjustments to the state of knowledge (including hypotheses), the tools used to explore and simulate potential outcomes, and actions the following year. This includes:

    - Using data from the previous several years to update models (including data from the past year, e.g., Figure 25)
    - Examining changes in the probabilities of critical hypotheses affecting management actions
    - Identifying new hypotheses that may arise from what has been learned thus far
    - Using these analyses to fine-tune actions for the coming spring and summer, based on projections regarding the type of water year that is expected to occur

    This would be facilitated through an annual symposium, held during late winter of each year, to discuss key management and technical questions based on what has been learned thus far, and to agree on a set of adjustment action items.

3. **After several years**, there will need to be adjustments or fine-tuning of the overall flow, habitat, hatchery/genetic and salvage strategies based on what has been learned so far. For the AM example and flow actions related to hypothesis M-1, this could include adjustments in standard flow operations by the entities that operate dams and diversions (BOR, USACE, MRGCD), within limits defined in the regulatory instruments that bound their operations. These discussions could be part of an extra Executive Committee session added every third year (for example) to the annual symposium described above. For channel rehabilitation actions related to hypothesis M-3, this could involve changes to their design to provide a diversity of suitable spawning habitats across a wide range of water years. Consideration of adjustments to the criteria for changing the listing status of silvery minnow and flycatcher are made by the U.S. Fish and Wildlife Service, and may be informed, in part, by this AM process based on what is learned.

Connected models similar to the ones to be used in simulations to explore AM actions and design (Figure 8), and improved with additional data, could be used to explore the sets of conditions and hypotheses under which current recovery criteria could be met. Such analyses may also provide the Program and the U.S. Fish and Wildlife Service with additional criteria to assess population status and trends (whether or not these are formally adopted). For example, decision analyses of actions to protect endangered spring and summer chinook in the Snake River used a recovery criterion that was related to the geometric mean abundance over an 8-year period (Peters and Marmorek, 2001). The geometric mean dampens out the effects of strong year to year fluctuations and occasional outlier values.

In addition to annual analyses and rapid learning from year-to-year, the Program must develop more comprehensive synthesis reports on a four- to five-year interval. Such reports would be intended for the Executive Committee and would convey information in a clear and succinct manner to inform management decisions. Synthesis reports need to focus on major scientific and technical uncertainties (e.g., in the Platte River Recovery Implementation Program, synthesis reports focus on a small set of ‘Big Questions’ that encapsulate uncertainties related to species’ responses to management actions – see Smith et al., 2011). Synthesis reports should include text and visual representations of data, attempt to draw together large amounts of data and analysis into conclusions about critical uncertainties and related hypotheses, and provide decision-makers with guidance on observed trends and next steps. This type of report is crucial for the Program to link science with decision-making, to resolve hypotheses and critical uncertainties when possible, and to help prioritize continued implementation of management actions and associated monitoring to ensure data are being generated relative to the most important Program questions and decision-making needs.

Decision rules would guide adjustment of actions at any of these timescales, and would also provide the ‘safe-fail’ mechanism described in previous sections. An example of safe-fail decision rules from another system is provided in Appendix D. The development of these decision rules could occur through the same process as that for exploring and selecting the AM actions to be implemented (Figure 8), whereby alternative decision rules would be modeled to test for their reliability and effectiveness.

**What this section should contain in AM Plan Version 2:**

Decisions at the various timescales would be described with greater specificity, based on the actions the Program selects to implement under the AM Plan, when the implications of potential decisions on specific entities would be clearer (depending on which entities have decision-making authority over these actions). Similarly, decision rules would be more specific, tailored for the chosen actions.

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# Appendix A: Exploring Water Management Alternatives – the British Columbia Water Use Planning Process

**Introduction**

This appendix describes an example of a process similar to that described in Section 1.6, as applied to water use planning in British Columbia, Canada.

**Water Use Planning Framework**

British Columbia's water use planning process was initiated to review the existing water use plans for 20 major hydroelectric facilities throughout the province and develop new plans where necessary. Once reviewed and accepted by the appropriate authorities, a Water Use Plan (WUP) defines how water control facilities will be operated. The water use planning process is a participatory process to develop recommendations and preferred operating strategies that specify how flows and reservoirs should be managed. Each WUP involves a Consultative Committee with stakeholder representation to deal with policy issues and tradeoffs, supported by several Technical Advisory Committees to work through various technical issues, including monitoring and research studies, and simulating the outcomes of each operating alternative under consideration. Developing a WUP in a participatory manner is a highly complex task. The WUP is multi-dimensional, comprising tradeoffs among environmental, economic, social, and recreational objectives, and it concerns multiple stakeholders, including the public, First Nations (aboriginal groups), and both agencies responsible for the generation of power and those responsible for the conservation of environmental values. The process must also integrate information from a diverse knowledge base, such as community observations, scientific research, traditional ecological knowledge, and the experiences of energy facilities elsewhere (Gregory et al., 2006).

One of the drivers underlying the WUP process was changing societal values regarding the balance between economic and environmental considerations. A strong public will to modify flows in order to benefit fisheries resources was apparent, but the potential effects that changes in hydrologic conditions from the existing management regimes might have on those resources remained highly uncertain (Gregory et al., 2006). The dominant sources of uncertainty, pervasive throughout all of the WUPs, were uncertainty regarding the effects of potential changes in flow on the quantity and quality of habitat, uncertainty regarding the effects of potential changes in habitat on ecological productivity, and an overall paucity of high-quality baseline data. Consequently, models to predict the potential benefits of changing flow conditions were highly uncertain, in contrast with the very good models to predict the costs of forgone power generation from such changes, making it difficult to accurately quantify the tradeoffs between fish productivity and power generation associated with a particular change. This fish-power tradeoff was expected to be the predominant concern for WUPs; however, fish-fish tradeoffs became equally important at many sites, and at some sites recreation-power or flood-power tradeoffs also became important (Gregory et al., 2006). The example provided below from the Bridge River WUP represents a fish-power tradeoff.

The analytical framework employed within the WUP process reflects the principles of decision analysis, combining elements of decision theory (i.e. how decisions should be made) and behavioral decision research (i.e. how decisions are made). Decision analysis allows the values of participants and the uncertainty embodied in alternative management actions to be explicitly represented in a structured framework in order to reduce the probability of selecting management strategies that will likely results in poor outcomes. Adaptive management was also identified under the WUP Guidelines as a key principle within the process, anticipated to be a useful tool for some elements of the WUPs.

### The Lower Bridge River

The Bridge River is a tributary of the Fraser River in southwestern British Columbia. The Bridge River is part of BC Hydro's Bridge-Seton hydroelectric complex, consisting of three impoundment dams, three reservoirs, and four generating stations. The construction of the Terzaghi Dam (an impoundment dam) in 1960 left a 4km section of the Lower Bridge River (LBR) dry. Groundwater flow and downstream tributaries contributed water below this dry section, but overall the level of flow in the LBR had been reduced by over 100-fold. In the 1990s, research was conducted with intention of guiding restoration efforts but standard methods for assessing instream flow could only explain 50% of observed variability in fish density, opening more questions and revealing large uncertainties (Gregory et al., 2006). In 1998, after 8 years of litigation and research, an out-of-court settlement was reached, establishing an agreement to release 3 $m^3/s$ (a compromise among parties) in perpetuity, or at least until the available information improved (through follow-up monitoring and other avenues) and a subsequent agreement could be negotiated (Gregory et al., 2006). This is the historical foundation for the Bridge River WUP consultative process initiated in 1999.

The Bridge River WUP Consultative Committee was comprised of 13 members from local communities, First Nations, environmental groups, BC Hydro, and government agencies, who represented economic, environmental, social, and cultural values. The Consultative Committee followed a structured decision process, collaboratively developing objectives, performance measures and indicators; identifying relevant knowledge gaps, and conducting studies where possible to address those gaps; identifying alternative management strategies for reservoirs and instream flow; and evaluating those alternatives based on the agreed upon objectives and performance measures. All parts of the systems were examined, but only the decision regarding instream flow in the LBR is presented in the current example[12,13].

### Characteristics of the Lower Bridge River Decision

*Competing Hypotheses*

The central goal of the LBR decision process was to determine the level of flow that would achieve an acceptable balance between releasing water into the LBR to increase fisheries productivity and retaining that water in the reservoir to generate power when diverted through the hydro-electric facilities. However, even if an acceptable tradeoff between fisheries values and power generation values was clearly defined, the ability to determine what level of flow would achieve this balance was obscured by the substantial uncertainty regarding the overall relationship between the level of flow and the productive capacity of the river. As with most of the WUPs, this uncertainty was composed of uncertainty both around the effect of changes in flow on habitat and changes in habitat on productivity. In the LBR, more water would provide more wetted area but it would also likely result in reduced temperature, increased turbidity, altered hydraulic conditions, and increased velocity. The existing data from instream flow research for the LBR were insufficient to characterize the functional relationship between the level of water released from the reservoir and salmonid recruitment, or even provide estimates of the likelihood of a given set of parameters; however, the data assisted in bounding the potential hypotheses describing that relationship (Failing et al., 2004). Two competing hypotheses were identified, both plausible but conceptually divergent. First, the hypothesis characterized as "high good" asserted that increased water would increase

[12] The Executive Summary of the Bridge River WUP Consultative Committee Report (2003) is available at: http://www.bchydro.com/etc/medialib/internet/documents/environment/pdf/wup_bridge_river_executive_summary_pdf.Par.0001.File.wup_bridge_river_executive_summary.pdf

[13] The final, accepted, and implemented plan, the Bridge River Power Development WUP (2011), is available at: http://www.bchydro.com/etc/medialib/internet/documents/planning_regulatory/wup/lower_mainland/2011q2/bridge_river_wup_rev.Par.0001.File.Bridge-River-WUP-Rev-for-Accept-2011-03-17.pdf

the wetted channel area and result in a proportional increase in salmonid productivity, effectively implying that habitat quality was independent of level of water released. Second, the hypothesis characterized as "low good" asserted that increased water would create unsuitable hydraulic conditions for fry/parr habitat, effectively implying that habitat quality was dependent of level of water released and that increases in habitat quantity would be insufficient to compensate for the decreases in quality.

*Alternative Approaches to Environmental Management Problem*

Adaptive management (AM) was identified as one potential approach to reducing these uncertainties and ultimately selecting an appropriate long-term operating strategy. Although the parties agreed in principle to the possibility of AM, there were many parties that were skeptical of the ability of AM to deliver superior results. The alternative strategies evaluated included non-experimental management strategies with flows of 1, 3, 6, or 9 $m^3/s$, or an AM strategy with experimental trials of at each of those flow levels (Failing et al., 2004). The evaluation of these strategies was based on the perspective that adaptive management is one potential environmental management approach and its merits and tradeoffs should be compared relative to other alternative approaches (Failing et al., 2004, Gregory et al., 2006).

*Assessing the Value of an AM Approach*

When assessing the value of a proposed AM initiative, the two most critical questions are: 1) "Do the expected benefits of an AM approach exceed the expected cost?" and 2) "Will the proposed experimental design provide an improvement in knowledge sufficient to justify future management changes?" (Gregory et al., 2006). Associated with any AM initiative will likely be a complex set of benefits and costs (e.g. economic, environmental, social, upfront, ongoing, delayed, direct, opportunity costs, etc.). Some of these impacts will be deterministic, but many will be probabilistic, necessitating probabilistic estimates of the long-term benefits to determine whether they justify the likely costs (Gregory et al., 2006). One of the values of AM is to generate new information that can reduce critical uncertainties, facilitating changes in management decisions that lead to better outcomes that increase stakeholder value. The experimental design must be able to discriminate between natural variation and impacts attributable to the experimental treatments. Evaluation criteria used to assess the success of different treatments must be clearly defined because each treatment may have multiple indicators with different responses (Gregory et al., 2006).

**Evaluating Experimental and Non-Experimental Alternatives in the Lower Bridge River**

*Decision Analysis*

A structured decision analysis framework was employed by the Bridge River Consultative Committee in order to select among the alternative experimental and non-experimental management strategies for the LBR. The framework incorporated expert judgment, Monte Carlo simulations, a decision tree, and stakeholder values (see Failing et al. (2004) for detailed description). In order to maintain both technical integrity and compatibility with the decision process, Failing et al. (2004) identify the several components they believe to be essential. First, the impacts of each alternative should be communicated to stakeholders in a simple manner that clearly and concisely represents tradeoffs between the values of interest. To facilitate the most intuitive and transparent comparisons, impacts were represented in natural units (i.e. forgone power revenue is reported in dollars and increased fisheries productivity is reported in kilograms of biomass). This required agreement on an integrative measure that would be acceptable as a proxy for a broader array of aquatic ecosystem attributes. Using natural units was considered superior to the confusing and non-intuitive process of converting different impacts into measures of utility (Failing et al., 2004). Second, impacts need to be represented in probabilistic terms. Uncertainty always exists and should not be a barrier to evaluating impacts in a structured manner. Third, the results of the decision analysis should be reported in terms of improved future outcomes and not in terms of improved knowledge or reduced uncertainty. For society, "knowledge is means to more fundamental ends, not an end in itself" (Failing et al., 2004). Finally, decision makers need to evaluate whether the potential benefits (which likely accrue over time) are sufficient to justify the potential costs (which may be significant much earlier), which is fundamentally a value-based judgment.

The decision analysis used a decision tree to estimate the expected benefits of each of the alternative management strategies. The uncertainties represented in the decision tree were parameterized by using a combination of expert judgment and Monte Carlo simulations. The expected costs were estimated from established hydro-electric power generation models and a simplified decision tree. The expected benefits and costs were presented in a simple framework that exposed the fundamental tradeoffs for stakeholders to evaluate. Stakeholder values were used to refine the experimental AM design and ultimately select the preferred alternative.

*Estimating the Expected Benefits of Alternative Management Strategies*

The potential benefit of interest for each management strategy is an increase in fisheries productivity. Given the uncertainty regarding which of the competing hypotheses is most accurate and the absence of adequate data to either quantify the likelihood of each hypothesis or estimate the fisheries response to a particular flow, expert judgment was used to estimate the probabilities and outcomes necessary to parameterize the decision tree and calculate the expected benefits of each management strategy. Although relying upon only two experts was deemed adequate for the present case, Failing et al. (2004) recommend using three to five experts. The alternative management actions included in the decision tree were the non-experimental flow regimes of 1, 3, 6, and 9 $m^3$/s and the AM strategy with experimental trials at the same four flow levels. The two uncertain states of nature included in the decision tree were the hypothesis describing the relationship between flow and fisheries response (i.e. "high good" and "low good") and the ability of the AM trials to successfully discriminate between the competing hypotheses. The productivity outcomes were estimated in terms of kilograms of biomass.

Expert judgment was relied upon to provide estimates of: 1) the biomass response to each flow regime, under each hypothesis; 2) the probability of each hypothesis being true; and 3) the probability that the experiment would be able to correctly discriminate between the competing hypotheses. Failing et al. (2004) also recommend that expert judgment should be used to estimate the probability of other negative ecological effects, although no significant responses were evaluated in this particular case. Both of the experts attended an initial scoping meeting to clarify the nature and intent of the biomass metric and further agreed to a common set of relevant data and background information to use as the basis for their estimates. In order to capture the uncertainty in the potential biomass response to each flow regime (given a particular hypothesis being true), each expert provided an estimate of the median biomass response and a 90% confidence interval. A Monte Carlo simulation was used to combine the two sets of expert judgments into single distribution of the predicted biomass response for each flow regime and hypothesis. The median and 90% confidence intervals from these new distributions were used as the parameter inputs for the decision tree. Further details on the process of eliciting these expert-based estimates are found in Failing et al. (2004).

*Estimating the Expected Costs of Alternative Management Strategies*

The costs of each management strategy are lost revenues from forgone power generation and the costs of monitoring. These costs were evaluated over 25 years, combined into a series of annual costs, levelized, and then entered into the decision tree to calculate the annual costs for each management strategy (Failing et al., 2004). The cost estimate of each of the non-experimental options is represented by a single value because the decision tree does not incorporate any uncertainty around the costs of a particular level of flow. However, the cost estimate of the experimental AM option is represented by a range of values because there is uncertainty regarding which of the flow regimes will ultimately be selected following the conclusion of the trials.

*Evaluating the Results and Refining the Design*

The expected benefits and expected costs for each of the alternative management strategies were presented on a two dimensional plot to communicate the results of the analysis to stakeholders in the clearest manner possible. In response to the preliminary results, value judgments of stakeholders were used to refine the analysis in several important ways. First, stakeholders decided to modify the experimental design of the AM strategy by changing the order in which the trials were conducted. The original design (not detailed here) was structured such that there was a possibility, depending on the results of the initial trials, of situations in which the 1 $m^3$/s flow level would not get tested; however, the results of the decision analysis convinced stakeholders and scientists that 1 $m^3$/s could potentially represent a win-win situation and the experimental design should be modified such that testing at that level would be guaranteed (Failing et al., 2004). Second, stakeholders evaluated the possibility of including a stopping rule, which would grant authority to stop trials given sufficient improvement at low flow levels. For participants primarily concerned with program length and costs considered, a stopping rule was considered as a positive addition, whereas for participants primarily focused on maximum learning, a stopping rule was considered negative (Failing et al., 2004). A stopping rule was ultimately not included but could be very useful in other circumstances. Third, stakeholders rejected the 9 $m^3$/s option, concluding from the results that it would be too costly and offered only a low probability of substantial improvement over 6 $m^3$/s. Given concerns about the expense, the possibility of unacceptable effects on riparian vegetation and wildlife, the duration of the entire AM program, and the low probability of changing management decisions, stakeholders also decided to remove the 9 $m^3$/s trial from the experimental AM design, though not completely rejecting the possibility of testing this flow in the future if presented with new information that justified such action (Failing et al., 2004).

The decision tree was then recalculated based on the modified design. Removing the 9 $m^3$/s trial substantially reduced the expected cost of the AM option from $4.9 million to $3.5 million and reduced the overall length of the AM program (Failing et al., 2004). In response to the new results, stakeholders were required to compare the experimental and non-experimental alternatives, evaluate the tradeoffs between costs and benefits and select a preferred strategy, in an inherently values-based decision process. Ultimately, none of the stakeholders supported the 9 $m^3$/s option, some supported the 6 $m^3$/s option, and most felt they could support either the 3 $m^3$/s or 1 $m^3$/s options. However, the experimental AM approach was supported by all stakeholders, who felt that the incremental benefits of the experimental AM program (including the immeasurable benefits of increased learning, cooperation and collaboration among the parties) were substantially larger than the incremental costs when compared to either of the leading non-experimental options (Failing et al., 2004).

In the present decision analysis, the biomass outcomes were characterized by a probabilistic distribution but the probabilities of uncertain states of nature (i.e. competing hypotheses and experimental ability to correctly discriminate between them) were represented as point estimates. However, if desired, the decision analysis framework utilized by the Bridge River Consultative Committee would easily facilitate further sensitivity analyses around these probability values. For example, increasing the probability of the experiment to correctly discriminate between the two competing hypotheses would allow participants to assess how the expected benefits of the AM program might increase in response to improvements in the reliability of the experiments and subsequently evaluate whether the improved performance would be sufficient to justify the additional investment required to strengthen the experimental design (Failing et al., 2004).

## Discussion

Using a representative set of experts to obtain explicit, quantitative estimates of the probability and magnitude of outcomes improved several aspects of decision quality (Failing et al., 2004). Technical and non-technical decision makers were given the same set of information presented in a clear, concise manner. A structured decision making process helped shift the focus away from positional debates. A critical distinction was made between technical judgments regarding the probability and magnitude of the potential benefits of alternatives and values-based judgments regarding whether those benefits justify their costs.

Providing explicit, quantitative estimates of the potential benefits also proved to be extremely valuable in managing the expectations of stakeholders, some of whom previously held unrealistic hopes regarding the magnitude benefits that could be realized (Failing et al., 2004). Qualitative estimates do not provide adequate bounds on expectations because it may not be clear what “low” or “high” levels mean in terms of actual costs or benefits. Furthermore when the tradeoffs between explicit, quantified benefits and costs were presented to stakeholders, it offered the context of a concrete management choice within which stakeholders could meaningfully assess their “willingness to pay” for improved environmental outcomes, whereas prior to such specification the willingness to pay question was difficult, abstract, produced answers that varied by many orders of magnitude with little connection to plausible results, and was therefore a relatively uninformative exercise (Failing et al., 2004).

In the case of the Lower Bridge River, after an explicit analysis of experimental and non-experimental management alternatives, AM was ultimately supported by aboriginal participants, community members, managers, and scientists, who concluded that the increased knowledge generated from the experimental approach would provide greater confidence in making an appropriate longer term management decision (Gregory et al., 2006). Failing et al. (2004) conclude that AM has the greatest management relevance where there is a high probability of gaining useful information and high consequences of such information in changing endpoint that stakeholders value, but further suggest that “AM may best be applied or focused on critical elements of the decision, rather than the entire problem”.

## References

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# Appendix B: RPA Elements and Actions from the 2003 BO

| RPA Element and Action | Authority: |
|---|---|
| **Water Operations Element** | |
| A) Between April 15 and June 15 of each year, the action agencies, in coordination with parties to the consultation, shall provide a one-time increase in flows (spawning spike) to cue spawning. The need for, timing, magnitude, and duration of this flow spike will be determined in coordination with the Service. | BOR, USACE (in coordination with parties to the consultation, USFWS) |
| B) In coordination with the Service, Reclamation and the USACE shall release any supplemental water in a manner that will most benefit listed species. | BOR, USACE (in coordination with USFWS) |
| C) Reclamation, in coordination with parties to the consultation, shall conduct routine monitoring of river flow conditions when flows are 300 cfs or less at San Acacia, and report information regularly to the Service through the water operations conference calls and meetings. | BOR (in coordination with parties) |
| D) Reclamation, in coordination with parties to the consultation, shall ensure that active flycatcher territories supported by pumping from the LFCC are provided with surface water or moist soils in the Rio Grande from June 15 to September 1. If, as a result of the proposed action, active territories are dried along the Rio Grande or irrigation drains, options for providing these territories with surface water or moist soils will be pursued and implemented if at all practicable. We anticipate that implementation of this element would not require ponded surface water throughout the entire nesting season. For example, water could be provided to a site for a few days, the water source cut off, the area allowed to move from standing water to moist soils, and the water source turned back on prior to the site drying. The practicability and methods (releases from drains, pumping, or other means) of providing water to a site will be determined through coordination with the Service. | BOR (in coordination with parties to the consultation) |
| E) Action agencies, in coordination with parties to the consultation, shall provide continuous river flow from Cochiti Dam to the southern boundary of silvery minnow critical habitat from November 16 to June 15. *[in dry yrs &/or when Compact storage restrictions are in effect]* | BOR, USACE (in coordination with parties to the consultation) |
| F) Action agencies, in coordination with parties to the consultation, shall provide year-round continuous river flow from Cochiti Dam to Isleta Diversion Dam with a minimum flow of 100 cfs at the Central Bridge gage. *[in dry yrs &/or when Compact storage restrictions are in effect]* | BOR, USACE (in coordination with parties to the consultation) |
| G) Reclamation shall pump from the LFCC as soon as needed to manage river recession. The pumping capacity must meet or exceed the total capacity of pumps used in the 2002 irrigation season (150 cfs). Pumping shall continue when it will benefit the flycatcher and its habitats. Areas upstream, downstream, and between pumps shall be surveyed prior to intermittency for the presence of breeding flycatchers and pumping continued, if the Service determines it will benefit flycatchers. Coordination with the Service regarding managing river recession and keeping flycatcher areas wet will occur. *[in dry yrs &/or when Compact storage restrictions are in effect]* | BOR (in coordination with USFWS) |
| H) Action agencies, in coordination with parties to the consultation, shall provide continuous river flow from Cochiti Dam to the southern boundary of silvery minnow critical habitat from November 16 to June 15. *[in average years]* | BOR, USACE (in coordination with parties to the consultation) |
| I) Action agencies, in coordination with parties to the consultation, shall, from June 16 to July 1 of each year, ramp down the flow to achieve a target flow of 50 cfs over San Acacia Diversion Dam through November 15. *[in average years]* | BOR, USACE (in coordination with parties to the consultation) |
| J) Action agencies, in coordination with parties to the consultation, shall provide year-round continuous river flow from Cochiti Dam to Isleta Diversion Dam with a target flow of 100 cfs over Isleta Diversion Dam. *[in average years]* | BOR, USACE (in coordination with parties to the consultation) |
| K) Reclamation shall pump from the LFCC if needed to manage river recession and maintain connectivity. The pumping capacity must meet or exceed the total capacity of pumps used in the 2002 irrigation season (150 cfs). Pumping shall continue when it will benefit the flycatcher and its habitats. Areas upstream, downstream, and between pumps shall be surveyed prior to intermittency for the presence of breeding flycatchers and pumping continued, if the Service determines it will benefit flycatchers. | BOR (in coordination with USFWS) |

| RPA Element and Action | Authority: |
|---|---|
| Location of pumps and decisions regarding cessation of pumping will be made in coordination with the Service. *[in average years]* | |
| L) Action agencies, in coordination with parties to the consultation, shall provide continuous river flow from Cochiti Dam to the southern boundary of silvery minnow critical habitat from November 16 to June 15, with a target flow of 100 cfs at the San Marcial Floodway gage. *[in wet years]* | BOR, USACE (in coordination with parties to the consultation) |
| M) Action agencies, in coordination with parties to the consultation, shall, from June 16 to July 1 of each year, ramp down the flow to achieve a target flow of 100 cfs over San Acacia Diversion Dam through November 15. *[in wet years]* | BOR, USACE (in coordination with parties to the consultation) |
| N) Action agencies, in coordination with parties to the consultation, shall provide year-round continuous river flow from Cochiti Dam to Isleta Diversion Dam with a target flow of 150 cfs over Isleta Diversion Dam. *[in wet years]* | BOR, USACE (in coordination with parties to the consultation) |
| O) Reclamation shall pump from the LFCC if needed to manage river recession and maintain river connectivity. The pumping capacity must meet or exceed the total capacity of pumps used in the 2002 irrigation season (150 cfs). Pumping shall continue to maintain river connectivity. *[in wet years]* | BOR |
| **Habitat Improvement Element** | |
| P) Action agencies, in coordination with parties to the consultation, shall prevent or minimize destruction of potential or suitable flycatcher habitat when installing pumps or groundwater wells and coordinate with the Service prior to their installation if this action may affect flycatcher habitat. | BOR, USACE (in coordination with parties to the consultation, USFWS) |
| Q) Action agencies, in coordination with parties to the consultation, shall improve gaging and real-time monitoring of water operations to provide dependable, accurate readings, including installation of gages near Los Lunas, and Highway 380, and all diversions, drains, returns and main ditches. | BOR, USACE (in coordination with parties to the consultation) |
| R) Reclamation, in coordination with the Service and parties to the consultation, shall complete fish passage at San Acacia Diversion Dam to allow upstream movement of silvery minnows by 2008. Reclamation and parties to the consultation, in coordination with the Service and Isleta Pueblo, shall work to complete fish passage at Isleta Diversion Dam, located on lands owned by Isleta Pueblo, by 2013. Processes successful in achieving fish passage at San Acacia Diversion Dam should be incorporated into the construction of fish passage at Isleta Diversion Dam. A plan for monitoring the effectiveness of fish passage must be completed, funded, and implemented for each year's operation and maintenance. In the interim, implement all feasible short-term fish passage/river reconnectivity actions. | BOR (in coordination with USFWS, Isleta Pueblo, parties to the consultation) |
| S) In consultation with the Service and appropriate Pueblos and in coordination with parties to the consultation, action agencies shall conduct habitat/ecosystem restoration projects in the Middle Rio Grande to increase backwaters and oxbows, widen the river channel, and/or lower river banks to produce shallow water habitats, overbank flooding, and regenerating stands of willows and cottonwood to benefit the silvery minnow, the flycatcher, or their habitats. Projects should be examined for depletions. It is the Service's understanding that the objective of the action agencies and parties to the consultation is to develop projects that are depletion neutral. By 2013, additional restoration totaling 1,600 acres (648 hectares) will be completed in the action area. In the short term (5 years or less), the emphasis for silvery minnow habitat restoration projects shall be placed on river reaches north of the San Acacia Diversion Dam. This restoration will be distributed throughout the action area. Habitat restoration projects fulfilling RPA element J[14], from the June 29, 2001, biological opinion[15], | BOR, USACE (in consultation with USFWS, Pueblos, and in coordination with parties to the consultation) |

[14] Conduct habitat/ecosystem restoration projects in the MRG to increase backwaters and oxbows, widen the river channel, and lower river banks to produce shallow water habitats, overbank flooding and regenerating stands of willows and cottonwoods to benefit the silvery minnow and flycatcher and their habitats. Restoration will take place on at least one site per reach on the Rio Grande from the area of Velarde to the headwaters of Elephant Butte Reservoir. The reaches include the following, as described on page 13 of the assessment: Velarde, Española, Cochiti, Middle, Belen, Rio Puerco, Socorro, San Marcial. Based on the size of a successful breeding area used by a group of flycatchers on the Middle Rio Grande, each restoration site will encompass approximately 60 acres

| RPA Element and Action | Authority: |
|---|---|
| shall be completed. The action agencies and parties to the consultation, in coordination with the Service, shall develop time tables and prioritize areas for restoration. Projects should result in the restoration/creation of blocks of habitat 24 hectares (60 acres) or larger. Consultation with the Service for each site will tier to this biological opinion. Monitoring will be conducted for each project annually for 10 years in order to assess whether created habitats are self-sustaining, successfully regenerating, and are supporting the flycatcher and silvery minnow. Monitoring reports will be provided to the Service by January 31 of each year. Adaptive management principles will be used, if necessary, to obtain successful restoration of silvery minnow and flycatcher habitats. The environmental evaluation process for two projects should begin within 30 days of issuance of this biological opinion and construction should begin no later than twelve months from that date. | |
| T) When bioengineering (as described in Reclamation's biological assessment) cannot be used in Reclamation river maintenance projects, habitat restoration will be implemented to offset adverse environmental impacts resulting from river alteration. Habitat restoration efforts should replace the ecological functions and values of the affected area, both temporally and spatially. A restoration plan, to be approved by the Service, should be produced for each restoration site that includes (but is not limited to): (1) The acreage and ecological value of the habitat to be impacted and restored, (2) measurable success criteria, (3) time frames for achieving project objectives, and (4) a remediation plan should the restoration site not succeed. Habitat restoration will occur within the same or adjoining reach as the river maintenance project, or in tributaries of those reaches, in consultation with the Service. | BOR (plan approval by USFWS) |
| U) Action agencies, in coordination with parties to the consultation, shall collaborate on the river realignment and proposed relocation of the San Marcial Railroad Bridge project, which is necessary to increase the safe channel capacity within the Middle Rio Grande. Construction for the relocation of the San Marcial Railroad Bridge will be initiated by September 30, 2008. | BOR, USACE (in coordination with parties to the consultation) |
| V) Each year that the NRCS April 1 Streamflow Forecast is at or above average at Otowi and flows are legally and physically available, the Corps shall bypass or release floodwater during the spring to provide for overbank flooding. The overbank flooding will be used to create an increased number of backwater habitats for the silvery minnow and flycatcher. The timing, amount, and locations of overbank flooding will be planned each year in conjunction with the Service and may be conducted in coordination with compact deliveries. | USACE (in conjunction with USFWS and in coordination with compact deliveries) |
| W) The Corps, in coordination with the Pueblo of Santa Ana, shall investigate and increase sediment transport through Jemez Canyon Dam. The Corps, in coordination with the Pueblo of Santo Domingo, shall also investigate and increase sediment transport through Galisteo Dam. By December 31, 2007, the Corps, in coordination with Cochiti Pueblo, shall complete an environmental baseline study and investigate the feasibility of transporting sediment from Cochiti Lake. The environmental baseline study shall address the issue of contaminated sediment raised by Cochiti Peublo in comments received in response to the draft Biological Opinion. Prior to the release of any sediment from Cochiti Lake, the Corps shall conduct government-to-government consultations with Cochiti Pueblo as well as other downstream Pueblos that may be affected by this action. The action agencies and parties to the consultation shall investigate other locations in which sediment transport could be improved. | USACE (in coordination with Pueblos of Santa Ana, Santo Domingo, and Cochiti), BOR and parties to the consultation |
| X) Action agencies, in coordination with parties to the consultation and in consultation with the Service, shall prevent encroachment of saltcedar on the existing channel and destabilize islands, point bars, banks, or sand bars in the Angostura, Isleta, and San Acacia Reaches. The methods used and areas proposed for destabilization should be agreed upon by the Service, Reclamation, the Corps, and appropriate Pueblos and landowners. This activity should not adversely affect flycatcher habitat. This action should be undertaken where reaches are dry and the Service encourages the action agencies and parties to the consultation to begin this action during the summer of 2003. Projects should be examined for depletions. It is the Service's understanding that the objective of the action agencies and parties to the consultation is to develop projects that are depletion neutral. | BOR, USACE (in coordination with parties to the consultation and in consultation with USFWS) |

(approximately 100 meters wide by 2.5 kms long) along the river's edge, incorporating modifications of these dimensions based on site-specificity, as needed.

[15] United States Fish and Wildlife Service (USFWS). 2001. *Programmatic Biological Opinions on the Effects of Actions Associated with the U.S. Bureau of Reclamation's, U.S. Army Corps of Engineers', and Non-Federal Entities' Discretionary Actions Related to Water Management on the Middle Rio Grande, New Mexico.* Consultation Number 2-22-01-F-431, June 29.

| RPA Element and Action | Authority: |
|---|---|
| **Salvage and Captive Propagation Element** | |
| Y) Action agencies, in coordination with parties to the consultation, shall provide $300,000 annually to NMESFO for distribution to propagation facilities for the continuation of captive propagation activities (including egg collection, transportation, relocation, rearing, breeding, etc.). The City has committed to coordinate egg collection activities for propagation efforts and will identify egg collection locations in coordination with the NMESFO, NMFRO, the action agencies, and parties to the consultation. | City (in coordination with USFWS, BOR, USACE, and parties to the consultation) |
| Z) Action agencies, in coordination with parties to the consultation, shall provide $200,000 annually for the first three years of this consultation for the expansion of facilities propagating silvery minnows (the Hatchery, NMFRO, New Mexico State University, the City, Rock Lake State Fish Hatchery, and any other approved locations). | BOR, USACE (in coordination with parties to the consultation) |
| AA) Upon the successful operation and evaluation of the recently constructed naturalized refugium (Breeding and Rearing Facility #1), the action agencies, in coordination with parties to the consultation, shall construct two new naturalized refugia breeding and rearing facilities for the captive propagation of the silvery minnow. The first new breeding and rearing facility must be completed by May 31, 2005, and the second new facility must be completed by May 31, 2006. One facility should be located in the Cochiti or Angostura Reach and the other facility should be located in the Isleta or San Acacia Reach. The design, siting, and operation of the facility should be determined in coordination with the Service and Pueblos, as appropriate, and should include design adaptations following the “lessons learned” from the operation of the Breeding and Rearing Facility #1. | BOR, USACE (in coordination with parties to the consultation) |
| BB) Beginning in 2008, action agencies, in coordination with parties to the consultation, shall provide the NMESFO $100,000 annually for five years for monitoring and augmentation of silvery minnows reintroduced into its historic range under section 10(j) (experimental populations) of the ESA. | BOR, USACE (in coordination with parties to the consultation) |
| CC) The Service in coordination with the New Mexico Department of Game and Fish and all appropriate Pueblos, shall conduct silvery minnow surveys and habitat assessment studies in the Rio Grande above Cochiti Lake in preparation of silvery minnow releases under the Service’s Regional Director’s 10(a)(1)(A) permit. All silvery minnows that may be released will be marked. These surveys will be completed by December 31, 2004. | USFWS (in coordination with NMDGF and Pueblos) |
| **Water Quality Element** | |
| DD) With the increased emphasis and importance of the Angostura Reach for silvery minnow conservation, it is imperative that the addition of treated wastewater to the river provides water quality conditions protective of silvery minnow. The protective concentration of total residual chlorine (chlorine) for silvery minnow is less than or equal to 0.013 mg/L. The protective concentration of ammonia, as nitrogen [ammonia] (at 25 EC and pH 8), for silvery minnow is less than or equal to 3.09 mg/L for larvae and less than or equal to 9.3 mg/L for post-larvae. | City |
| EE) Action agencies, in coordination with parties to the consultation, shall provide funding for a comprehensive water quality assessment and monitoring program in the Middle Rio Grande to assess water quality impacts on the silvery minnow. This assessment and monitoring program should use available data from all sources. | BOR, USACE (in coordination with parties to the consultation) |
| **Reporting Elements** | |
| FF) Action agencies, in coordination with parties to the consultation, shall provide a consolidated report on the status of all RPA elements to the Service by December 31 of each year. | BOR, USACE, parties to the consultation (submitted to USFWS) |

# Appendix C: Compilation of Critical Uncertainties and Hypotheses Submitted by Program Participants

This appendix lists the critical uncertainties and hypotheses provided to our team during and subsequent to the first Planning Session in February 2011. It is not a comprehensive, full or final set, but a compilation of those submitted to our team thus far. They have been grouped, but they have not been re-worded, and as a result there are varying degrees of overlap and redundancy among some items in the list.

This version of the AM Plan doesn't focus on completing this list, or ensuring all of the uncertainties are correctly grouped, although the Program may wish to do so at a later date. The list is sufficient as-is to illustrate how uncertainties can be organized and examined to facilitate next steps in AM planning. The list below represents an initial attempt from early in the AM Plan development process to group specific hypotheses according to general categories of uncertainty. The overarching critical uncertainties and broad hypotheses presented in Section 1.3 are based on this initial list but have been updated according to specific input from Program participants.

## Silvery Minnow Conceptual Model (M)

**Fish passage at San Acacia and/or other structures *will/will not* result increased silvery minnow range and population size.**

- Importance of San Acacia fish passage
- Fish passages: would different passages at other diversion dams (Angostura) have different benefits than San Acacia?
- Do the diversion dams at San Acacia and Isleta fragment the population and affect demographic and genetic viability?
  - o Does the RGSM migrate long distance in its first year of life, and does this trait enable it to return upstream to natal area?
  - o Is artificial fish passage necessary at San Acacia and Isleta?
  - o Is the genetic diversity of the RGSM so severely reduced as to risk an extinction vortex?
  - o Is it necessary to periodically translocate fish across reaches to ensure demographic and genetic viability--or is there enough exchange already?
- It is not clear how providing upstream fish passage at San Acacia and Isleta diversion dams would contribute to silvery minnow population viability.
  - ➢ H: Providing refugial habitat in the Isleta and San Acacia sub-reaches during river drying events will eliminate the need for upstream passage of silvery minnow at the San Acacia and Isleta diversion dams to maintain silvery minnow population viability.
- It is not known how the upstream passage of non-native and competitor species along with silvery minnow will impact the silvery minnow population.
  - ➢ H: Upstream passage of non-native and competitor species will not adversely affect the silvery minnow population in upstream sub-reaches.
- Silvery minnow may be able to move upstream past Isleta diversion dam, and perhaps even San Acacia diversion dam (SADD), if the diversion/gate operations are modified.
  - ➢ $H_1$: Opening one or more gates in the Isleta diversion dam during times when silvery minnow are moving upstream will provide adequate connectivity of the Albuquerque and Isleta sub-reaches.
  - ➢ $H_2$: Opening one or more gates in SADD, at times when silvery minnow are moving upstream and flows are sufficient to innundate the concrete apron and portions of the rip rap apron, will allow silvery minnow to move upstream of the SADD.
- What are the demographic benefits of providing fish passage? Which fish passage structure provides the most immediate benefits to the RGSM population?

        - H: Upstream passage of fish is blocked by diversion dams. Fish have to swim upstream to return to natal areas after eggs and larvae drift long distances downstream.
- Use of Cochiti Reach and areas above Cochiti Reach for habitat
- Fish passage/fragmentation – Do fish migrate? Are they capable of migrating? Does fragmentation have a negative impact? Could it have a positive impact? Persistence of RGSM in MRG after 80 years of fragmentation might be telling us something?
- The relationship between genetic diversity and habitat fragmentation caused by diversion dams is not known.
        - $H_1$: Providing upstream fish passage past diversion dams in the MRG is likely to have little to no impact on the genetic characteristics of the silvery minnow population as long as the current augmentation program continues.
        - $H_2$: Providing upstream fish passage past diversion dams in the MRG will provide sufficient genetic mixing that augmentation will no longer be required in the MRG for genetic maintenance.

**In the Middle Rio Grande, the silvery minnow preferentially selects *in-channel/off-channel* spawning habitat.**

- What are the top habitat parameters restoration projects should focus on for SWFL/RGSM?
- Are there reach priorities for habitat restoration that should occur?
- The magnitude of downstream drift of eggs and larvae, and its effect on silvery minnow population viability, is not agreed upon.
        - H: Downstream drift of eggs and larvae does not constitute a significant limiting factor for the silvery minnow population.
- The influence of habitat restoration within reaches on silvery minnow movement, growth, survival, and reproductive success is not known.
        - H: Providing sufficient nursery habitat and egg retention features within each sub-reach of the MRG through a combination of habitat restoration and flow management actions will eliminate the need to provide upstream fish passage at diversion dams in the MRG.
- What are the demographic benefits of expanding the range of RGSM into the Cochiti Reach of the Middle Rio Grande?
        - H: Moving the core population upstream reduces loss of drifting eggs and larvae to the Elephant Butte inflow.
    - If there is some degree of demographic risk to the Rio Grande reaches under different management options, would the addition of the 4th reach provide some benefit to stabilizing the population in the Rio Grande?
    - Has there been any serious look at creating a population in the Chama between Abiquiu and the confluence?
    - Is there an informed guess as to why the population went extinct above Cochiti?
    - As this probably won't be a self-sustaining population (at least for a while) what might the demographic benefits be?
    - What would be the demographic rates (including K) of this reach?
    - How big a population could be sustained?
    - How will downstream dispersal be addressed?
- What are the demographic benefits of reducing downstream egg drift? How does egg and larval displacement affect extinction probability? For example, this can be done by habitat restoration or manipulating shape of hydrograph?
        - $H_1$: Transport velocity of drifting eggs and fish will increase and dispersion will decrease in channelized systems.
        - $H_2$: Substantial portion of ichthyoplankton would be transported downstream prior to reaching a free swimming stage.
        - $H_3$: Silvery minnow adaptively and preferentially spawns in low water exchange lateral habitats, including most importantly backwater and other hydrologic retentive floodplain

habitats (if they have access to them) when possible to reduce downstream displacement of eggs and larvae; if there is no access that doesn't mean they won't spawn.

- $H_4$: Upstream retention of incubating minnow embryos varies with discharge.
- $H_5$: Reduction of egg and larval drift and retention in upstream river reaches serves to reduce impacts of habitat fragmentation that would otherwise restrict movement between subpopulations and source-sink exchanges.
- $H_6$: Strategic lowering of banks by modest amounts (e.g., 1.0 foot in some areas) can significantly reduce the threshold at which portions of the east floodplain becomes inundated (e.g., from 3200 to 2000 cfs).
- $H_7$: Early floods keep the food chain productive, and coupling with river is longer so there is a heightened probability of recruitment from these events.
- $H_8$: Low water exchange habitats with persistent linkages to perennial flowing river segments are characterized by a heightened degree of environmental stability and have a heightened potential for rapid faunal exchanges with running water habitats.
- $H_9$: Historically, the primary minnow spawning habitat was over the floodplain which helped limit downstream displacement of eggs and larvae.
- $H_{10}$: Facultative spawning – the minnow are not restricted to the floodplain for spawning, although it might be the preferred. The fish will take advantage of floodplain habitat when it is available but will also spawn in river as necessary. They are very adaptable.
- $H_{11}$: The minnow either spawn in floodplain or the water carries the eggs out there, or both.
- $H_{12}$: In regards to egg drift, retention rates are highly variable.
- $H_{13}$: Floodplain connectivity is extremely important – provides good food, longer inundation results in better habitat.
- $H_{14}$: However floodplain connectivity is greatly affected by management and the floodplain aggradation will only get worse; if the channel doesn't move, it will get worse even if the hydrology stays the same.
- $H_{15}$: Fewer eggs are observed in the river when there is overbank flooding and higher flows – is it because they aren't there or are they just harder to collect?
- $H_{16}$: There is a continuum between pelagic and riparian spawning.
- $H_{17}$: Sediment plugs can have a benefit to floodplain inundation.

- If habitat restoration reduces downstream displacement of eggs and larvae, where should habitat restoration be conducted to have greatest demographic benefit (e.g., upstream versus downstream; wet versus dry)?
  - $H_1$: The spatial correlation of the minnow population within a reach and the distance below which you can more or less ignore the correlation between sites appears to be below 60 km.
  - $H_2$: There is a need to take inventory and map where these features exist in order to attach probability and geo-spatial relationships.
  - $H_3$: Where the channel is narrower and deeper [in Isleta and San Acacia] there is inundation of bars and islands because the narrow spot in the river is getting filled up - thus even in the low water years with not much run off, there is some habitat being created.
  - How and where should habitat be restored/distributed in Angostura?
  - If habitat restoration can improve survivorship in first 45 days, or in the first year, (by increasing egg entrainment or providing YOY habitat) where should habitat restoration be conducted to have greatest demographic benefit (e.g. upstream versus downstream; wet versus dry)?
    - $H_1$: Raise the flow some and fish can start to get into some of the edge habitat; eggs along edge may have a higher probably of being retained but once in the thalweg, there is a much lower probably of being retained.
    - $H_2$: If the minnow are primarily a pelagic spawner, then fragmentation and reach length are the main issues but if the minnow is primarily a riparian spawner then the habitat quality and incisions/inundation would be the driver.
- By implementing management strategies to address the identified threats, can the long-term lambda be increased to greater than 1? (Compare relative benefits of implementing all actions that have a positive demographic benefit and compare to current baseline).
  - $H_1$: The majority of minnows die within 2 months after first spawn (Age-1).

    - $H_2$: Most minnow (that don't die within 2 months after first spawn) will die within 2 months of second spawn (Age-2).
    - $H_3$: Few minnow live >Age-2.
    - $H_4$: Survival of post-spawn adults is the key population bottleneck for minnows today.
- How do we get past/agree on habitat needed for RGSM? In-channel, overbank, both? How much of each? Which should we focus on?
- Habitat – what habitat is demonstrably beneficial to spawning, survival, etc., and at what times – separate the flow component from habitat – habitat may be a function of flow, but not necessarily
- Spawning strategy – do fish select preferred spawning habitats for localized egg retention/rearing success, or is it a broadcast "throw your eggs to the drift" process – still a considerable schism between the two camps with no clear hope of resolution.
- Carrying capacity – how many fish can the system support – what are their spatial/food supply requirements, is there a "correct" number of fish and if so is this a stable number, or is it wildly variable?
- What are environmental cues for spawning (temperature, turbidity, etc.)?
- What is RGSM carrying capacity for each reach in MRG?
- The primary mechanism for silvery minnow population mixing in the MRG before installation of the diversion dams is unknown.
- The controlling constraint on silvery minnow population viability is not known.
    - H: Downstream drift of eggs and larvae does not constitute a significant limiting factor for the silvery minnow population.
- The external and internal factors that cause silvery minnow to move among habitats in the river are not known.
    - $H_1$: Silvery minnow move upstream in response to river drying events.
    - $H_2$: Silvery minnow move upstream in response to high flows during spring run-off.
    - $H_3$: Silvery minnow "hug" the bank lines and do not move during high flows.
    - $H_4$: Silvery minnow move in order to find better quality habitat (food supply, water quality, depth and velocity of flows, substrate composition, etc.)
    - $H_5$: A large number of silvery minnow need to move upstream each year to replace silvery minnow lost to downstream displacement.
    - $H_6$: Only a few individual silvery minnow possess the "desire" to move upstream more than a few kilometers. Silvery minnow do not migrate upstream as a population.
- The natural degree of positive rheotropic response silvery minnow possess, as a species and as individuals, has not been studied.
- There is a need to do basic aging/growth and fundamental fisheries work on the minnow.
- Increasing average life lengths for minnow would increase the overall population recruitment and recovery potential for the minnow.
- Is food supply limiting the RGSM?
    - Has the modified flow regime of the Middle Rio Grande altered the historic productivity of the river and limited food supplies for fish?
    - Does drying of the river channel, especially below Isleta, delay and affect primary and secondary production?
    - Is there an adequate food supply for metalarval and post-larval RGSM after hatching?
    - Has disconnection of floodplains affected productivity of the Middle Rio Grande?
- Does density-dependence of first year survival reduce the per capita RGSM population contribution of the largest recruitment pulses in the range experienced during the period recorded by the population monitoring?
- Is the availability of the limiting resource controlling density-dependence of first year RGSM survival enhanced by summer flow under the range of conditions experienced during the period recorded by the population monitoring?

- Is food the limiting resource which controls density-dependence of first year RGSM survival? This is suspected to be the case, but needs to be tested.
  - If the limiting resource which controls density-dependence of first year RGSM survival is primarily food, what habitat and flow factors control RGSM food availability?
- Does density-compensation of reproduction at the lowest RGSM population densities experienced during the period recorded by the population monitoring allow reproduction to respond to good spawning conditions as if the population were fully or nearly-fully seeded?
- Will the density-compensation of RGSM reproduction allow rapid rebound even from consecutive years of poor recruitment? What is the number of consecutive years that can be tolerated?

**Silvery minnow recovery in the Middle Rio Grande *requires/does not require* all river reaches to remain perennially wet.**

- Can the population effects of periodic seasonal drying of the Middle Rio Grande downstream from Isleta be offset by maintaining short wetted reaches of habitat?
  - Can small river segments (~1 km long) at water outfalls and irrigation returns--and possibly through groundwater pumping--be kept wet to sustain RGSM through drying events to minimize losses of reproductive adults during drying events?
  - Can enough fish be kept alive in these refuges to affect overall population abundance, status, and trends?
- What are the relative demographic benefits of creating many small perennially wet reaches versus one large connected reach? Where should this reach be located to maximize demographic benefits (e.g., minimize P(E)).
  - $H_1$: Drying conditions along the Rio Grande may have similarly benefited silvery minnows, when refugia ponds persisted.
  - $H_2$: Refugial habitat can serve to maintain an adequate number of minnow to hold the population through periods of river drying.
  - $H_3$: Canals might provide a way back to the river and/or temporary support environments as conduit for viable route for egress to the river after a drying period.
- What are the relative demographic benefits of managing to keep the river perennially wet only to San Acacia versus keeping the entire river wet for part of the year and then drying much of the river to Isleta? What are the relative extinction risks for each population?
  - $H_1$: Flow relationships with October population monitoring – what happens in the months between spring and October? This is the best relationship we have right now.
  - $H_2$: Reproductive success is the primary driver of population success; successful reproduction depends on the environmental variability.
- What is the relative demographic benefit of applying available water in upper versus lower reaches?
  - H: Consistent flow encourages a core population to become establish upstream that can be a source population to downstream reaches.
- What is the relative demographic benefit of pumping in times when supplemental water is unavailable? Where and how much might be used (upstream versus downstream; single reach versus many small reaches?)?
  - H: Pumping to maintain refugial areas can help a portion of the population to survive drying events and provide broodstock when natural flows resume.
- What is the demographic effect of reducing the frequency and magnitude of catastrophic drying events?
  - $H_1$: The extent of river drying or the duration of persistent low flows appears to have deleterious effects on the survival of the minnow during summer.
  - $H_2$: Channel drying produces habitat conditions competitively favoring community domination by silvery minnow, and was historically a key factor to maintaining species domination throughout the Rio Grande.

- Have conditions in the San Acacia Reach during the period recorded by the population monitoring generally been more favorable to RGSM than in the Angostura and Isleta reaches?
- Does drying, to the extent experienced during the record of population monitoring, detectably depress RGSM first year survival?

**Recruitment flows and additional flow augmentation *are/are not* necessary to achieve silvery minnow recovery in the Middle Rio Grande.**

- Different effects of Cochiti water release on RGSM habitat conditions in all reaches.
- The Service would like to suggest AM consider the benefit of removal of the Low Flow Conveyance Channel (LFCC) as a testable uncertainty.
- What is the relationship between river flow and reproductive/recruitment success of the RGSM?
    - Can high releases from Cochiti Dam be used to provide floodplain spawning/nursery habitat?
    - What summer/fall flows are needed to ensure sufficient year-around survival and recruitment for a self-sustained population?
    - In years of water shortage, is it best to provide target delivery flows (2003 BO) until the system dries below Isleta, or is it better to keep the river flowing as long as possible and minimize the length and duration of drying?
- What is the demographic benefit of providing greater frequency of adequate recruitment flows?
    - $H_1$: Disconnected floodplains are a key habitat limitation.
    - $H_2$: Floodplain – freshly wetted organics; invertebrates; warmer, slow flows stimulate primary productivity.
    - $H_3$: Channelized, disconnected floodplain habitats disconnect potential major historical post-spawn minnow food sources for weeks to months in spring resulting in a possible food limitation.
    - $H_4$: The silvery minnow is a floodplain spawner.
    - $H_5$: Years with strong spring runoff can be expected to have an association with positive response of number of fish in river; can explain 80 to 90 percent of the density over time.
    - $H_6$: Heightened floodplain productivity is enhanced by lower water exchange rates, heightened subsidy of allochthonous energy inputs at the aquatic-land interface, and heightened temperatures.
    - $H_7$: Recruitment is based on eggs hatching and larvae finding food.
    - $H_8$: Nursery habitat by egg retention or riparian spawning is an important mechanism.
    - $H_9$: Eggs have been found in areas of backwater where there is no current, suggesting adult fish laid eggs there.
    - $H_{10}$: Food in riparian areas seems to be important – seem to find more eggs in areas where there has been stable vegetation over the years, although this is anecdotal and hard to test.
    - $H_{11}$: The principal factor limiting minnow life expectancy and population numbers today is food availability after spawning caused by the extensive disconnection of the floodplain from the river channel along the MRG.
- How do flows support recruitment?
- Do summer habitat(s) support aquatic community?
- What is the relationship between flow and specific life history stages of RGSM (for recovery)?
- What are the top 3 environmental parameters that drive RGSM population?

**Long-term recovery of the silvery minnow in the Middle Rio Grande *requires/does not require* propagation and salvage.**

- How to factor hatcheries, refugia, stocking, and salvage into population recovery efforts?
- What are the benefits of population augmentation
- What is the benefit of stocking minnows?
- Do hatchery augmentation and river salvage have a significant effect on the population of RGSM?

   - Should the wild population of RGSM be augmented with hatchery fish or is survival of hatchery fish too low to make a difference?
   - Does the addition of hatchery fish affect genetic diversity of the wild population?
- Does salvage of RGSM from drying areas for translocation to upstream wetted reaches have a positive effect on the RGSM population--or are numbers of surviving translocated fish too low to make a difference?
- What are the demographic benefits of augmentation and salvage?
   - ➢ H: Rescue, supplementation, and monitoring might contribute to population changes in drier years.
   - Is it beneficial to stock younger versus older fish? There are augmentation data from the last several years that would provide reasonable historic augmentation rates.
   - How many fish are required to remediate other problems on the river that might compromise the population?
   - What season is the best to stock (mortality adjustment)? Could stocking just before a spawn bolster the spawning?
   - How proportionally large does an augmentation event have to be to impact the population? How do we know how big the augmentation group is compared to the total population?
   - How important is salvage of silvery minnow from drying areas to the population?
   - If there is a general downstream movement of the population, then it is important to keep the Albuquerque population. Could salvage play a successful role?
- It is not known how the values of AR and ARH compare for all lots of silvery minnow that have been captive-reared/bred and stocked in the river with values of AR and ARH for wild silvery minnow.
- How much population mixing is required to maintain genetic diversity is not well understood.

**Others**

- What is the most cost-effective way to move closer to recovery? Bang for buck?
- The effect that entrainment in irrigation infrastructure has on silvery minnow population viability is not known.
   - ➢ H: The current amount of silvery minnow entrainment in irrigation facilities does not have a significant adverse impact on silvery minnow population viability.
- What is benefit of removal of the Low Flow Conveyance Channel?
- What is the demographic effect of reducing the frequency and magnitude of catastrophic water quality events? What WQ scenario might reasonably represent the future conditions?
   - ➢ $H_1$: Water quality caused by human discharges has had an unlikely significant adverse influence on silvery minnows at the population level.
   - ➢ $H_2$: Water quality was not and is not a key factor driving low population numbers of minnow in the Rio Grande.
   - ➢ $H_3$: Localized conditions of high water quality risk have occurred in the MRG, which may have caused and still may be causing local mortalities, but these effects are not significant at the population for the minnow.
- Effectiveness of RGSM sampling techniques.
   - Relationship between results of Rio Grande silvery minnow survey monitoring protocol and true population size.
   - Timing of sampling throughout the reaches.
   - Population monitoring (scale and accuracy). Level of monitoring/type/questions/hypotheses that should occur.
   - Monitoring – can current methods actually collect and identify fish in a manner that allows a reliable indication of population size, distribution, and trends?

    - Does population estimation from small seine captures in localized habitats grossly under estimate numbers of silvery minnows in the MRG?
    - Population monitoring is good for trends but there is uncertainty over population estimates, age classes, etc.
- Because of extreme interannual variability in recruitment, and strong density-compensation of recruitment during years with favorable spawning conditions, will empirical estimates of lambda based on the mean and variance of observed recruitment be a good predictor of RGSM population viability?
- Is the very low genetic effective population size calculated from the models applied to RGSM genetic monitoring data an artifact of sampling heterogeneity?
- Utility of PVA/PVHA
- Do results of PVA modeling support current Recovery Plan targets for down-listing and recovery?
- Have all identified threats in listing document be adequately addressed in PVA? (e.g., predation)
    - ➢ H: Reducing identified threats can help to increase species security and viability.
- What are the demographic benefits of creating additional populations within the RGSM historic range (e.g., Pecos River between Santa Rosa Dam and Sumner Reservoir)?
    - ➢ H: Additional populations provide redundancy that helps to reduce overall species extinction risk.

## Flycatcher Conceptual Model (F)

**Flow augmentation *is/is not* required to create/maintain wetted breeding habitat for the flycatcher.**

- Value of San Acacia habitat restoration (reach most likely to dry)

**Flycatcher recovery in the Middle Rio Grande *requires/does not require* habitat restoration in the San Acacia Reach and/or other river reaches.**

- Do SWFL habitat creation/modification activities lead to population increases?
- What are the top habitat parameters restoration projects should focus on for SWFL/RGSM?
- Are there reach priorities for habitat restoration that should occur?
- What is the most cost-effective way to move closer to recovery? Bang for buck?
- How are habitat patches used by willow flycatchers?

**Others:**

- Population monitoring (scale and accuracy). Level of monitoring/type/questions/hypotheses that should occur?

## MRG System Conceptual Model (S)

**Flow augmentation of varying magnitude, duration, frequency, timing, and rate of change from Cochiti Dam and other sources *will/will not* affect river morphology and habitat quantity/quality in the Middle Rio Grande.**

- Do Program habitat restoration projects result in suitable RGSM and SWFL habitat? Is that habitat utilized?
- Response of species to different water years and different water management strategies
- Sustainability of actions over time
- Water quantity, and how to manage that quantity
- Adjudication of water rights
- Relationship between predicting water year and planning management actions accordingly

**Sediment augmentation and/or providing sediment movement through or around diversion structures *are/are not* required to maintain riverine habitat for the silvery minnow and flycatcher.**

- How are fluvial geomorphic processes determining habitat for SWFL/RGSM?

**Others**

- What to do about invasive species, if anything (impacts of tamarisk beetle; water consumption of native and non-native vegetation)?
- Other species of concern, and the impacts on habitat restoration on wildlife corridors. What strategies and tactics will have multiple ecosystem benefits in addition to the 2 target species?
- Effectiveness and cost of all actions
- Will conditions adequate for RGSM population persistence also prove adequate for SWFL recruitment?
- Achievability of recovery goals and recovery criteria (what are the target population levels for both species?)
- Basic effectiveness of habitat monitoring techniques and rolling that back into design of sites
- Status of current critical habitat designations and recovery plans
- What questions are we trying to answer/RPA elements trying to meet by monitoring?
- Prioritization of type and size of habitat restoration (What is too small? How much of each type of habitat restoration?)
- What does a rehabilitated/restored MRG look like? What are we working towards? And how will we know when we get close to that? What is the physical representation of success?

## Uncertainties beyond the Conceptual Models

- How does Program determine good science?
- Overall Program focus/priorities? Habitat restoration, science, % of each, other?

# Appendix D: Example of 'Safe-Fail' Decision Rules from the Columbia Basin

The Federal Columbia River Power System Adaptive Management Implementation Plan (NOAA, 2009) utilizes an "expanded contingency process" that includes *early warning indicators* and *significant decline triggers* to initiate the processes of evaluating, preparing and implementing rapid response actions. This approach is even more precautionary and responsive than earlier management provisions where contingency planning would be initiated only if fish abundance and productivity displayed decreasing trends in 2013 and 2016 (scheduled comprehensive evaluations).

Both the early warning indicators and significant decline triggers in the Columbia River AM Plan are based on a four-year mean of natural adult abundance (Chinook salmon and steelhead). If this metric falls below a 20% likelihood of occurrence, an early warning indicator is tripped, and if below 10%, a significant decline trigger is tripped. Additional indicators and triggers are also being developed. The early warning indicator provides a signal that the decline in abundance warrants further scrutiny and may reach the level of a significant decline in 1-2 years. Within 120 days of the observation that an early warning trigger has been tripped, specified parties will evaluate the status of the species and determine which (if any) rapid response actions should be implemented. If warranted, rapid response actions must be implemented within 12 months. The significant decline trigger provides a signal that immediate mitigation is required. If this abundance level were to persist it would conflict with the BO's "No Jeopardy" condition and reinitiate consultation. Within 90 days of the observation that a significant decline trigger has been tripped, specified parties will determine which rapid response actions are required and must then implement them as soon as practicable and not later than 12 months from the initial trigger. Concurrently, within 4-6 months of the trigger, specific modeling and analysis will be completed to determine whether the rapid response actions are likely to be sufficient or whether long-term contingency actions will need to implemented.

Rapid response actions constitute a menu of short-term contingency actions with the potential to immediately improve fish survival developed collectively by multiple federal agencies. The regulatory processes are already in place such that rapid response actions are ready to be implemented relatively quickly (1-12 months); however, these are only intended to be temporary responses. Rapid response actions include actions at dam projects and reservoirs, increased predator control, modified harvest, and safety-net hatchery programs. Long-term contingency actions are substantially larger mitigation measures that will take greater than one year to implement. Each long-term contingency action will have a unique timeline and many will require additional negotiations to modify existing agreements or regulations. Potential long-term contingency actions identified by the relevant federal agencies include phase II hydro actions, reintroduction of salmon populations in extirpated areas, more aggressive predators control, more substantial harvest modifications and re-initiated harvest review process, longer-term conservation hatcheries, hatchery reform, John Day reservoir operations at minimum operating pool (April-June), and breaching lower Snake River dams.

**References**

NOAA Fisheries. 2009. *FCRPS Adaptive Management Implementation Plan*. 2008-2018 Federal Columbia River Power System Biological Opinion.