RECLAMATION

Managing Water in the West

Middle Rio Grande River Maintenance Program Comprehensive Plan and Guide

Middle Rio Grande Project, New Mexico
Upper Colorado Region

U.S. Department of the Interior
Bureau of Reclamation

April 2012

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Photo: Jonathan AuBuchon, Rio Grande near Jemez River confluence, flow approximately 3,100 cubic feet per second, April 2010.

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April 2012

Acronyms and Abbreviations

AAO	Albuquerque Area Office
AMAFCA	Albuquerque Metropolitan Arroyo Flood Control Authority
ARRA	American Recovery and Reinvestment Act
BASE	baseline condition in model
BDANWR	Bosque del Apache National Wildlife Refuge
cfs	cubic feet per second
CWA	Clean Water Act
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
HEC-RAS	Hydrologic Engineering Centers River Analysis System
LFCC	Low Flow Conveyance Channel
mm	millimeter
MRGCD	Middle Rio Grande Conservancy District
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act
NMF-V	no maintenance future modeling scenario - vertical
NMF-H	no maintenance future modeling – horizontal scenario
Project	Middle Rio Grande Project
Reclamation	Bureau of Reclamation
REHAB	Rehabilitate channel and flood plain scenario
RGSM	Rio Grande silvery minnow
Plan and Guide	The Middle Rio Grande River Maintenance Comprehensive Plan and Guide
River Maintenance Program	The Middle Rio Grande River Maintenance Program
RM	river mile
Service	U.S. Fish and Wildlife Service

SRH-1D	Sedimentation and River Hydraulics One-Dimensional Sediment Transport Dynamics Model
SRH-2D	Sedimentation and River Hydraulics Two-Dimensional Sediment Transport Dynamics Model
SSCAFCA	Southern Sandoval County Arroyo Flood Control Authority
SSPA	S.S. Papadopulos and Associates, Inc.
SWFL	Southwestern willow flycatcher
URGWOM	Upper Rio Grande Water Operations Model
URGWOPS	Upper Rio Grande Water Operations
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WDFW	Washington Department of Fish and Wildlife

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1. Introduction

The Middle Rio Grande River Maintenance Plan and Guide (Plan and Guide) serves as a guide for the Bureau of Reclamation's (Reclamation) future river maintenance activities within the existing Middle Rio Grande Project (Project) authorization. The objective of the Plan and Guide is to provide a foundation of information for the Middle Rio Grande River Maintenance Program (River Maintenance Program) activities and to help resource managers select sustainable maintenance strategies for each reach that meet multiple objectives. The Middle Rio Grande River Maintenance Program covers the Middle Rio Grande from Velarde to Caballo Reservoir (figure 1.1).

River maintenance philosophy has changed over time (see Middle Rio Grande River Maintenance Plan, Part 1 Report [Reclamation 2007]), and a shift towards a geomorphic process-based approach for projects began in the 1990s. As the understanding of geomorphic processes on the Middle Rio Grande continued to grow, the need for a comprehensive evaluation of the system as a whole became apparent. First, the existing River Maintenance Program was reviewed. Next, the entire Middle Rio Grande (by reaches of similar geomorphology) was systematically investigated to allow comparison of maintenance needs of the reaches and to determine the effectiveness of reach scale strategies. Third, maintenance methods were assessed for applicability on the Middle Rio Grande. The result is an engineering and geomorphic review that incorporates ecological needs (within river maintenance authorization) that can be used to readily plan and implement the most cost-effective and environmentally sound strategies that potentially reduce Reclamation's long-term commitment of resources.

Reclamation's authorization (see Part 1 Report, section 3.1, for more information) for erosion protection, limited flood control, and water delivery continue unabated. Most historical needs remain important in the present and have been joined by new considerations. In recent years, the program has evolved to accommodate Reclamation's increased responsibility for environmental protection to comply with the National Environmental Policy Act (NEPA) and the regulatory requirements resulting from the presence of endangered species. The combination of immediate site-specific requirements and long-term strategies mean that several components are necessary for the program. These components are listed below:

- Trend Monitoring through Data Collection and Analysis; Geomorphic Analysis; and Hydrologic, Hydraulic, and Sediment Transport Modeling and Analysis

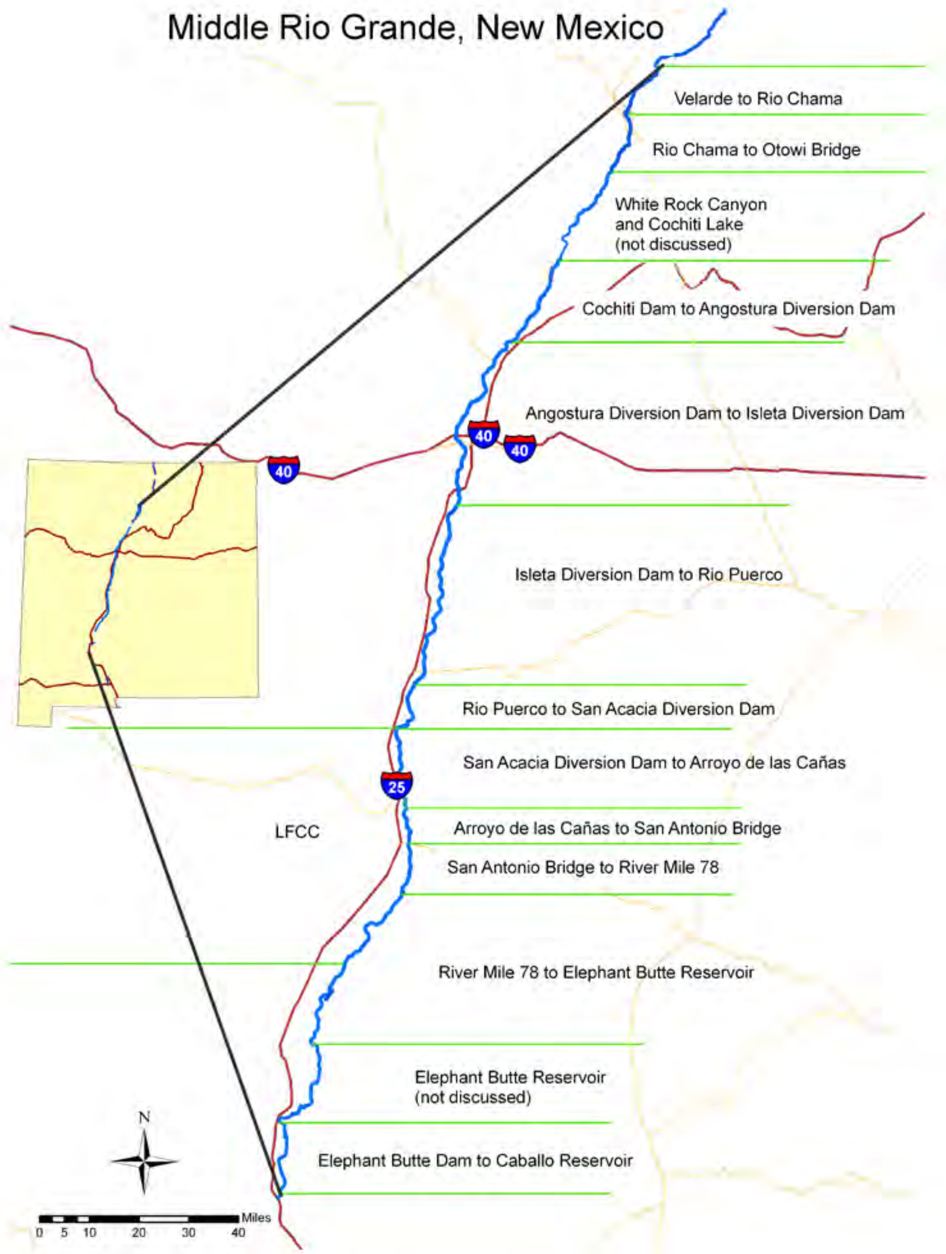

Figure 1.1. Location of Middle Rio Grande and Plan and Guide reaches.

- Initial Project Investigation and Assessment
- Alternative Development, Evaluation, and Selection
- Design and Project Description
- Environmental Compliance
- Construction and Maintenance
- Monitoring and Adaptive Management

The Plan and Guide supports compliance with applicable laws and regulations as previously described. The Plan and Guide is intended to help make informed decisions on future program activities.

1.1 River Maintenance Comprehensive Plan and Guide Vision and Objective

> *The vision of the Middle Rio Grande River Maintenance Comprehensive Plan and Guide is to develop long-range guidelines for the Middle Rio Grande River Maintenance Program that accomplishes Project purposes in an environmentally and economically sound manner.*

In meeting the above vision, Reclamation is required to accomplish its mission within the Federal authorization of the Middle Rio Grande Project (Flood Control Acts of 1948 and 1950) and other applicable Federal environmental statutes (i.e., NEPA, Clean Water Act [CWA], and Endangered Species Act [ESA]). The Middle Rio Grande is a complex and continuously changing river system involving many river management and maintenance challenges and issues. This Plan and Guide integrates these complex challenges and issues by formulating goals and strategies that are in harmony with legal, institutional, economic, geomorphic, ecologic, and hydrologic realities on the Middle Rio Grande.

This Plan and Guide provides a comprehensive assessment to help the River Maintenance Program select sustainable maintenance strategies for 11 distinct geomorphic Middle Rio Grande reaches. The identified maintenance strategies in this Plan and Guide are formulated and intended to address Reclamation's mission on the basis of a holistic view of the Middle Rio Grande reach needs and conditions. This holistic view includes:

- Looking at the whole system from Velarde to Caballo
- Reviewing the entire area on a consistent basis
- Working toward addressing causes of maintenance needs rather than only symptoms (to the extent practical)
- Creating a flexible framework to assess channel and flood plain conditions and significance on multiple spatial and temporal scales

- Examining the geomorphology, engineering, ecosystem, and economics effects of strategy implementation both within a reach and upstream or downstream
- Coordinating with other stakeholders in our shared management of the Middle Rio Grande while remaining within the River Maintenance Program authorization.

All of these steps lead to a more effective River Maintenance Program.

In accomplishing effective river management, Albuquerque Area Office (AAO) decisionmakers and other stakeholders need to consider the goals, strategies, and the reach-based strategy assessments (involving geomorphic, engineering, ecological, and economic criteria) presented in this Plan and Guide. The intent of the Plan and Guide and its assessments is to establish maintenance priorities along the Middle Rio Grande and to support a strategic long-term decisionmaking process for future maintenance. Effectiveness ratings are provided as part of each suitable strategy assessment. These effectiveness ratings are comparative between the suitable strategies and the reaches. They will provide defensible guidelines for making future maintenance strategy and reach priority selection.

The updated goals for this Plan and Guide are consistent with the ongoing and future river channel dynamics and are in accordance with Reclamation's authorized mission. The strategies are screened for their geomorphic suitability in each reach according to the current and future river processes and trends. The strategies presented also seek to enhance both the existing ecological diversity and value to the extent possible, realizing that this holistic approach must strike a balance with other elements of Reclamation's Middle Rio Grande authorized mission. Related to Reclamation's mission on the Middle Rio Grande, four reach characteristics are evaluated: channel instability, water delivery impact, infrastructure/public health and safety, and endangered species habitat values and needs. These reach characteristics are a valuable tool to ensure that Reclamation's mission and interests in the given reach are being met by the strategies.

An important note of this Plan and Guide is that an enhanced contemporary review was undertaken to achieve the best long-term goals and strategies for the River Maintenance Program. In looking at river maintenance, this new methodology is evident throughout this Plan and Guide (when compared to other recent programmatic documents) and is most strongly reflected in the new goals, strategies, and the strategy assessments for each of the reaches. It is also important to note that the strategies formulated and their assessment in this Plan and Guide are supported by state-of-the-science/practice literature reviews, sediment transport and hydraulic modeling, and geomorphic modeling and assessment. Also, for each of the defined plan strategies, suites of applicable methods are described that will be employed by future projects to meet each strategy's intent.

Strong consideration was given to the current and future geomorphic processes and trends occurring in the Middle Rio Grande for the current flow and sediment regimes. Future river maintenance strategy implementation is planned to be as compatible as possible with these geomorphic processes and trends as well as the ecosystem function needs identified in this Plan and Guide. This strong approach seeks to understand and treat the causes of channel instability rather than the trending symptoms as much as is practical. The best available tools related to predicting the future channel conditions and needs through sediment transport and hydraulic and geomorphic modeling are used in this Plan and Guide. Analyses with these tools are at appropriate levels given the scope and scale of the Plan and Guide

Lastly, this Plan and Guide provides recommendations for future River Maintenance Program decisions regarding analyses, data collection, and maintenance practices including environmental compliance needs (see chapter 16). The combined executive summary for parts 1 and 2 provides an overview of the analysis and recommendations.

In summary of the vision and objective, this Plan and Guide provides the framework to achieve the best set of decisions possible by:

- Identifying changing river conditions and new techniques to manage them
- Reducing emergency maintenance to protect infrastructure
- Providing net habitat improvement (within River Maintenance Program authorization)
- Implementing long-term strategies
- Evaluating and documenting effects of strategies and methods for better future use
- Coordinating with other agencies

1.2 Middle Rio Grande River Maintenance Plan Part 1 Report Purpose and Scope

The Part 1 Report (Reclamation 2007) describes the program and its needs and benefits and includes a review of the Middle Rio Grande Project authorization, the current conditions of the river, and how environmental laws have been integrated into river maintenance activities. The Part 1 Report (Reclamation 2007), published in May 2007, is available online at the following Web site address:

http://www.usbr.gov/uc/albuq/envdocs/reports/mrgRivMaint/index.html

1.3 Middle Rio Grande River Maintenance Program Comprehensive Plan and Guide Purpose and Scope

This report documents the second step in developing comprehensive guidelines for the River Maintenance Program. It supplies frameworks for guiding River Maintenance Program activities and should be considered with the Middle Rio Grande Maintenance Plan Part 1 Report that describes the River Maintenance Program, its needs, and benefits. The Plan and Guide includes feasibility assessments for reach-based strategies, project design and implementation approaches, and planning future analyses, data collection, and updates in future maintenance practices. It incorporates results from current studies to help guide Program decisions for future analyses, data collection, and maintenance practices including environmental compliance needs. The purpose of this report is to:

- Provide the technical information required to review existing program goals and to update those goals as appropriate. **Goals** are outcome statements that describe desired conditions on the Middle Rio Grande

- Identify and evaluate maintenance strategies. **Strategies** are the basic approaches and paths towards achieving the goals on a reach-wide basis.

- Recommend which strategies to move forward for further analysis and to review possible maintenance methods for applicability on the Middle Rio Grande. **Methods** are the tools used to implement those strategies for achieving the goals.

The Plan and Guide consists of the following sections and subject areas for reaches:

- **The Main Report provides an overview and summary of the analysis:**
    - **Chapter 1: Introduction** (introduces the plan)
    - **Chapter 2: Maintenance Methods.** Describes maintenance methods applicable to the Middle Rio Grande and how they might be used.
    - **Chapter 3: Maintenance Goals and Strategies.** Describes the goals for maintaining the Middle Rio Grande, the six reach scale maintenance strategies that may be pursued to achieve the goals, and the methods that are applicable to a given strategy.
    - **Chapter 4: Strategy Assessment Methodology.** Briefly describes the assessment approaches used to evaluate the six maintenance strategies for each of the Middle Rio Grande's 11 reaches of relevance to river maintenance.

  - **Chapters 5 through 15:** Each chapter briefly describes that respective reach and discusses the results of the analysis, showing which strategies were eliminated and which strategies might work for each reach. These chapters present generalized results and implications of these strategies for these particular reaches.

  - **Chapter 16: Summary and Recommendations.** Briefly outlines information needs and recommendations for the next steps.

- **Appendix A: Middle Rio Grande Maintenance and Restoration Methods.** Provides more information on the methods and treatments discussed in chapter 2.

- **Appendix B: Modeling and Indicator Results.** Provides more information on the technical approach to analyses and modeling used to determine the effects of each strategy on each reach.

- **Appendix C: Strategy Assessment.** Provides more information on the strategy assessment approach and results of the assessment for each reach.

- **Appendix D:** Independent Review Comments. Provides comments from two independent reviews. The first was performed during strategy assessment methodology development and the second after assessment results were available.

The analyses and assessment presented in this report are at an appraisal level and were conducted to identify needs and opportunities, formulate and evaluate an array of strategies, and recommend at least one suitable strategy per reach that warrants additional Federal investment in a feasibility study. Existing data and new analytical tools are used. Quantitative costs and effectiveness estimates are for comparative purposes between strategies and limited to ranges. Final recommendations are based on these assessments and the available information presented herein. This appraisal level analysis is intended to provide a foundation and framework for additional tiered studies and reach-wide analyses. Further feasibility investigation is needed to select and implement strategies. Suitable strategies are evaluated at an appraisal level based upon criteria of engineering effectiveness, economics, reduction in negative environmental effects, and/or increased environmental benefits, resulting in a greater overall effectiveness than current practices.[1] It also provides a consistent level of analysis and set of information on each of the reaches to help prioritize maintenance strategies.

Several followup steps are planned for the future. One followup step is to use the information in the combined reports to select the first reaches for further study, followed by strategy feasibility analysis, selection, and design for implementation

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[1] Please note that this report uses capitalization to denote specific terms of analysis: Goals, Strategies, Reach Characteristics, Evaluation Factors, Attributes, and Indicators. Please see the inside of the back cover for definitions of unique terms.

in those reaches. Another step is to define the information needs and the data collection and analysis program to meet those needs. Needs include project design data; better understanding of drivers, processes, and trends in the system; and updating the list of applicable methods with state-of the-knowledge as new techniques or additional information on existing methods are developed.

The level of analysis and modeling of eight reaches (from Cochiti to Elephant Butte) were purposefully kept at a similar level of detail to allow a consistent methodology for comparison of strategies by reach. While the remaining three reaches—Velarde to Rio Chama, Rio Chama to Otowi Bridge, and Elephant Butte Dam to Caballo Reservoir—were not modeled due to a lack of data, they were analyzed using existing data and professional judgment. White Rock Canyon and Cochiti Lake and Elephant Butte Reservoir pool are not discussed, because these areas do not have current jurisdiction and needs.

1.4 Reclamation, Stakeholder, and Regulatory Considerations

The Middle Rio Grande River Maintenance Plan, Part 1 (Reclamation 2007) contains a complete description of the role of Reclamation, other Federal and State agencies, Middle Rio Grande Conservancy District (MRGCD), and regulatory requirements on the study area (see sections 2.5 and 3 of the Part 1 Report). Coordination with stakeholders and consideration of their policies and responsibilities will help ensure that Reclamation's maintenance program is compatible with the roles and responsibilities of others. Stakeholder regulatory considerations include, but are not limited to, NEPA; ESA; National Historic Preservation Act (NHPA); and CWA, sections 404, 402, and 401.

Several local groups, other governmental agencies, and Native American pueblos are working on river management activities where Reclamation is not directly involved. Additionally, under the Middle Rio Grande Collaborative Endangered Species Program, Reclamation helps support the analysis, design, and construction for habitat restoration on the river. For Reclamation's river maintenance activities to function and provide the most sustainable benefits as possible, the geomorphic and environmental benefits and effects of all the restoration activities need to be integrated as much as possible.

Various local governments and pueblos have their own policies about river maintenance and river restoration activities (including land use practices). During the feasibility and design phases, inquiries are made to determine these policies so they can be appropriately included in projects. In some instances, Reclamation may be able to positively influence the actions of others to benefit the river. Reclamation professionals have the privilege and responsibility to educate the public, public representatives, and representatives from other governmental agencies/pueblos about river characteristics and the potential response of rivers to their actions. This includes providing education about both positive and negative effects of policies and management actions.

1.5 Water Operations

With numerous upstream large dams and diversions, the flow of the Middle Rio Grande is highly managed. Flow releases and water management can have significant effects upon river maintenance works. Due to flood control considerations and with the current set of constraints (safe capacity flow for levee, San Marcial Railroad Bridge, etc.), the released flows often are curtailed before impacting river maintenance works. For example, the levee safe flow conveyance capacity can be limited from the north boundary of the Bosque del Apache National Wildlife Refuge downstream to river mile (RM) 60 depending upon Elephant Butte Reservoir stage and local and reach scale sediment deposition. Increasing levee capacity could increase upstream reservoir peak flow releases.

High-flow releases could reduce future vegetation encroachment, maintain the active channel width, and provide overbank flows that improve ecosystem health.

The rate of lateral migration along actively eroding banks is influenced by the magnitude, duration, and frequency of high flows and the balance between sediment transport capacity and supply. Actively migrating bank lines can result in erosion of the bosque along with new deposition areas upon which new riparian vegetation can grow, thus supporting riparian succession. In degrading reaches (where the bed elevation is lowering), the river channel is in the process of converting to a single thread, slightly sinuous channel. Increased flow magnitude, duration, and frequency of floods may accelerate the conversion process as may decreased sediment supply. However, in many reaches, higher discharges have many benefits as described above.

Use of water operations as a river maintenance strategy or method is not part of the scope of this report. However, it should be noted that the reductions in peaks, increased low flows of longer duration, and reduced sediment supply have disrupted the historical geomorphic pattern. The previous pattern was that large, high energy flows reworked sections of the river and flood plain, removed vegetation, supplied sediment, may have relocated the main channel to lower elevations, and resulted in a wide, braided, sandy channel well connected to the flood plain. During long periods of lower peaks, vegetation encroached, and the channel narrowed and may have deepened until the river experienced the next flow large enough to reset the system again. High flows could enable some of these processes to continue, which shape channel morphology and ecosystem health as part of overall river management.

This report does touch upon the effects of water operations on the river and river maintenance works. Coordination with water management officials, particularly during peak flows, is essential for public safety. More information on Rio Grande water operations and infrastructure can be found in the Reclamation, U.S. Army Corps of Engineers (USACE), and New Mexico Interstate Stream Commission's 2007 Final Environmental Impact Statement, Upper Rio Grande Basin Water Operations Review (USACE et al. 2007).

1.6 Geomorphology/Ecology Process-Based Approach

Traditional river engineering works often have created environmental problems as a result of imposing unnatural conditions on rivers by modifying channel cross sections and length, creating lateral confinements, and altering flow and sediment supply (Thorne et al. 1997, Gore and Petts 1989, Gore 1985, Brookes 1988, and Brookes and Shields 1996). On the Middle Rio Grande, much of the channelization as well as the flow and sediment load reduction was planned to reduce and reverse aggradational trends in the channel. Constructed channel and reservoir works to control aggradation and flooding have been so effective that the channel has deeply incised and narrowed in many reaches. This imposed flow and sediment supply regime has contributed to listing the Rio Grande silvery minnow (*Hybognathous amarus*) (RGSM) and Southwestern willow flycatcher (*Empidonax traillii extimus*) (SWFL) as endangered species. This also contributed to the channel disconnection from the flood plain in many reaches.

Given this new flow and sediment regime, the geomorphic/ecological process-based approach is based on the current understanding of the current and future river processes and seeks to preserve and enhance both the existing ecological diversity and river stability within the context of existing authority. Future river maintenance is planned to be as compatible as possible with geomorphic trends (see section 4.1.1) and ecosystem functions. Recognizing that there are physical (i.e., lateral), water use, and legal constraints on the Middle Rio Grande, the goals of this approach may not be completely obtainable. In addition, applying the geomorphic/ecological process-based approach as much as possible will enable the river to maintain a larger degree of sediment continuity and to work with natural processes and form while minimizing future maintenance requirements (Thorne et al. 1997). This approach seeks to understand and treat the causes of channel instability rather than the symptoms as much as is practical. Geomorphic and computational hydraulic and sediment engineering analyses are the cornerstone of this approach to river maintenance.

1.7 Adaptive Management

Adaptive management is a planned, systematic process to achieve the best set of decisions possible in the face of uncertainty and lack of knowledge as outcomes from future strategy/project implementation and river response dynamics become better understood. It requires a series of steps:

- Defining river maintenance and ecosystem function objectives (may include stakeholder involvement)
- Identifying the approach to potential alternatives
- Predicting channel response (using state-of-the-art design and analysis methods) to each alternative
- Selecting the alternative approach that best meets objectives
- Developing monitoring plans (including baseline data collection)
- Implementing the selected alternative and monitoring plans
- Comparing monitoring results to predictions and objectives
- Adjusting the strategy/project approach as needed to achieve the desired objectives
- Documenting all steps

The intent is to adjust the implementation in a timely manner to address any concerns that may arise and provide valuable lessons learned to projects in the future.

Adaptive management also "recognizes the importance of natural variability" (Williams et al. 2007) in river response caused by dynamic river conditions and the project/strategy implementation. "It is not a trial and error process, but rather emphasizes learning by doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits" (Williams et al. 2007). Monitoring and evaluating will lead to improved scientific knowledge on the effects of projects/strategies upon the geomorphology and ecosystem and ways to improve future projects. Documenting the project objectives, process, and predicted results is necessary to understand which activities work (or do not) and why. The *why* is important because success or failure can result from factors such as incorrect assumptions, inadequate design/analysis methods, poorly implemented designs, changing conditions at the project site, flawed interpretation of monitoring data, or any combination of these factors. This information is essential to improve both the current and the next project/strategy or to repeat the success.

Using an adaptive management approach for river maintenance in dynamic river systems often extends the time period of a project/strategy implementation, but project goals more likely are to be met. Traditional maintenance methods are implemented within one construction season. In contrast, some projects incorporate plans for reviews and work in subsequent construction seasons after the occurrence, or in the absence, of significant channel forming flows. This approach works well with projects that "assist" channel responses (i.e., the Phase 3 maintenance activities as described in section 2.1.3 in the Part 1 Report [Reclamation 2007]).

Adaptive management of projects is different than maintenance of projects. Maintenance generally restores or reconstructs originally implemented features. The amount, frequency, and type of maintenance actions are generally known as described in chapter 2. However, the variability of the drivers and controls of geomorphology (e.g., very low or very high flows, incoming sediment load, and nonuniform bed/bank materials) can lead to rapidly changing channel conditions that may require emergency actions. The bank erosion just upstream of San Acacia that threatened Drain Unit 7 in 2005 is a good example of a maintenance emergency due to high peak flows. Changing channel conditions also may cause the need to modify existing project implementations in nonemergency situations.

Adaptive management may change originally implemented channel conditions and features, and the frequency and type of adaptations are not known prior to implementation. Implementing effective adaptive management requires answering several questions including:

- What are the measureable management objectives?
- How much evidence, monitoring, and analysis are needed to conclude that adaptive management changes should be made?
- How will scientific and engineering results be used in future decision processes?
- How frequently will monitoring and analysis be conducted?
- How frequently will decisions be made?
- Who decides to implement adaptive management?

The answers to these questions are beyond the scope of this appraisal level evaluation. More detailed evaluations will be made of strategies in each reach that are determined to warrant further analysis in this report (see chapters 5–15), and adaptive management needs in strategy implementation will be revisited there.

Adaptive management is already a part of river maintenance, and these efforts will continue in the future. The amount and type of adaptive management will depend upon the level of uncertainty in strategy and project implementation effects and knowledge gaps. Current adaptive management may need to be altered in the future to be consistent with the Middle Rio Grande Endangered Species Collaborative Program adaptive management (Murray et al. 2011)

2. Maintenance Methods

2.1 General Types of Methods

Many channel rehabilitation, restoration, and maintenance methods are used on rivers for multiple purposes. An extensive—but not exhaustive—literature review has been conducted to identify a suite of methods. Appendix A: Middle Rio Grande Maintenance and Restoration Methods provides the following more detailed information:

- A summary of method performance confidence rating, advantages, disadvantages, and range of applicability (table A.1)
- A summary of geomorphic response, engineering effectiveness, and economics cost and habitat outcomes of each method[1] (table A.2)
- An extensive summary of each method

The methods recommended for the Middle Rio Grande are presented in more detail in appendix A of this Plan and Guide. For each method in appendix A, there is a description of the:

- General range of application
- Objectives and benefits of a method
- Features
- Common modes of failure
- Common countermeasures if needed
- Advantages and disadvantages
- Geomorphic response
- Ecological benefits and effects
- Requirements
- Level of reliability
- Potential construction issues
- Design flood criteria

[1] Note that these topics are discussed for each method. These are specific to the methods and are not the same as the evaluation factors used to evaluate the strategies. See the inside of the back cover for a definition of unique terms.

- Durability
- Project life

In this chapter, the terms "maintenance" or "river maintenance" include river restoration/rehabilitation, bank protection/stabilization, and other methods. The applicable methods for the Middle Rio Grande have been organized into groups of methods with similar features and objectives:

- Infrastructure Relocation or Setback
- Channel Modification
- Bank Protection/Stabilization
- Cross Channel (River Spanning) Features
- Conservation Easements
- Change Sediment Supply
- Habitat Improvements and Mitigation

Each of these categories contains multiple methods. Combining methods provides a means to meet multiple objectives as discussed in section 2.10. It is anticipated that new or revised methods will be developed in the future. Reviewing new or revised methods and updating method summaries on a periodic basis is advisable so that existing and newer methods receive full consideration during the planning and design phases. A systematic geomorphic and engineering analysis at a reach scale should be undertaken prior to project planning, design, and implementation. This will help to reduce the likelihood of project failure or excessive ongoing maintenance costs. No single method or combination of methods is applicable in all situations. Although there is little guidance available for method selection (including combinations of methods), the selection process should include an evaluation of geomorphic response and the Engineering Effectiveness, Ecosystem Function, and Economics Evaluation Factors. Method selection also should be consistent with the Biological Opinion, 2003 (U.S. Fish and Wildlife Service [Service] 2003) and with applying bioengineering and nonstructural approaches as much as is practical.

2.2 Infrastructure Relocation or Setback

Protecting riverside infrastructure and facilities constructed near the riverbanks may laterally constrain river migration and prevent access to the historical flood plain. The objective of this method is to provide space for the river to evolve in response to changing conditions and to minimize the need for additional future river maintenance actions. Potential facilities to be relocated include levees, dikes, access roads, canals, drains, culverts, siphons, utilities, etc. Relocating riverside infrastructure may provide the best opportunity for current geomorphic processes to occur unencumbered by local lateral infrastructure constraints. This method can encourage geomorphic processes to continue and may provide an opportunity for the river to achieve a long-term, dynamic equilibrium (Newson et al. 1997 and Brookes et al. 1996). These geomorphic processes include lateral migration, which can maintain the health of the riparian zone through erosion of banks and sediment deposition. Bank erosion can remove older growth riparian areas while deposition can create new flood plain and riparian areas. Thus, lateral migration can help maintain a riparian zone with a mosaic of different age classes of native plant communities (Brookes 1996).

Levee relocation can provide the potential for river flows to access historical flood plain areas (Bauer et al. 2004, Brookes 1996, and Petts 1996). The magnitude and frequency of access depends upon local topography and the availability of flows that go overbank into adjoining flood plain riparian zones. When riverside infrastructure is placed outside the meander belt width or braid plain, future bank protection often is not needed. Otherwise, new bank protection likely will be needed in the future.

For incised channels, lateral migration may provide an opportunity to establish a new inset flood plain and riparian zone surfaces. This is especially important when incision has led to the main channel being disconnected from its historic flood plain. Connected flood plains are inundated during flood peaks that occur about every 2–5 years. Disconnected flood plains are inundated less frequently, leading to reduced ecosystem health. Re-establishing or establishing greater connectivity with the flood plain can be considered a successful rehabilitation project even if the channel is narrower than historical widths (Brookes et al. 1996 and Kondolf et al. 2007). In many reaches of the Middle Rio Grande, levee relocation may involve moving riverside drains and other structures.

2.3 Channel Modification

Channel modifications are actions used to reconstruct, relocate, and re-establish meander bends or relocate the channel in a more advantageous alignment consistent with project goals. Channel modification actions also can result in a larger channel capacity and cause changes in channel shape. Excavating new channel alignments and plugging existing channel entrances are part of this method. The entire river cross section and/or the channel locations can be affected by this method, whereas bank stabilization actions generally modify one bank line. Channel modification techniques have been used to address geomorphic disequilibrium, thereby reducing risks of bank erosion (Washington Department of Fish and Wildlife [WDFW] 2003). The scale of effects can be large for these methods, including changes to channel processes, channel profile, plan shape, cross section, bed elevation, and/or channel location in a segment or longer reach. Therefore, a thorough understanding of fluvial geomorphic processes and channel response is an essential part of developing channel modification projects for a given river reach. Changes to the channel profile or plan shape will result in a change in the energy and sediment transport capacity (WDFW 2003). This is a desirable outcome in the case of the temporary channel into Elephant Butte Reservoir. Estimates of future channel response can be improved significantly by using SRH-1D[1] and SRH-2D[2] models.

2.4 Bank Protection/Stabilization

Bank protection works may be undertaken to protect the riverbank against erosion, and geotechnical failures and to reduce the hydraulic load acting on the soil (Hey 1994, Brookes 1988, Escarameia 1998, and McCullah and Gray 2005) at locations where undermining a bank would result in erosion of riverside facilities and flood control levees. Bank protection methods apply to cases where bank line and toe erosion are the primary mechanisms for bank failure. This includes small bank slope failures or slump block failures.

In situations where the bank slope is unstable due to geotechnical processes, other methods would need to be applied in addition to bank stabilization (Escarameia 1998). These methods could include placing additional material at the toe of the slope or removing upslope material to eliminate rotational failure potential (Terzaghi et al. 1996). Bank protection is best applied when the river grade is stable. If the channel is incising, then the toe of any bank protection could be undermined and fail. Channel lengthening or flood plain establishment and connectivity should be incorporated to bring sediment transport capacity down to match the rate of sediment supply. Otherwise, there will be increased potential for channel degradation and lowering of the water table. Grade control also can be used to stabilize the channel bed prior to implementing bank protection/ stabilization measures.

2.5 Cross Channel (River Spanning) Features

Four different types of river spanning features are suggested for potential application on the Middle Rio Grande: deformable riffles, rock sills, riprap grade control (with or without upstream seepage control), and gradient restoration facilities. All of these are considered loose rock structures, without grout or concrete.

The objective of cross channel or river spanning features is to control the channel bed elevation or grade or to create pool habitat. Cross channel or river spanning features also can be used for water diversion structures. Grade control features

[1] Sedimentation and River Hydraulics One-Dimensional Sediment Transport Dynamics Model.
[2] Sedimentation and River Hydraulics Two-Dimensional Sediment Transport Dynamics Model.

are used in cases where channel incision has or will cause excessive lateral migration and undermining of levees and riverside infrastructure (Bravard et al. 1999). Grade controls reduce the gradient by controlling the bed elevation and dissipating energy in discrete steps (Bravard et al. 1999). These structures physically control the downward cutting of the riverbed in one local reach (Bravard et al. 1999), upstream of the structure. These structures do not halt continued channel bed lowering downstream from the structures or the increased shear stress caused by channel confinement (e.g., channel narrowing by degradation and vegetation growth, levees, bridge crossings, roads). In some cases, aquatic and riparian habitat can be improved by raising the riverbed and halting continued downward cutting of the bed (Bravard et al. 1999). Raising the riverbed or halting continued downward cutting of the bed can improve or preserve the hydraulic connection between the river channel and flood plain. These actions also can maintain or raise the water table elevation. The location of grade control structures and the number and spacing depend upon accurate estimates of dynamic equilibrium bed slopes and the occurrence of future channel degradation. Grade control may reduce the tendency for lateral channel migration by reducing channel incision, especially where the bed elevation is maintained above the root zone of the adjacent riparian forest.

2.6 Conservation Easements

Conservation easements are land agreements that can preserve the existing land use and ownership, prevent new land use or development from occurring, and allow the river access to naturally migrate through the easement area as part of fluvial processes. Conservation easements also preserve the riparian zone in its current state and create opportunity for future adjustments as determined by fluvial processes and flood plain connectivity. Conservation easements promote the preservation of the riverine riparian forest and ecosystem (Karr et al. 2000). Conservation easements may or may not involve infrastructure relocation or setback. Conservation easements, similar to infrastructure relocation or setback, may be used as an opportunity for the river to access historical flood plain areas.

2.7 Change Sediment Supply

Knowledge of sediment supply, transfer, transport, and deposition processes is a prerequisite to developing sustainable river maintenance and restoration (Sear 1996). In particular, the sustainability of river channel strategies and methods depends upon the relationship of sediment supply and transport capacity. Balancing sediment supply with capacity often involves watershed and land use changes, which are outside Reclamation’s Middle Rio Grande Project congressional authorization in the Flood Control Acts of 1948 and 1950.

Sediment transport and supply vary with discharge over time and in space within a river network. Understanding these changes is essential to river maintenance—regardless of the methods employed. Where the river system has sediment supply less than transport capacity, the results are generally channel incision, bank erosion, and possibly a channel planform change from a low-flow braided sand channel with shifting sand substrate to a single thread, mildly sinuous channel with a coarser bed (when gravel is available). In general, when sediment supply decreases, the channel width decreases, channel depth increases, local slope decreases, and sinuosity increases. Adding a sediment supply can slow or eliminate these tendencies in a particular reach, but it may cause sediment deposition in a downstream reach. Adding sediment supply also may increase the rate of downstream reservoir sedimentation. Sediment can be augmented by a number of different methods such as placing sediment in the channel during low flows for erosion during high flows or pushing sediment into the river with machinery or conveyor belts during high flows, etc. Once the river has narrowed and incised and the slope has reduced, reversal is difficult. The method of changing the sediment supply strives to reinstate a sediment balance rather than limiting the effects of a sediment imbalance (Bravard et al. 1999). See section 4.4.1.1.2 and appendix C, section C1.4.1.3, for a description of the planform evolution model of the cycle of planform change on the Middle Rio Grande (Massong et al. 2010).

Where a river system has more sediment supply than sediment transport capacity, channel aggradation will occur. In general, aggradation results in the channel width increasing, channel depth decreasing, local slope increasing, sinuosity decreasing (Schumm 1977), and decreased channel and flood capacity. Flood capacity also can be reduced by sediment berms forming along the channel banks (Schumm 2005). Reducing the sediment supply can slow these trends, while reversing these trends is more difficult to achieve. Sediment supply to downstream reaches can be reduced by establishing sediment deposition basins or re-routing river flows to lower topographic areas that can facilitate deposition within that reach.

2.8 Habitat Improvements and Mitigation

A combination of methods will be used at all river maintenance sites on the Middle Rio Grande to provide net positive habitat benefits within the River Maintenance Program authorization. Methods that provide for a net positive habitat benefit or rehabilitate a desirable channel process will be used wherever possible. When site conditions or other factors (such as landowner receptivity) limit using more desirable methods, habitat features should be added to provide for a net positive habitat benefit. Some of the habitat improvement methods are methods that have both habitat and river maintenance benefits. For the Middle Rio Grande, many of these methods currently are being used, planned for the future, or have been done. Habitat improvement features add complexity to the system, which is generally beneficial to the establishment and development of riparian vegetation, though this is generally only on a local level. Clearing or removing native riparian vegetation as a result of constructing river maintenance features would reduce riparian habitat, and mitigation may be necessary.

2.9 Methods Confidence Ratings

Method performance confidence rating, advantages, disadvantages, and general range of applicability are summarized in appendix A for methods in each group. The confidence that a method will perform its intended purpose is based upon whether the local response is well known and the amount, level, and type of information known. The definitions for confidence levels are:

- **Level 3.** Well established, widely used, well documented performance, reliable design criteria, numerous case studies, well known local geomorphic response that is well documented.

- **Level 2.** Often used but lacks the level of detail, quality of information and reliability that characterizes level 3, little or no long-term monitoring, limited design criteria, limited knowledge about the local geomorphic response, and limited documentation.

- **Level 1.** Emerging promising technique that does not have a track record, field or lab data, or design or test data; has few literature citations; has sparse documentation; and where little is known about local geomorphic response, etc.

Many of the level 1 and level 2 methods have promise for successful implementation but do not have design guidelines based upon hydraulic and engineering performance. If design guidelines do exist, they are qualitative and based upon anecdotal information that is not applicable to most river systems. Methods needing additional development of criteria and design guides include longitudinal bank lowering, transverse features, deformable riffles, and low-head stone weirs.

2.10 Combination of Methods

2.10.1 Maximize Multipurpose Benefits

Each method has different features, geomorphic response, and benefits or effects upon the channel morphology. River maintenance projects often have multiple objectives—such as stabilizing a bank, which is eroding towards riverside infrastructure, creating variable depth and velocity habitat, and expanding flood plain connectivity to reduce the energy of high flows and benefit habitat of riparian and aquatic species. Some methods provide for increased habitat value while others do not. For a net positive benefit, methods can be combined. A large number of method combinations are available for use (depending upon project needs, local habitat needs, and local site conditions). These combinations can provide multiple benefits.

2.10.1.1 Examples of Methods Combinations

Two examples of possible methods combinations are provided to illustrate potential method combinations and increased benefits from such combinations. These are not actual plans at this time.

2.10.1.2 Example 1: Lateral Migration

The first example is a site where the riverbed elevation has lowered, and the river has changed from a wide, low-flow, braided sand bed channel to a single thread gravel-dominated bed, which is slightly sinuous. This change has been caused largely by the combination of reduced flow peaks and upstream sediment supply. The slightly sinuous channel is migrating laterally, and the river likely will erode riverside infrastructure within a few years. In this reach, RGSM habitat has degraded as the channel bed has lowered—leading to the channel becoming disconnected from the historical flood plain. Bank line habitats such as backwaters, shallow overbank flows adjacent to the main channel, cover, and variable depth and velocity flow conditions have largely disappeared. The channel bed lowering has eliminated periodic overbank flooding so that the riparian forest plant community is becoming decadent (mature trees, which are not being replenished by younger trees). After evaluating alternatives based upon geomorphic response and the Engineering Effectiveness, Ecosystem Function, and Economics Evaluation Factors, a preferred alternative was selected. The preferred alternative consists of these features:

- Relocated river channel into an alignment away from the levee while maintaining some channel curvature (channel relocation using pilot channels or pilot cuts).

- Lowered bank line area created by placing the fill from the relocated channel excavation at a lower elevation than the historical flood plain to re-establish flood plain connectivity. Fill also could be placed with a lateral slope so that there are variable inundation levels for different river flow rates (longitudinal bank lowering).

- Bendway weirs along the outside bank of the relocated channel bend to prevent bank erosion.

- Large woody debris placed at various locations throughout the project area for fish cover. Most native tree species have low durability; and, thus, the large woody debris structures constructed from these native tree species have a short project life.

- Several high-flow side channels re-established along the inside of the bend, formed by the relocated channel.

- Native riparian woody and shrub species plantings in the newly created flood plain areas.

In this example, seven methods are used for a single project to protect the riverside infrastructure, provide for flood plain connectivity, create variable velocity habitat types, and initiate establishment of a new riparian zone in the lowered bank line area.

2.10.1.3 Example 2: Lower Bed Elevation

The second example is a site where the riverbed elevation has lowered, and the channel has changed from a wide, braided sand bed channel to a multithread gravel dominated bed, which is slightly sinuous with flow around an island. The island is vegetated with mature woody species and is a distinct, longer term feature of the channel. The channel bed elevation lowering and channel width reduction are caused largely by the combination of reduced flow peaks and upstream sediment supply. The channel flowing around the right side (looking downstream) of the island is a slightly sinuous, laterally migrating channel. The migrating right channel likely will cause erosion of riverside infrastructures within a few years. In this reach, RGSM habitat has degraded as the channel has evolved to a narrow channel, which is not connected to the historical flood plain. Bank line habitats such as backwaters, shallow overbank flows adjacent to the main channel, cover, variable depth, and velocity flow conditions have largely disappeared. The channel bed lowering has eliminated periodic overbanking, so that the riparian forest plant community is becoming decadent. A preferred alternative is selected after evaluation of alternatives based upon geomorphic response and the Engineering Effectiveness, Ecosystem Function, and Economics Evaluation Factors. The preferred alternative consists of these features:

- Along the outside (eroding) bank line of the right channel around the island, the bank line is lowered to create a flood plain. The decreased depth and flow velocity on the outside of the bend in the lowered bank area would slow erosion. Sediment excavation would be minimized by balancing cut and fill.

- Placed small-sized riprap and fabric-encapsulated soil lifts with dense willow plantings along the eroding bank of the right channel (deformable stone toe with bioengineering and bank lowering).

- Placed small-sized riprap in the bed of the channel at the inlet of the right channel with a lower elevation toward the island. The riprap would be placed to raise the bed elevation about 0.5 foot on the right side but at the existing channel elevation on the left side (near the island), thereby preserving fish passage. The lower elevation portion of the riprap will become the new thalweg location, causing flows to concentrate more along the noneroding bank of the right channel instead of along the eroding bank line (deformable riffle). The deformable riffle would increase flow in the left channel to reduce bank erosion potential in the right channel around the island.

- Lowered bank line along the noneroding bank of the island, to increase flood plain connectivity. Sediment excavation would be minimized by balancing cut and fill (longitudinal bank lowering).

- Placed large woody debris at several locations throughout the project area to provide fish cover and variable depth and velocity habitat.

- Planted native tree and shrub species in the lowered bank line on the left side of the channel (riparian vegetation establishment).

Example two includes six methods for a single project to protect the riverside infrastructure, provide for flood plain connectivity, create variable velocity habitat types, allow for continuation of current geomorphic processes at a slower rate (deformable bank line and deformable riffle), and initiate establishment of a new riparian zone in the lowered bank line area.

2.10.1.4 Levee Raising

The third example is a site where the riverbed has been rising due to sediment supply being greater than transport capacity and the main channel has filled with sediment to such an extent that the levee capacity has been reduced to below the 2-year return period peak flow. The main channel still has an active channel without a plug, but the potential for plug formation is present. The levee has developed several small seeps, which have been repaired by adding local fill material to increase the length of the seepage path. A channel is forming along the toe of the levee, which could potentially erode the levee fill material. A preferred alternative is selected after evaluation of alternatives based upon geomorphic response and the Engineering Effectiveness, Ecosystem Function, and Economics Evaluation Factors. The preferred alternative consists of these features:

- Along the reach where the channel capacity is reduced below the 2-year return period peak flow, the levee is raised, and the slopes of both levee sides are reduced to increase the length of the seepage path. Fill material is placed on the inside of the levee (riverside) to accommodate the increased levee height without encroaching upon the low-flow conveyance channel berm road. The fill material on the inside of the levee also would be used to fill in the channel forming along the toe of the levee. Levee raising fill material is pit run, and a gravel road base is placed as the last layer for vehicle traffic (levee strengthening).

- Along the levee where a channel is forming that could erode levee fill material, especially in plug prone areas, several spur dikes are placed to cause peak flow river waters to be re-directed back into the riparian forest (spur dikes).

- Planting native tree and shrub species in the channel forming along the levee is not included because it is anticipated that, during peak spring runoff flows, this area provides prime conditions for natural regrowth of native vegetation (riparian vegetation establishment).

This example includes two methods for a single project to increase levee capacity and prevent the development of a channel along the levee toe that could erode levee fill material.

3. Maintenance Goals and Strategies

3.1 Existing Maintenance Goals

The authorized maintenance goals for the Middle Rio Grande Project have evolved over time and include:

- Provide for effective transport of water and sediment to Elephant Butte Reservoir
- Conserve surface water within the Middle Rio Grande Basin
- Protect riverside structures and facilities
- Reduce and/or eliminate aggradation in the Middle Rio Grande
- Reduce the rate of channel degradation from Cochiti Dam south to Socorro[1]
- Provide habitat improvements for the ESA-listed species within the Middle Rio Grande Project area[2]

The first four goals are from the original Middle Rio Grande Project authorization. The first goal, "Provide for effective transport of water and sediment to Elephant Butte Reservoir," is currently interpreted as managing upstream channel aggradation and maintaining channel connectivity, which reduces water losses and allows for effective water delivery into Elephant Butte Reservoir. The fifth goal, "Reduce the rate of channel degradation from Cochiti Dam south to Socorro," is a result of the changing sediment regime of the river—resulting from the changing hydrology of the watershed and efforts to reduce sediment loads that began on a large scale in the 1950s. Note that transient or temporary conditions will be addressed to the extent possible, but this is not a River Maintenance Program goal. An example of a temporary condition is the degradation from about RM 78 downstream resulting from base level lowering of Elephant Butte Reservoir. This degradation is expected to switch to aggradation as the reservoir rises. The sixth goal, "Provide habitat improvements for the ESA-listed species within the Middle Rio Grande Project area," comes from Federal responsibilities under the 1973 ESA. More information on these goals can be found in the Part 1 Report (Reclamation 2007).

[1] Channel degradation can lower the water table, reduce channel stability, and be a factor in initiating new lateral channel migration.

[2] Habitat improvements are provided within the mission and authorization of the River Maintenance Program.

The geomorphology of a river results from physical processes, geologic and anthropogenic influences on those processes, and the history of changes—both natural and anthropogenic—within its watershed and channel. "Because alluvial channels are open systems with mobile and deformable boundaries, they have the ability to self regulate to the imposed flow and sediment load" (Goudie 2004). This means that the river seeks to balance its sediment transport capacity and sediment supply. This balance of sediment transport capacity versus sediment supply affects channel processes and strongly influences geomorphic changes and conditions.

In recent times (late 1990s to 2005), the Rio Grande watershed has been in a regional drought. This major reduction in water supply and peak flows caused the river to narrow, mostly through vegetation colonization of formerly active bars. In 2005, the spring snowmelt runoff was above normal, and the majority of the river channel had stable bars and bank lines; so the channel did not widen to the extent it might have without the vegetation stabilization. The Rio Grande between Cochiti Dam and Elephant Butte Reservoir has responded in a variety of ways. In sections that had extensive island growth and vegetative stabilization that occurred during the drought, the river has narrowed, deepened, and generally abandoned all but a single dominant channel. This narrowing may indicate a future increase in river maintenance sites because channel narrowing and incision can result in lateral migration (Knighton 1998). Meanders generally develop with a wavelength equal to 10–14 times the channel width. In other words, the number of meander bends per river mile increases with decreasing channel width. In areas where a single channel already existed and bank-attached bars had stabilized with vegetation, the channel has laterally migrated, especially where incision is deep enough to allow flow beneath the bank line root zone. Lateral migration can be rapid; in 2005 at several sites (such as RM 111), the bank line moved more than 25 feet in just a few days. Lateral migration and incision also occurred with the atypical July–October 2006 monsoon rains.

The reach from San Antonio downstream has been very active in the last few years. In the lower portion of the reach, there has been degradation due to the low pool elevation of Elephant Butte Reservoir with some temporary local degradation due to the reduced sediment supply downstream from plugs. The degradation has increased the channel capacity under the San Marcial Railroad Bridge but impacted riparian habitat and endangered species with the drop in the local water table and loss of floodplain connectivity. Plugs have formed in several locations resulting in flooding, increased risk to infrastructure, and possible losses in water delivery; but endangered species appear to have benefited.

These changes in the channel morphology and physical processes demonstrate the speed at which change occurs in the Middle Rio Grande and help explain the rapid increase of river maintenance sites of concern throughout the management area. Along with these highly visible changes, the bed sediments are coarsening throughout most of the main stem Middle Rio Grande (Bauer 2007 and Bauer 2009), thereby changing the governing processes for sediment transport and contributing to bank erosion and meander development and other in-channel processes.. Although recently developed islands and bars are inundated during high flows, the loss of both main channel width and the large historical flood plain system indicates that a major change in drivers and controls altering the balance of sediment transport capacity and sediment supply for the river system is occurring with concomitant reduction in suitable SWFL and RGSM habitat. This complex and changing river system presents many maintenance challenges.

Together, modifications of flows and sediment supply have resulted in continuing trends of incision, channel migration, planform conversion, and riverbed coarsening to gravel, which are rapidly changing the morphology of the Middle Rio Grande channel and, thus, requiring renewed consideration about appropriate management goals, strategies, and methods.

3.2 Updated Maintenance Goals

The Middle Rio Grande is a vital part of the local economy and a valuable ecological resource. Updated maintenance goals have been developed that reflect the evolution of river engineering and management practices, changing river conditions, and compliance with environmental statutes. They are designed to reflect the river system as a whole, where possible, and to help implement the best methodology to achieve the original project authorization. River maintenance strategies and associated methods to achieve these updated goals remain consistent with the objectives in the Middle Rio Grande Project authorization and other Federal responsibilities. The goals may need to be updated if the current geomorphic trends of the Middle Rio Grande change or if there are additional advances in the practice of river management. The updated goals are:

- Support Channel Sustainability
- Protect Riverside Infrastructure and Resources
- Be Ecosystem Compatible
- Provide Effective Water Delivery

Each of the subsections below defines an updated goal and describes the relationship to the existing goals detailed in the Part 1 Report (Reclamation 2007). Appropriate strategies to help meet each goal are introduced in this section. In many cases, multiple strategies may be needed to work towards achieving a goal. The best outcome for the river system as a whole requires a balance between desirable outcomes for individual goals. This is to be expected for multiple uses of a limited resource.

3.2.1 Support Channel Sustainability

Channel sustainability is the concept that a river channel is in dynamic equilibrium and maintains its functions of transporting water and sediment while providing variety in lotic and riparian areas, with little or no human intervention such as channel maintenance. A river channel changes over time because of the changing drivers of water and sediment load, and change may be limited by controls such as bank and bed stability, base level, flood plain lateral confinement, and flood plain connectivity. Dynamic equilibrium includes a river channel that is actively changing through lateral migration, bed lowering, or aggradation, but where the degree and rate of change is within acceptable limits, given constraints on the river system. These limits are often reach specific and acceptability may include striking a balance among the updated goals. Currently, the Middle Rio Grande is changing, and there is not a tendency for the river to reach a state of dynamic equilibrium (i.e., a balance between sediment transport capacity and supply) soon in most reaches. Rather, there is rapid evolution, as discussed in section 3.1, requiring significant continuing maintenance. Also, given the existing constraints on and needs of the system, some level of continuing maintenance will always be necessary. These constraints and needs include public safety, riverside infrastructure protection, water delivery requirements, and endangered species needs. To encourage a trend towards dynamic equilibrium, selected strategies and methods should, where possible, incorporate natural channel processes, have a reach-based focus, and include channel and flood plain processes associated with hydrologic connectivity (overbank flooding and alluvial ground water).

The authorized goals listed in the Part 1 Report (Reclamation 2007) that apply to this updated goal are:

- Reduce and /or eliminate aggradation in the Middle Rio Grande
- Reduce the rate of channel degradation from Cochiti Dam south to Socorro
- Protect riverside structures and facilities
- Provide habitat improvements for the ESA-listed species within the Middle Rio Grande Project area

The first three authorized goals pertain to the concept of balancing changes within an acceptable level of variation. The final authorized goal pertains to providing for ecosystem needs as required by law.

3.2.2 Protect Riverside Infrastructure and Resources

Infrastructure in this context includes riverside irrigation facilities, levees, and roads. Both biological and cultural resources should be protected. The primary source of potential impacts is channel migration and bank failure, but channel bed lowering and aggradation also can affect infrastructure. The similar authorized goal is to protect riverside structures and facilities. A policy has not yet been developed concerning subsurface facilities, such as those that deliver San Juan-Chama water for municipal and industrial use. Archaeological and cultural resources have been, and will continue to be, considered on a case-by-case basis. Indian trust responsibilities and the age of the infrastructure also should be considered.

3.2.3 Be Ecosystem Compatible

One of the authorized goals is to provide habitat improvements for the ESA-listed species within the Middle Rio Grande Project area. Ecosystem compatible maintenance actions support that goal but also include elements of channel sustainability through promotion of ecosystem sustainability to help reach recovery goals for habitat. The overlap is primarily channel change that both rejuvenates and alters or abandons habitat. The limits to acceptable change may be much wider for the general ecosystem than for individual species. The habitat needs of endangered species in particular limit the timing, duration, degree, and location of change and the appropriate strategies and tools. All strategies and tools must comply with the Biological Opinion, 2003 (Service 2003) and future amendments.

3.2.4 Provide Effective Water Delivery

The updated goal to provide effective water delivery is similar to the authorized goals to provide for the effective transport of water and sediment to Elephant Butte Reservoir and to conserve surface water in the Middle Rio Grande Basin. For the River Maintenance Program, providing effective water delivery includes considering water loss minimization, compact and international treaty requirements, and environmental requirements. This goal includes safe passage of the mean annual flood but does not include flood control activities. Policy has not been developed for subsurface diversion facilities.

3.3 Maintenance Strategies

Strategies define reach scale management approaches to meet the river maintenance goals described in section 3.2 above, according to the physical and biological processes understood to be driving the current and predicted geomorphic trends of importance to river maintenance.

The balance of sediment (or lack thereof) affects channel processes and strongly influences geomorphic changes and conditions. An imbalance between sediment transport capacity and supply is the key cause of most channel and flood plain adjustments. Reach scale trends observed on the Middle Rio Grande that can result in river maintenance actions include the following:

- Channel narrowing
- Vegetation encroachment
- Incision or channel bed degradation
- Increased bank height
- Bank erosion
- Coarsening of bed material
- Aggradation
- Channel plugging with sediment
- Perched[1] channel conditions

Reach scale channel trends (see section 4.1.1 for descriptions)[2] and their underlying processes can create the need for channel maintenance at specific sites or the need can be more extensive. For example, channel incision and narrowing can lead to lateral migration, potentially followed by erosion of riverside facilities and infrastructure at a single bend or at multiple locations which might be best addressed by a reach strategy.

The following reach strategies were developed to address these trends resulting from physical processes on the Middle Rio Grande:

- Promote Elevation Stability
- Promote Alignment Stability
- Reconstruct and Maintain Channel Capacity
- Increase Available Area to the River
- Rehabilitate Channel and Flood Plain
- Manage Sediment

These reach strategies are intended to help more completely integrate the physical processes occurring on the Middle Rio Grande with river maintenance activities. They were developed to meet the updated goals within the context of the River Maintenance Program authorization. Each strategy has different methods, geomorphic responses, and effects upon the balance between sediment supply and transport capacity and river maintenance goals. Each reach generally has multiple constraints such as water delivery, protection of riverside infrastructure, local variations in geology, and endangered species habitat.

[1] Perched conditions are when the river channel is higher than adjoining riparian areas in the floodway or land outside the levee.

[2] Appendix C, tables C1-4–C1-9, contains a more detailed description of the current and predicted geomorphic trends that each strategy addresses and the geomorphic reach effects.

3.3.1 Promote Elevation Stability

The objective of this strategy is to reduce the extent and rate of bed elevation changes. Promote Elevation Stability has two very different suites of methods to address the two different conditions and trends (i.e., raising the bed for degrading reaches and lowering the bed for aggrading reaches).

For the degrading reaches, this strategy involves a variety of potential cross-channel methods (see appendix A) that reduce continued incision. Constructing cross-channel features throughout a reach would be an example of implementing this strategy on a reach basis (see appendix A for more details on this method category). This could involve stabilizing the bed through maintaining a preferred river channel elevation with more permanent features or increasing the erosion resistance of the bed material to decrease the rate of channel incision. The strategy also will help provide hydraulic and hydrologic connectivity between the main channel and the flood plain. The increased elevation stability also could decrease or stabilize the bank height and minimize bank erosion to the extent that this strategy would reduce future degradation below the zone where roots help to stabilize the bank material. Because this strategy reduces future channel incision, it is also likely to reduce the probability of future bed material coarsening.

Since aggradation affects and leads to bed elevation concerns, this strategy also would include minimization of aggradation where appropriate. It should be noted that to minimize the overlap between strategy methods and effects, implementation of this strategy is focused on method categories that directly address incision or channel bed degradation because there are other complementary strategies that directly address aggradation (see table C1.4 in appendix C). These other strategies are Reconstruct/Maintain Channel Capacity, Increase Available Area, and Manage Sediment. This means that Promote Elevation is not analyzed in aggrading reaches.

Promote Elevation Stability can help address the following reach scale trends: increased bank height, incision or channel bed degradation, bank erosion, and coarsening of bed material, which have been observed in several reaches of the Rio Grande due to a combination of reduced peak flows and sediment supply and increased lateral constraints. Increased elevation stability would reduce or prevent future channel incision and could be used as a means to reduce future lateral migration and potential future river maintenance sites.

Promote Elevation Stability addresses all four river maintenance goals, but its applicability to Be Ecosystem Compatible depends on the methods used for implementation.

3.3.2 Promote Alignment Stability

The objective of this strategy is to allow the river channel to adjust as much as possible horizontally while monitoring bank line movement. If the safety or integrity of riverside facilities and structures is likely to be compromised within the next few years, then bank protection measures are provided to protect infrastructure and reduce the risk of future migration. There are two basic types of lateral channel movement: migration, which generally occurs under degrading and tall bank conditions, and avulsion, which generally occurs under aggrading, and perched channel conditions.

Constructing bank protection/stabilization features throughout the reach would be an example of implementing this strategy on a laterally migrating reach (see section 2.4 for more details on these methods). This could involve longitudinal bank stability methods such as bank slope re-grading, stabilization with more erosion resistant material (vegetation, riprap, etc.), bank lowering, and/or channel relocation, etc. It also may involve using features that alter flow patterns to minimize the hydraulic actions near the bank that affect bank stability.

This strategy can help address the following reach scale trends: bank erosion, channel plugging with sediment, and perched channel conditions. Under perched channel conditions, the historical river maintenance approach has maintained the current alignment and typically has addressed the situation with other strategies such as Reconstruct and Maintain Channel Capacity. When the trends of channel plugging with sediment or perched channel conditions are present, channel avulsion or relocation is possible. For this case, Promote Alignment Stability would reinforce the new bank location. Other strategies that could be used to address channel plugging with sediment and perched river conditions include Increase Available Area to the River and Manage Sediment.

In many reaches, the river’s alignment is changing due to channel narrowing, vegetation encroachment, reduced sediment supply, channel incision and increased bank height, and flow redirection from island/bar deposition and local bank morphology. These changes can result in an increase in channel lateral migration, river meandering, and bank erosion so that infrastructure protection may become necessary.

This strategy can address all four river maintenance goals, but applicability to Be Ecosystem Compatible strongly depends on the methods used to implement it.

3.3.3 Reconstruct and Maintain Channel Capacity

The objective of this strategy is to help ensure safe channel capacity and to provide for effective water delivery. This strategy most likely would be implemented in reaches where sediment deposition would create unsafe channel capacities. Capacity can be lost through channel narrowing, vegetation encroachment, aggradation, the channel plugging with sediment and perched channel conditions. Constructing channel modification features throughout a reach would be an example of implementing this strategy on a reach basis (see appendix A for more details on this method category). This could involve changing the channel profile, plan shape, cross section, bed elevation, slope, and/or channel location to increase channel capacity.

This strategy also may address conditions where the channel bed is perched or higher than the flood plain, due to aggradation that has occurred in the past by increasing sediment transport capacity. This strategy applies to both reaches and individual sites where channel capacity is reduced. Reduction can occur through gradual aggradation over time, channel narrowing through island and bar deposits or vegetation encroachment, large sediment deposits at the mouths of ephemeral tributaries, and abrupt aggradation such as sediment plugs in the active river channel.

This strategy addresses Protect Riverside Infrastructure and Resources and Provide Effective Water Delivery.

3.3.4 Increase Available Area to the River

The objective of this strategy is to provide area for the river to evolve in response to changing conditions that allow natural channel processes to continue and minimize the need for additional future river maintenance actions. Relocating infrastructure and constructing setback features throughout a reach would be an example of implementing this strategy on a reach basis (see section 2.2 for more details on this method category). This could involve moving irrigation/drainage features and accompanying spoil levees to a location further away from the river, increasing the available area for the river to adjust.

Implementing the Increase Available Area to the River, however, depends on land use outside of the current system constraints and would require an evaluation of the traditional land use and its importance, including the priorities of existing landowners. Implementing this strategy is generally more cost effective in primarily agricultural use areas than in urban/suburban use areas because of lower land values (and, thus, lower acquisition costs). In reaches where land use is or could change from primarily agricultural use to urban/suburban use, undertaking planning and land acquisition prior to land use changes is important.

The ideal conditions for the river would be for the river and flood plain area to be large enough to accommodate more than the expected width of potential lateral migration; otherwise, the need for future channel maintenance work is more likely. Responses to this strategy could include a wider channel, increased lateral migration, reconnection and expansion of the flood plain, and reduction of the potential threat to riverside infrastructure from river bank erosion.

The strategy addresses the following reach scale trends for reaches where sediment transport capacity is greater than sediment supply: channel narrowing, incision or channel bed degradation, increased bank height, bank erosion, and coarsening of bed material. For reaches where sediment transport capacity is less than sediment supply, this strategy also addresses aggradation, channel plugging with sediment, and a perched channel (as increasing the available area allows channel relocation to a lower elevation).

This strategy addresses Support Channel Sustainability, Protect Riverside Infrastructure and Resources, and Be Ecosystem Compatible. Effects of this strategy on Provide Effective Water Delivery are uncertain and reach dependent.

3.3.5 Rehabilitate Channel and Flood Plain

The objective of this strategy is to help stabilize the channel bed elevation and slope in reaches where transport capacity is greater than supply. Rehabilitate Channel and Flood Plain reconnects abandoned flood plains, which reduces the sediment transport capacity of higher flows and more closely matches the existing sediment supply.

Figure 3.1 is a conceptual drawing of this strategy that shows the longitudinal bank lowering of the terraces immediately adjacent to the channel. The creation of a new lower flood plain would reduce the main channel velocity and create areas of slower velocity at high flows. Potential outcomes include a higher width-to-depth ratio at higher flows, development of high-flow side channels, a reduction in bank erosion (potentially reducing the amount of infrastructure protection required in the future), and greater flood plain connectivity. Reduced channel velocity during peak flow events can lead to finer-grained bed sediments.

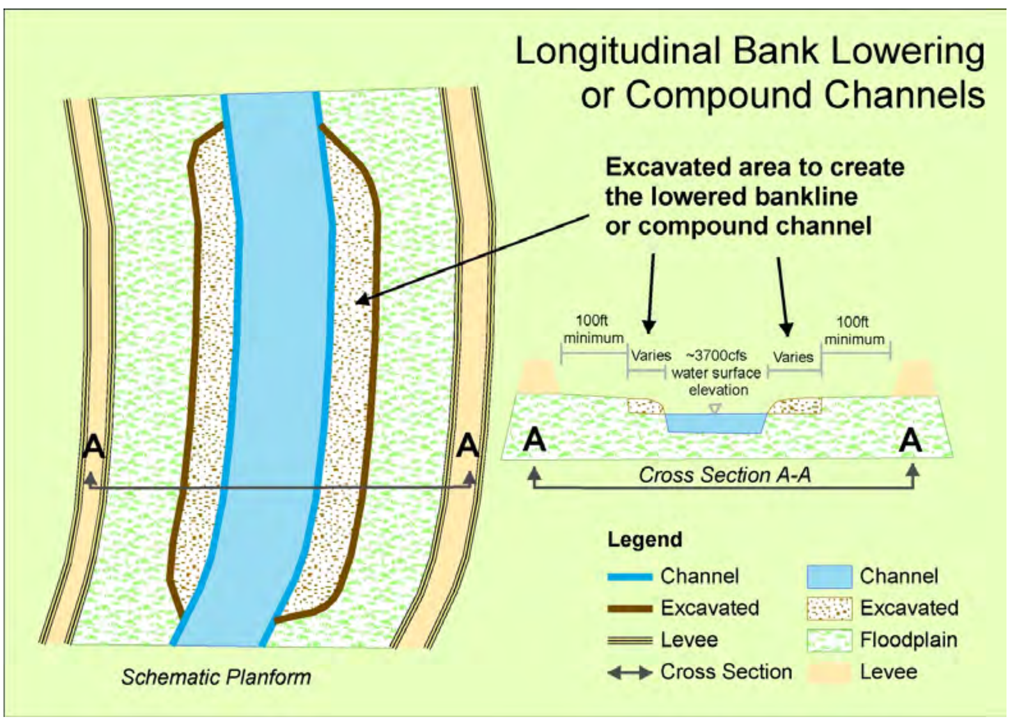

Figure 3.1. Conceptual drawing of Rehabilitate Channel and Flood Plain.

Constructing channel modifications throughout a reach would be an example of implementing this strategy on a reach basis (see section 2.3 for more details on this method category). Given the existing understanding of geomorphic trends and processes on the Rio Grande, this strategy may include a smaller channel designed to function with current water and sediment inputs inside a flood plain large enough to pass higher flows. Rehabilitate Channel and Flood Plain also may allow the channel banks to erode and deposit on a potentially more continuing basis, which would renew habitat but likely at a smaller scale than historically.

Rehabilitate Channel and Flood Plain addresses the following reach scale trends: channel narrowing, vegetation encroachment, increased bank height, incision or channel bed degradation, bank erosion, and coarsening of bed material.

This strategy addresses Support Channel Sustainability, Be Ecosystem Compatible, and Protect Riverside Infrastructure and Resources, although the degree to which it speaks to these goals depends on the methods used. Effects of this strategy on Provide Effective Water Delivery are uncertain and reach dependent.

3.3.6 Manage Sediment

The objective of this strategy is to aid in balancing sediment transport capacity with sediment supply by manipulating that supply. Changing the sediment supply throughout a reach would be an example of implementing this strategy on a reach basis (see section 2.7 for more details on this method category). Once either adding or removing sediment is implemented, this would need to be continued indefinitely for the benefits to be realized in the long term. There is uncertainty about the channel response with various amounts of sediment addition or removal which would require adaptive management. Currently, there is an excess of sediment transport capacity in most of the reaches; so in these reaches, the strategy generally would involve sediment augmentation (adding appropriately sized sand sediment) into the system. Features like arroyo reconnection, sediment bypass of water storage structures, and bank destabilization would augment the sediment supply and help the channel reach a balance of sediment supply and transport capacity. This is most likely implemented, however, through combining with other strategies (see section 3.3.7). Little research is available on augmenting rivers with sand size materials.

In some areas, however, the supply exceeds the transport capacity, and aggradation can be a significant concern. The primary method to accomplish a reduction in sediment supply is through natural or constructed sediment basins. By bringing the sediment load into closer balance with the sediment transport capacity, the threat to riverside infrastructure from channel movement should be reduced. This also may minimize impacts from aggradation, channel plugging with sediment, and a perched channel.

Inadequate sediment supply may cause channel incision, which increases sediment transport capacity and results in additional incision, coarsening bed material, and bank erosion and decreases flood plain connectivity. Excess sediment supply can result in a loss of channel capacity and in perched channel conditions.

The strategy addresses the following reach scale trends when the transport capacity is greater than supply: incision or channel bed degradation, increased bank height, and coarsening of bed material. When the transport capacity is less than supply, the strategy also addresses aggradation, channel plugging with sediment, and perched channel conditions.

This strategy addresses Support Channel Sustainability and Be Ecosystem Compatible. The effects of this strategy on Provide Effective Water Delivery are uncertain and reach-dependent. This strategy also may apply to Protect Riverside Infrastructure and Resources; however, it is difficult to ensure no impact to infrastructure.

3.3.7 Strategy Combinations

Each strategy has different methods, engineering effectiveness, geomorphic response and benefits, or effects upon the habitat and water delivery. Reach needs indicate that multiple objectives exist such as water delivery, stabilizing the bed and banks, protecting riverside infrastructure, creating variable depth and velocity habitat, promoting dynamic equilibrium by balancing sediment transport capacity with supply, and reconnecting the main channel with the flood plain. Some strategies promote improved habitat while others do not. Thus, for a net positive environmental benefit and to meet multiple objectives, strategy combinations most likely will be used. In this section, reference is made to methods found in chapter 2.

An example of possible strategy combinations has been developed based upon river conditions on the Middle Rio Grande. Note that these are not actual plans at this time but are an example to show how strategies could be combined. Strategy selection, including combinations, should be based upon analysis of each reach. Many of the strategies include methods that have promise for successful implementation but do not have design guidelines based upon hydraulic and engineering performance. If design guidelines exist for these types of methods, they are qualitative and based upon anecdotal information, which is not applicable to most river systems. Strategies and their corresponding applicable methods that need additional development of criteria and design guides include Rehabilitate Channel and Flood Plain (longitudinal bank lowering), Promote Alignment Stability (transverse features), and Promote Elevation Stability (deformable riffles and low-head stone weirs).

3.3.7.1.1 Example of Potential Strategy Combination: Lowered Bed Elevation with Local Bank Failure

In the Rio Grande reach from Angostura Diversion Dam downstream to near Isleta Diversion Dam, the riverbed elevation has lowered, and the river in the upstream portion of the reach has changed from a wide low-flow, braided, sand bed channel to a single thread, gravel-dominated riverbed that is slightly sinuous. This change has been caused largely by reduced upstream sediment supplies, influenced by channel narrowing as a result of reduced peak flows. The slightly sinuous channel is migrating laterally because the coarsening bed material has increased bed stability, and the river may erode riverside infrastructure within a few years. In the downstream portion of the reach, the channel bed is lowering but remains a sand bed channel and has not converted to a gravel-dominated bed. In both parts of the reach, RGSM habitat has degraded as the channel has lowered and has become disconnected from the historical flood plain. Bank line habitat components (such as backwaters, shallow overbank flows adjacent to the main channel, cover, and variable depth and velocity flow conditions) have largely disappeared, especially in the upstream part of this reach. The channel bed lowering has eliminated periodic overbanking so that the riparian forest plant community is becoming decadent.

After evaluating strategies during a feasibility assessment, a preferred set of strategies might be selected as described below:

- In the downstream portion of the reach, Promote Elevation Stability would prevent further bed level lowering. Local lateral migration still may occur where Promote Elevation Stability would be needed. It is likely that there will be only a few local lateral migration locations because the amount of bed level lowering estimated by the mobile bed hydraulic model is relatively small (approximately 2–3 feet total vertical change over the entire reach).

- For the upstream portion of the reach, the primary strategy would be Promote Alignment Stability. Coupled with this strategy, Rehabilitate Channel and Flood would be used to increase flood plain connectivity to promote dynamic equilibrium where the sediment transport capacity is nearer the sediment transport supply.

- In local areas of the upstream portion of this reach, Increase Available Area to the River would be used to relocate the riverside infrastructure, allowing the river to migrate laterally and to establish a new inset flood plain.

In this example, four different strategies would be combined in a single reach to provide water delivery, protect riverside infrastructure, prevent continued bed lowering, re-connect the main channel with a flood plain, establish a new riparian zone, and create more variable depth and velocity habitat types. Further, in both portions of this reach, habitat improvement and mitigation might be used to provide important SWFL and RGSM habitat.

This is an example of the many possible combinations of the reach scale applications of strategies. Strategy selection, including combinations, should be based upon further analysis of each reach.

3.4 Strategy Correlation with Goals and with Methods

The updated goals are outcome statements to describe desired conditions on the Middle Rio Grande; strategies are the basic approaches to achieve the goals on a reach-wide basis, and methods are the means to implement those strategies. Each strategy may not be applicable to all updated goals. The strategies that help achieve a goal are listed under that goal below:

- **Support Channel Sustainability:** All strategies should help support this goal, but the applicability of Promote Elevation Stability, Promote Alignment Stability, Reconstruct and Maintain Channel Capacity, and Rehabilitate Channel and Flood Plain depend on the specific method selected for implementation (in addition to this chapter, see appendix A for more information).

- **Protect Riverside Infrastructure and Resources:** All strategies, except Manage Sediment, support this goal. The effects of Manage Sediment are not predictable enough to ensure no impact to infrastructure. The applicability of Rehabilitate Channel and Flood Plain depends on the method selected for implementation (in addition to this chapter, see appendix A for more information).

- **Be Ecosystem Compatible:** All strategies can be ecosystem compatible, but the effects of Promote Elevation Stability, Promote Alignment Stability, Reconstruct and Maintain Channel Capacity, and Rehabilitate Channel and Flood Plain strongly depend on the method selected for implementation (in addition to this chapter, see appendix A for more information).

- **Provide Effective Water Delivery:** Promote Elevation Stability, Promote Alignment Stability, and Reconstruct and Maintain Channel Capacity all support this goal. The effects of Increase Available Area to the River, Rehabilitate Channel and Flood Plain, and Manage Sediment on effective water delivery are uncertain and reach dependent (in addition to this chapter, see appendix A for more information).

Each strategy contains many potential methods for implementation. To the extent possible, the type of method most expected to be used for each strategy is shown in table 3.1. To minimize the overlap between methods and strategies, the Promote Elevation Stability is assumed to be implemented through other strategies with methods that directly address aggradation. For a given strategy, many combinations of methods can be used in addition to the methods identified in table 3.1. The combination of methods used depends upon local river conditions, reach objectives, and environmental goals and effects. Methods in the habitat improvement and mitigation category are applicable to nearly all of the strategies for habitat improvement or mitigation of other river maintenance actions.

3.5 Adaptive Management Within Strategies

On the Middle Rio Grande, some strategies have a stronger adaptive management component than others.

Promote Elevation Stability has less opportunity for adaptive management but may require adjustments upstream and downstream if the slope is changed.

Promote Alignment Stability is intrinsically adaptive because watchful waiting is used to allow some lateral migration until infrastructure is threatened.

Reconstruct and Maintain Channel Capacity is simply re-creating the same channel and, as such, has little adaptive component.

Increase Available Area to the River has an adaptive component in ensuring that water deliveries are not significantly impacted. It is uncertain whether enough space can be acquired to permanently ensure that relocated levees would not be impacted by lateral migration.

Rehabilitate Channel and Flood Plain may need adjustments to ensure flows go overbank at the desired discharge and frequency and to ensure levees are not at risk.

Manage Sediment is likely to need adjustments as the channel responds to the changes on sediment load.

Table 3.1. Methods Associated with Strategies

Strategy / Method	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
INFRASTRUCTURE RELOCATION OR SETBACK				X		
CHANNEL MODIFICATION						
Complete Channel Reconstruction and Maintenance			X		X	
Channel Relocation Using Pilot Channels or Pilot Cuts					X	X
Island and Bank Clearing and Destabilization (Includes Channel Widening)					X	X
Pilot Cuts Through Sediment Plugs			X			
Side Channels (High Flow, Perennial, and Oxbow Re-establishment)					X	
Longitudinal Bank Lowering or Compound Channels					X	
Longitudinal Dikes			X			
Levee Strengthening			X			
BANK PROTECTION/ STABILIZATION						
Longitudinal Features-Fixed Bank Line and Thalweg Location						
Riprap Revetment		X				
Longitudinal Stone Toe with Bioengineering		X				

Table 3.1. Methods Associated with Strategies (continued)

Strategy / Method	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
Longitudinal Features-Erosion to Bank Line Stabilization						
Trench Filled Riprap		X				
Riprap Windrow		X				
Longitudinal Features- Mobile Bank line and Thalweg Location						
Deformable Stone Toe/ Bioengineering and Bank Lowering		X				
Bio-Engineering		X				
Transverse Features or Flow Deflection Techniques						
Bendway Weirs		X				
Spur Dikes		X				
Vanes or Barbs		X				
J-Hook		X				
Trench Filled Bendway Weirs		X				
CROSS CHANNEL (RIVER SPANNING) FEATURES						
Grade Control						
Deformable Riffles	X					
Rock Sills	X					
Riprap Grade Control (with or Without Seepage)	X					
Gradient Restoration Facility	X					
Low-Head Stone Weirs	X					

Table 3.1. Methods Associated with Strategies (continued)

Strategy / Method	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
CONSERVATION EASEMENTS				X	X	
CHANGE SEDIMENT SUPPLY						
Sediment Augmentation (increase sand size load)						X
Natural or Constructed Sediment Basins (Decrease Load)						X
HABITAT IMPROVEMENT AND MITIGATION[1]						
Rootwads		X				
Log Jams/Large Woody Debris		X				
Island and Bank Clearing and Destabilization			X			
Longitudinal bank lowering					X	
Side Channels (High Flow, Perennial, and Oxbow Re-establishment)		X			X	
Boulder Groupings	X	X				
Riparian Vegetation Establishment		X				
Bank Line Embayments	X	X			X	
Jetty Removal					X	

[1] Many of these methods can be used for both habitat improvement and mitigation and river maintenance purposes, and some are listed in more than one location in the table to show there are multiple applications.

4. Strategy Assessment Methodology

4.1 Strategy Assessment Approach

This section summarizes the approach used to describe the reaches and analyzes the strategies. Note that the unique terms list at the end of this report defines terms used in the strategy assessment.

4.1.1 Current Geomorphic Trends

Climate change, flood and sediment control, regulation of flows for irrigation, land use, vegetation changes, and channelization have altered the historical water and sediment supply to the river. An imbalance between sediment transport capacity and sediment supply, the perceived current condition of the Middle Rio Grande, is a key cause of most channel and flood plain adjustments (Lane 1995 and Schumm 1977). Factors affecting this imbalance can be categorized as drivers of adjustment and controls on adjustment. Both drivers and controls can be modified through natural or anthropogenic means. Important drivers on the Middle Rio Grande include flow frequency, magnitude and duration, and sediment supply. Changes in these drivers resulting in recent geomorphic channel change on the Middle Rio Grande include decreased flow peaks, increased low-flow duration, and decreased sediment supply, which influence many reaches. Decreased peak flows mean that the existing channel is not reworked on as large a scale as historically. Increased low flows of longer duration means that more water is available for longer during dry periods that can sustain vegetation, aiding vegetation encroachment, which helps form a narrower channel. Decreased sediment supply means channel erosion is more likely.

Controls on recent channel adjustments on the Middle Rio Grande include bank stability, bed stability, base level, flood plain lateral confinement, and flood plain connectivity. Bank stability can be affected by natural (e.g., riparian vegetation) or mechanical (e.g., riprap) means. Similarly, bed stability can come from channel armoring through bed material coarsening or from constructed cross channel features. An example of a base level control change is the drop in pool elevation of Elephant Butte Reservoir, which resulted in channel degradation upstream. Levees and geologic outcrops can create lateral confinement of the flood plain and limit channel migration. A well-connected flood plain dissipates the energy of flood flows, reducing the sediment transport capacity.

The effects of driver changes are different for different reaches of the Middle Rio Grande. The current result of the interplay between drivers and controls from the Rio Chama to Arroyo de las Cañas is a river channel that now generally is degrading and narrowing; and the bed is coarsening at various rates. The lower portion of the Middle Rio Grande, from San Antonio and downstream has been impacted by reservoir pool fluctuations at Elephant Butte Dam. Sections of this reach now alternate between periods of aggradation and degradation, influenced by the pool level of the reservoir. During wetter periods with a full reservoir, this reach continues to experience high levels of aggradation. The aggradation, coupled with confinement of the river, has resulted in a perched channel condition and a tendency for sediment plugs to form in this reach. During dryer periods, the reservoir elevations fall; and this base level drop is a main cause for erosion of the upstream channel deposits. Rapid aggradation is the most defining characteristic of this reach. This has not been the case in the last few years, but history shows that the current period of degradation should be relatively short, and the reach most likely will return to aggradation.

Current and historical geomorphic trends are observable adjustments of the river's self-regulating response to move towards the condition of balance between sediment transport capacity and sediment supply. The fact that many changes, both natural and anthropogenic, occurred contemporaneously on the Middle Rio Grande greatly complicates interpreting the observed trends of channel and flood plain adjustments and basing predictions on these trends. Figure 4.1 illustrates the timing of many of these events and dates of significant floods.

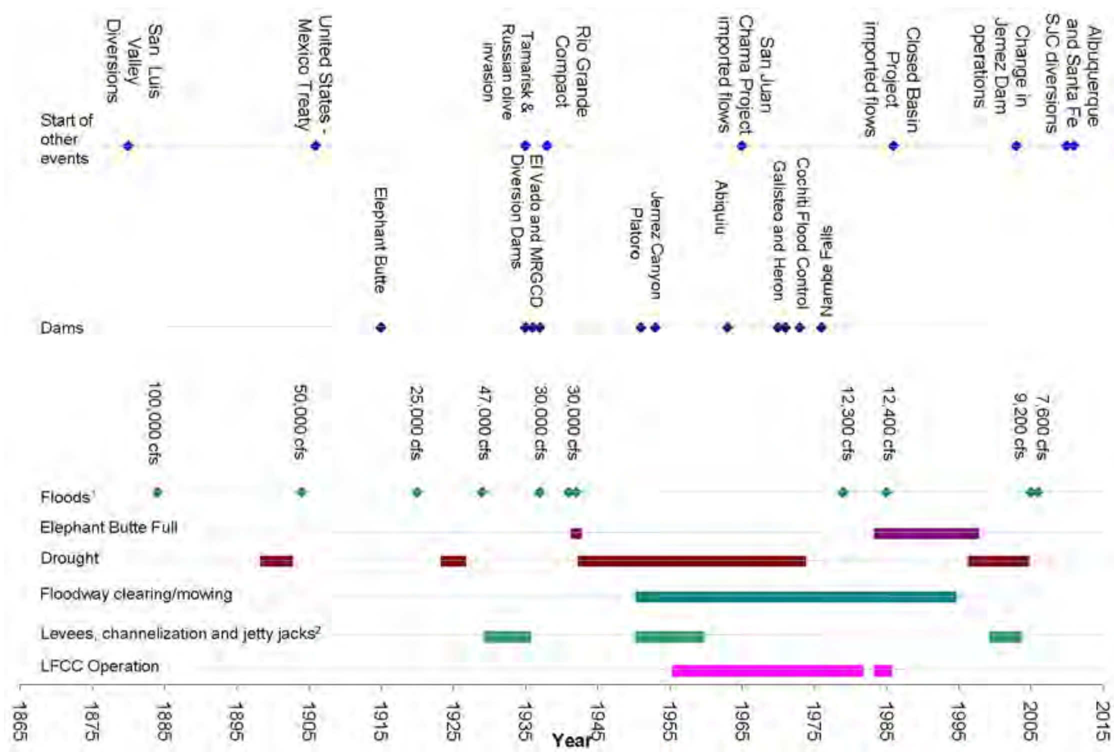

Figure 4.1. Timeline of events and significant floods.

Reach scale trends observed on the Middle Rio Grande that can result in river maintenance needs have been identified for each reach. The relationship between sediment transport capacity and supply varies for each trend. The trends are:

- **Channel Narrowing**

  When sediment transport capacity is greater than sediment supply, bed degradation or channel incision can occur. More bed degradation occurs in the channel thalweg (deepest area of the channel) than in shallower areas resulting in channel narrowing. When sediment transport capacity is less than sediment supply, sediment can deposit in the form of medial or bank-attached bars during high flows. When subsequent peak flows are lower, these bars may not remobilize, resulting in channel narrowing.

- **Vegetation Encroachment**

  Sediment transport capacity that is greater than sediment supply leads to bed degradation or channel incision as described under channel narrowing. As the channel incises more along the thalweg, adjoining higher areas of the riverbed are inundated and mobilized less frequently, creating a condition conducive to vegetation growth and reducing the width of the active channel. Sediment transport capacity greater than sediment supply can result in deposition, that becomes vegetated when not remobilized, thereby narrowing the channel. In either case, the increased duration of larger low flows further facilitates vegetation growth.

- **Incision or Channel Bed Degradation**

  When sediment transport capacity is greater than sediment supply and banks are more resistant than the bed, the river seeks to increase its sediment supply by transporting additional sediment from the bed, resulting in channel degradation or incision.

- **Increased Bank Height**

  When sediment transport capacity is greater than sediment supply, bank height increases as a result of channel degradation or incision. Bank height can increase due to sediment deposition near the bank line when flow goes overbank, because flow velocity and sediment transport capacity are reduced.

- **Bank Erosion**

  When sediment transport capacity is greater than sediment supply and the bed is more resistant than the banks, the river seeks to increase its sediment supply by transporting additional sediment from the banks, resulting in bank erosion. Coarsening bed material (discussed below) can make the bed more resistant than the banks. Channel degradation or incision leads to taller banks that are often less stable, again resulting in bank erosion.

- **Coarsening of Bed Material**

  When sediment transport capacity is greater than sediment supply and the channel bed degrades or incises, bed sediment of finer sizes (most easily transported) are removed from the bed while coarser sizes remain.

- **Aggradation**

  Sediment deposition occurs that raises the bed elevation when sediment transport capacity is less than sediment supply. Deposition can occur in both the main channel and the adjoining riparian zone, depending upon the magnitude of the sediment transport imbalance.

- **Channel Plugging with Sediment**

  When sediment transport capacity is less than sediment supply and sediment deposits in the main channel, flow from the top of the water column can go overbank at lower discharges. Because there is a higher concentration of sediment being transported near the bed than near the top of the water column, the proportion of the total sediment load being transported into the overbank areas is less than the proportion of overbank flow volume. As a result, the main channel sediment transport capacity is reduced, but the sediment supply decreases by a smaller percentage, resulting in additional deposition in the main channel. Continued overbank flows with sediment accumulation in the main channel further reduces main channel flow capacity. This process can continue until sediment completely fills the main channel.

- **Perched Channel Conditions**

  Perched channel conditions occur when the river channel bed is higher than adjoining riparian areas in the floodway or land outside the levee. When sediment transport capacity is less than sediment supply, with enough aggradation so that sediment-laden waters flow overbank into the riparian zone, flow velocity decreases, causing sediment deposition that raises the river bank. Continued bed raising and bank line deposition results in a channel, bordered by natural levees, which is higher than the adjoining areas between anthropogenic levees or geologic formations. This condition can be exacerbated by anthropogenic levees that decrease the available area for deposition. The river corridor or floodway also can become higher than land areas outside the levee when sediment deposition occurs across the entire riparian zone.

4.1.2 Strategy Implementation Modeling

The six reach-based river maintenance strategies are Promote Elevation Stability, Promote Alignment Stability, Reconstruct and Maintain Channel Capacity, Increase Available Area to the River, Rehabilitate Channel and Flood Plain, and Manage Sediment. Each strategy's properties and the methods used in their implementation are described in section 3.3. Methods are further discussed in appendix A.

Where data to model a reach are available (i.e., Cochiti Dam to Elephant Butte Reservoir), strategy implementation was modeled. This included sediment modeling to determine reach equilibrium conditions and hydraulic and meander belt analysis to generate indicators that are used in assessing the suitable reach and strategy combinations (see section 4.3 of this report and appendix B, chapter 5, for a more detailed discussion of indicators).

4.1.3 Reach Characteristics

Reach characteristics are used to help determine if a strategy is suitable for that reach, in strategy evaluations and in determining the significance of a reach, described in further detail in section 4.4. The reach characteristics are rated as high, medium, or low in four areas:

- Channel Instability (rated in terms of instability, see section 4.4.1)
- Water Delivery Impact (rated in terms of importance, see section 4.4.2)
- Infrastructure, Public Health, and Safety (rated in terms of importance, see section 4.4.3)
- Habitat Value and Need (rated in terms of importance, see section 4.4.4)

4.1.4 Strategy Suitability

Indicator results from the modeling, the characteristics of each reach, each strategy's properties and how those properties address the trends of change in a reach, and professional engineering and scientific judgment are used to screen out those strategies as not suitable that do not address the expected future trends of concern in a reach. Unsuitable strategies are not analyzed further (see section 4.5 for more information). Promote Elevation is not analyzed in aggrading reaches because other complementary strategies use methods that directly address aggradation (see section 3.3.1 and table C1.4 in appendix C for more information).

4.1.5 Geomorphic Effects of Strategy Implementation

Geomorphic effects of strategy implementation are discussed as reach-wide changes from baseline or existing conditions to inform the rating of evaluation factors (described in the next subsection). See section 4.6 for a discussion of geomorphic effects by strategy and appendix C, section C1.6.5 for a detailed discussion.

4.1.6 Evaluation Factors

The evaluation factors used in this report are based on site-specific bank and bed stabilization project evaluations by engineering, environmental considerations, and economics as described in Biedenharn et al. (1997).

The evaluation methodology was expanded to assess both bank and bed stabilization and nonbank and bed stabilization methods applied as reach scale strategies. The three evaluation factors used in this analysis are:

- Engineering Effectiveness (see section 4.7.1)
- Ecosystem Function (see section 4.7.2)
- Economics (in terms of implementation costs only) (see section 4.7.3)

Strategy assessment consists of several steps as shown in the flowchart in figure 4.2. Strategy ratings were developed to help determine which strategies will be recommended for more evaluation and which will not. Assessing the effects of an implemented reach scale strategy on these three evaluation factors is based on the suite of methods that would be used for a given strategy, taking into consideration the reach characteristics. Where the majority of the methods associated with a strategy was essentially the same type and had the same effect upon the attribute being evaluated, this majority was used in the rating.

4.1.6.1.1 Evaluation Factor Scoring

The indicators, historical trends (described in section 4.3), and professional judgment are used to discuss the geomorphic outcomes of strategy implementation for the suitable strategies as described in appendix C and section 4.6. The strategies then are rated at a reach-averaged appraisal level on the Engineering Effectiveness, Ecosystem Function, and Economics Evaluation Factors (discussed in sections 4.6–4.8 and in more detail in appendix C, section C1.7, Engineering Effectiveness Evaluation Factor; section C1.8, Ecosystem Function Evaluation Factor; and section C1.9, Economics Evaluation Factor).

Each evaluation factor has several attributes that feed into the final ratings. Attributes have been defined to focus the assessment on important areas of each evaluation factor. These attributes are rated using indicator modeling results, historical trends, geomorphic outcomes, and professional judgment. The rated attributes then are combined into a scoring table for each evaluation factor. The Engineering Effectiveness Evaluation Factor Attributes are grouped into two

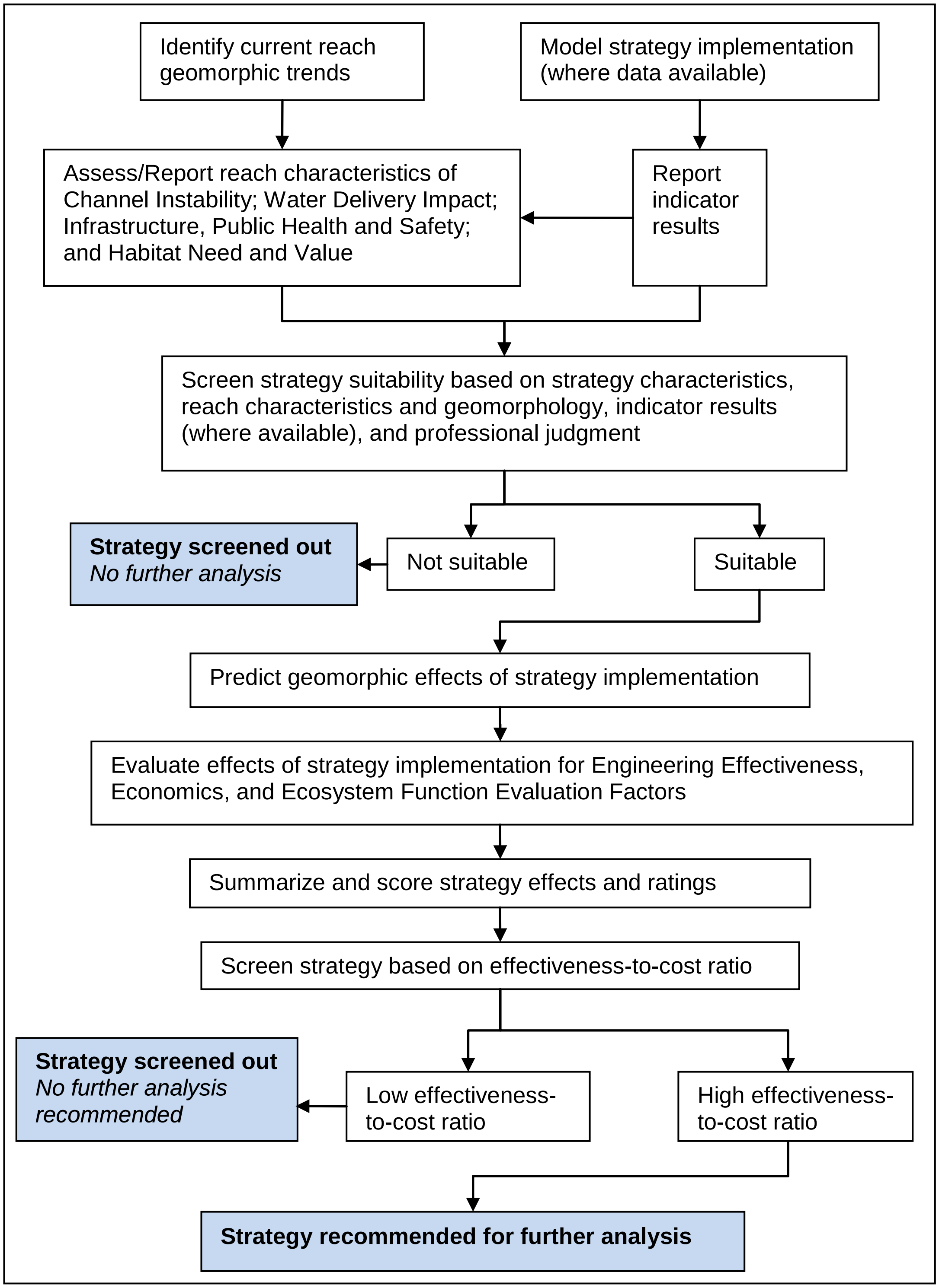

Figure 4.2. Flowchart of strategy assessment process.

categories: Strategy Performance and River Maintenance. The Ecosystem Function Evaluation Factor Attributes are grouped by two representative species: SWFL and RGSM.

4.1.6.1.2 Effectiveness-to-Cost Ratios

The scoring results from the Engineering Effectiveness and Ecosystem Function Evaluation Factors for each strategy in each reach are termed "effectiveness scores." The effectiveness scores are divided by the Economics Evaluation Factor (cost score) to provide information on which strategies should be more economical, reduce negative environmental effects, and/or have increased environmental benefits, resulting in greater overall effectiveness than current practices. Results are presented in tables and graphs in appendix C with summary graphs for each reach in chapters 5–15 of this main report.

4.1.7 Recommend Strategies

Strategy assessment results and reach characteristic ratings are used to recommend strategies for further study and will help the managers of the Middle Rio Grande make future maintenance decisions on the potential application of reach-wide approaches or strategies. A summary of the assessment results is presented in section 4.8 of this main report with more detail available in appendix C, section C1.9. Each reach chapter discusses the reach characteristics, strategy assessment results, reach specific information about strategy implementation, and recommendations on which strategies should be studied further for that respective reach.

4.2 Reach Definitions

The Middle Rio Grande has been defined for river maintenance purposes into 11 applicable reaches (table 4.1). More detailed information on reach definition and conditions can be found in the Part 1 Report (Reclamation 2007), chapters 5–15 of this report, and in appendix C. Each reach chapter covers one reach and contains the reach characteristics, reach-specific geomorphic effects of strategy implementation, and the results of the evaluation factors assessments for that reach.

4.3 Strategy Implementation Modeling

The variety of river management practices considered for implementation on the Middle Rio Grande fall into six basic strategies: Promote Elevation Stability, Promote Alignment Stability, Reconstruct and Maintain Channel Capacity, Increase Available Area to the River, Rehabilitate Channel and Flood Plain, and Manage Sediment. Refer to section 3.3 for a detailed discussion on these strategies. Three of the eleven reaches do not have sufficient data to incorporate them into a model. Table 4.2 provides a reference for the reach numbers used throughout section 4.3. Appendix B provides all supporting data and information for this section.

Table 4.1. Reach Definitions for the Middle Rio Grande

Reach	Length (RM)	River Miles
Velarde to Rio Chama[1]	13.0	285 to 272
Rio Chama to Otowi Bridge[1]	14.4	272 to 257.6
Cochiti Dam to Angostura Diversion Dam	22.9	232.6 to 209.7
Angostura Diversion Dam to Isleta Diversion Dam	40.4	209.7 to 169.3
Isleta Diversion Dam to Rio Puerco	42.3	169.3 to 127
Rio Puerco to San Acacia Diversion Dam	10.8	127 to 116.2
San Acacia Diversion Dam to Arroyo de las Cañas	21.2	116.2 to 95
Arroyo de las Cañas to San Antonio Bridge	7.9	95 to 87.1
San Antonio Bridge to River Mile 78	9.1	87.1 to 78
River Mile 78 to Elephant Butte Reservoir	28.0	78 to 46
Elephant Butte Dam to Caballo Reservoir[1]	14.6	26.6 to 12

[1]These reaches were not modeled; see section 4.3 for more information.

Table 4.2. Model Reach Numbers

Reach	Model Reach Number
Velarde to Rio Chama	Not modeled
Rio Chama to Otowi Bridge	Not modeled
Cochiti Dam to Angostura Diversion Dam	1
Angostura Diversion Dam to Isleta Diversion Dam	2
Isleta Diversion Dam to Rio Puerco	3
Rio Puerco to San Acacia Diversion Dam	4
San Acacia Diversion Dam to Arroyo de las Cañas	5
Arroyo de las Cañas to San Antonio Bridge	6
San Antonio Bridge to River Mile 78	7
River Mile 78 to Elephant Butte Reservoir	8
Elephant Butte Dam to Caballo Reservoir	Not modeled

4.3.1 SRH-1D Modeling

A one-dimensional mobile bed model, Sedimentation and River Hydraulics One-Dimensional Sediment Transport Dynamics Model, was developed and implemented to represent approximately 200 miles of the Middle Rio Grande. The goal of the model was to estimate an equilibrium slope for the model reaches identified in table 4.2 and to estimate the amount of material that would be added or removed from the reach to achieve that equilibrium slope. The change in bed material size by reach was also an output from the SRH-1D modeling. SRH-1D allows vertical adjustment of bed elevation via erosion and deposition of material but does not model changes in channel width or changes in channel length through lateral migration. The results of the SRH-1D model represent the no maintenance future (NMF-V) scenario and facilitate the development of the indicators listed in table 4.3. Appendix B explains in more detail the data inputs, modeling assumptions, modeling approach, and sensitivity analyses performed using SRH-1D.

4.3.2 NMF-H Modeling

The equilibrium stable slope was determined from the SRH-1D modeling for the vertical portion of the NMF-V. The no maintenance future modeling – horizontal (NMF-H) represents the assumption that all changes in the future will occur in the horizontal alignment of the river. The geometry to represent the NFM-H was developed by starting with the baseline geometry and adjusting the spacing between cross sections. Conceptually, the channel length and sinuosity may increase or decrease, but the valley length and reach boundaries would not change. Model results for the reaches from Cochiti Dam to Angostura Diversion Dam, Angostura Diversion Dam to Isleta Diversion Dam, Isleta Diversion Dam to Rio Puerco, San Acacia Diversion Dam to Arroyo de las Cañas, and River Mile 78 to Elephant Butte Reservoir show a reduction in slope (NMF-V modeling), which translates to an increase in channel length as represented by an increased spacing between cross sections and an increased sinuosity (NMF-H modeling). Similarly, the increase in reach slope for the Rio Puerco to San Acacia Diversion Dam, Arroyo de las Cañas to San Antonio Bridge, and San Antonio Bridge to River Mile 78 reaches translate to a decrease in channel length and an associated decrease in sinuosity (represented by decreased spacing between cross sections) for NMF-H. The results of the NMF-H modeling are used to develop the indicators discussed in section 4.3.5. More information on the NMF-H modeling may be found in appendix B.

4.3.3 Meander Belt Assessment

A sine-generated curve alignment for the river, along with the associated meander belt width, was developed for the baseline condition and the NMF-H scenario. The basic layout of the sine-generated curve for a given reach is the same because it is assumed that the average channel width remains constant regardless of

Table 4.3. Indicators for Strategy Assessment with Brief Descriptions

Indicator	Description
A. Longitudinal Channel Slope Stability	Assessment of bed slope stability
1. Strategy Slope/Stable Slope	Degree of variation between strategy bed slope and equilibrium condition bed slope
2. Strategy Slope/Baseline Slope	Degree of variation between strategy bed slope and baseline condition bed slope
3. Baseline Slope/Stable Slope	Degree of variation between current condition bed slope and equilibrium-condition bed slope
B. Wetted Area at 4,700 cubic feet per second (cfs)	Wetted channel area at 4,700 cfs (strategy/baseline)
C. Bed Elevation Change	Average change in channel bed elevation from baseline to strategy conditions (strategy/baseline)
D. Containment of 10,000 cfs	Water surface elevation for 10,000 cfs compared to minimum lateral constraint elevation.
E. Overbank Inundation	Assessment of overbank flow area and frequency
1. High-flow Inundated Area/Channel Area	Comparison of area inundated during a flood to main channel area (baseline only)
2. 4,700 cfs/Overbank Inundation Discharge	Comparison between 4,700 cfs and the discharge required to cause overbank inundation for one-half of the reach length (strategy only)
F. Sinuosity	Channel length compared to valley length
1. Strategy Sinuosity	Sinuosity of the channel for a given strategy (strategy only)
2. Strategy Sinuosity/Baseline Sinuosity	Comparison of the strategy sinuosity to the baseline sinuosity
G. Width-to-Depth Ratio at 4,700 cfs	Ratio of top width to hydraulic depth at 4,700 cfs (strategy/baseline)
H. Meander Width	Width of the sine-generated meander belt
1. Percent Fit of Length	Comparison of the meander belt width to the lateral constraints on a length basis (strategy only)
2. Meander Belt Width Area/Area Between Lateral Constraints	Comparison of the meander belt width to the lateral constraints on an area basis (strategy only)
I. Wetted Width at 4,700 cfs/Width Between Lateral Constraints	Comparison of the wetted width at 4,700 cfs to the width between the lateral constraints (strategy only)
J. Wetted Width at 4,700 cfs	Comparison of the wetted width at 4,700 cfs for a strategy to the wetted width at 4,700 cfs for baseline conditions (strategy/baseline)
K. Bed Material	Bed material grain size distribution
1. Percent Fines	Percent of bed material less than 0.063 millimeter (mm) (strategy only)
2. Percent Sand	Percent of bed material between 0.063 mm and 2 mm (strategy only)
3. Percent Gravel	Percent of bed material greater than 2 mm (strategy only)
4. Strategy D50/Baseline D50	Median bed material grain size (strategy/baseline)
5. Strategy D84/Baseline D84	The 84th percentile of the grain size distribution (strategy/baseline)

strategy, and that the meander wavelength is equal to 10 channel widths (Knighton 1998). The length of the river for a given strategy is based on the representative cross-section geometry, and the sinuosity for a strategy is calculated by comparing the river length to the length of the constrained valley centerline. Appendix B presents an example sine-generated curve layout along the valley centerline, as well as further information on the development of the meander pattern and the associated meander belt width by reach for the baseline condition and the NMF-H scenario. Constraints on channel migration because of resistant geology or actions that would be taken to protect infrastructure have been defined (Varyu et al. 2011). The results of the meander belt analysis are used to develop the indicators H1: Meander Width: Percent Fit of Length and H2: Meander Width: Meander Belt Width Area/Area Between Constraints, discussed in section 4.3.5. Indicator H1 is the percentage of the total channel length of a reach that fits between the constraints.

4.3.4 Hydrologic Engineering Centers River Analysis System (HEC-RAS) Strategy Modeling

A hydraulic model was developed for the entire domain from Cochiti Dam to Elephant Butte Reservoir for the baseline, NMF-V, and NMF-H conditions. The no maintenance future geometries are developed to estimate an envelope of the future equilibrium conditions. A hydraulic model then was developed by strategy, one reach at a time, with the rest of the domain made up of the baseline geometry. For example, assessment of Rehabilitate Channel and Flood Plain (see below) in the Cochiti Dam to Angostura Diversion Dam Reach would be performed by using the baseline cross-section geometry for model Reaches 2–8 and the cross-section geometry for the strategy in model Reach 1. Model runs used a constant flow of 4,700 and 10,000 cfs. The Upper Rio Grande Water Operations (URGWOPS) 2007 Environmental Impact Statement (USACE et al. 2007) recommends 10,000 cfs as the safe channel capacity, and 4,700 cfs represents a common high flow considering all reaches. Each geometry was also modeled with stepwise increases of 100 cfs to estimate the flow necessary to go overbank in 50 percent of a reach. The results of the hydraulic modeling are used to develop the indicators discussed in section 4.3.5.

4.3.5 Indicators

Twenty descriptive indicators were defined to help compare the strategies for each reach. Some of the indicators are grouped together because of similarities (table 4.3). The intent is to have these indicators reflect the physical properties of the strategy implementation, as much as possible, that are relevant to the evaluation factors. Unless otherwise stated, the indicators are distance-weighted, reach-averaged values and are a dimensionless ratio calculated by dividing the strategy value by the baseline value to reflect any change relative to baseline conditions. Indicators H1 (Meander Width: Percent Fit of Length) and H2 (Meander Width: Meander Belt Width Area/Area Between Lateral Constraints) come directly from the meander belt analysis results, while indicators C (Bed

Elevation Change), K1 (Bed Material: Percent Fines), K2 (Bed Material: Percent Sand), K3 (Bed Material: Percent Gravel), K4 (Bed Material: Strategy D50/Baseline D50), and K5 (Bed Material: Strategy D84/Baseline D84) come directly from the SRH-1D results. All other indicators are based on hydraulic modeling results. Further indicator descriptions, including graphics, and all model result tables are presented in appendix B.

These indicators provide a basis for comparing strategies for each reach. As discussed in appendix B, certain strategies may not be readily represented in this reach scale, one-dimensional modeling effort. For those strategies, the indicators, which are assumed to be representative of the strategy, are reported in the results tables in appendix B.

4.3.6 Differentiation of Indicator Results

To facilitate using the indicators for rating attributes, it was desirable to bin the results for each indicator into three categories. Only data from the unique scenarios (see section 5.4 in appendix B) were considered: no maintenance future vertical (NMF-V), no maintenance future horizontal (NMF-H), baseline (BASE), and rehabilitate channel and flood plain (REHAB)[1]. Furthermore, some of the indicator impacts were not considered when differentiating indicators. For example, impacts for indicator A1: Strategy Slope/Stable Slope, the cases of NMF-V, and NMF-H were predetermined to be equal to 1, so only the indicator impacts for BASE and REHAB were considered when binning A1 into the three categories.

Once the appropriate dataset was identified for each indicator, the first step to differentiating the indicator results was to break the dataset into quartiles. In this first-cut approach, the impacts between the 25th and 75th percentile were considered not significantly different than the median, with impacts below the 25th percentile and impacts greater than the 75th percentile considered significantly different than the median. These first-cut estimates of where to break the impacts into bins was then further refined using professional judgment. In some cases, the impacts are only binned into two categories when they varied in just a single direction from baseline. Finally, some bins were set for various other reasons. For example, for Indicator C: Bed Elevation Change, the error in the vertical data is ±0.5 feet; therefore, this was set as the range for the bins. Plots of all indicator impacts and the differentiation breaks can be found in appendix B.

4.4 Reach Characteristics

Existing conditions of a reach are described by reach characteristics. Reach characteristics provide information used in rating the strategy effects by reach and

[1] Note that REHAB is specific to the Rehabilitate Channel and Flood Plain Strategy.

can be used in decisions such as prioritizing the reaches for further investigation and maintenance. They are rated as high, medium, or low in four areas:

- Channel Instability (rated in terms of instability)
- Water Delivery Impact (rated in terms of importance)
- Infrastructure, Public Health, and Safety (rated in terms of importance)
- Habitat Value and Need (rated in terms of importance)

The ratings are comparative between reaches. Thus, a rating of low indicates that this reach characteristic may be less of a consideration for that reach as compared to other reaches. Table 4.4 is a summary table of the types of information used in rating the reach characteristics. The Channel Instability rating indicates the likelihood of significant channel change within a reach while the other three reach characteristic ratings reflect the importance of that characteristic within a reach. In addition, reach characteristics that are rated high in a reach more strongly influence strategy and method selection than reach characteristics rated medium or low. These reach characteristics are discussed for each reach in chapters 5–15.

Table 4.4. Reach Characteristics and Type of Information Used in Ratings

Channel Instability[1]	Water Delivery Impact	Infrastructure, Public Health, and Safety	Habitat Value and Need
Existing slope versus stable slope	Number of diversion points.	Land use: urban, agricultural, or public land.	Percent of suitable habitat available and percent occupied.
Meander belt fit	Effects of riverside drainage and irrigation channels.		Occupied habitat quality and trends.
Space available			Are there new occupations?
Volume of sediment change	Documented flow losses or gains.		Is the habitat improvable?
Planform change			

[1]Incorporates model results.

4.4.1 Channel Instability Reach Characteristic

4.4.1.1.1 Causes and Effects of Instability

The most important drivers and controls of channel and flood plain adjustments over a decadal timescale are discharge and sediment supply magnitude and frequency (driving or forcing events), system thresholds (controls) that define vulnerability, and recovery time to dynamic equilibrium for common flows (Harvey 2007). The current hydrologic regime has limited flood magnitude and modified flood frequency. The frequencies have changed in two ways: large peaks are less frequent because of flood management, while smaller flood peaks and low flows are more frequent because water storage and release for irrigation and water is pumped from the Low Flow Conveyance Channel (LFCC) to provide minimum flows for habitat. Consequently, the river system does not experience the tremendous peaks or very low flows of the past. Sediment supply has been altered through sediment control measures and changes in bed and bank stability.

System controls have changed through bank stabilization (both vegetation and mechanically based), coarsening of bed material, and floodplain connectivity and lateral confinement. Thus, the thresholds for channel and flood plain disturbances are higher, and the disturbing events are less frequent. The end result is a system that is less reflective of the arid Southwest and more reflective of regions with higher precipitation. This is shown in the shift toward a narrow, deep, mildly meandering, single thread channel for much of the Middle Rio Grande—a very different channel than the wide, sandy channel of recent history. This shift has resulted in greater uncertainty in predicting responses to both anthropogenic impacts and spatial and temporal variability because there is a shorter time period with information that can be used as a basis for predictions. Appendix C, section C1.4.1.1, provides examples of changes in degrading and aggrading reaches.

4.4.1.1.2 Channel Instability Rating Factors

The Channel Instability Reach Characteristic is rated as low for reaches where little change is expected in the next decade, medium for reaches where some change is anticipated but it is not expected to be extensive, and high for reaches where large-scale changes are possible in the next decade. Several factors are used to rate the instability of the channel for the Channel Instability Reach Characteristic. Ratings are derived from indicator modeling results, historical trends, and professional judgment. Reaches that were not modeled are based on historical trends and professional judgment. The rating factors are:

- **How far the existing slope is from the stable slope for a reach.** Amount of historical change and Indicator A3: Longitudinal Channel Slope Stability: Baseline Slope/Stable Slope are used. River Mile 78 to Elephant Butte Reservoir Reach is a special case and rated high, because the controlling effect of the reservoir pool elevation creates a high potential for slope change.

- **How well does the calculated meander belt width needed for a reach fit within the infrastructure and geologic constraints.** Historical meander belt and Indicator H1 Meander Width: Percent Fit of Length are used. If 10 percent or more of the meander belt does not fit, the rating is high; otherwise the rating is medium. No rating of low is given because, in all reaches, there are narrow sections of constraints that create areas of local concern.

- **How much extra area is available between the constraints outside the meander belt width to allow for channel adjustment.** Historical meander belt data and Indicator H2: Meander Width: Meander Belt Width Area/Area Between Lateral Constraints values are used.

- **How much sediment volume is expected to be removed or deposited before the stable slope is reached.** For modeled reaches, the volume of sediment deposited or removed for the reach to reach equilibrium slope is calculated. Final ratings are developed based on professional judgment, historical trends, and modeled results where available.

- **How likely the planform is to change.** Likelihood of planform change is estimated based on the stage of the reach in the Middle Rio Grande planform evolution model (see appendix C, section C1.4.1.3 [adapted from Massong et al. 2010]), bank height and stability, and the difference between baseline and stable slope. This is a qualitative estimate using professional judgment.

  The stages of the Middle Rio Grande planform evolution model move between Stages 1–3 on a common pathway; Stages A4–A6 occur in aggrading conditions when sediment transport capacity is less than sediment supply, and Stages M4–M8 are migrating conditions that occur when sediment transport capacity is greater than sediment supply. The planform stages may evolve in either direction or cycle back to Stage 1 and are defined as follows:

  - Stage 1 (Mobile sand-bed channel)
  - Stage 2 (Vegetating bar channel)
  - Stage 3 (Main channel with side channels)
  - Stage A4 (Aggrading single channel)
  - Stage A5 (Aggrading plugged channel)
  - Stage A6 (Aggrading avulsed channel)
  - Stage M4 (Narrow single channel)
  - Stage M5 (Sinuous thalweg channel)
  - Stage M6 (Migrating bend channel)
  - Stage M7 (Migrating with cutoff channel)
  - Stage M8 (Cutoff is now main channel)

More specific information on each of the factors and how they are rated can be found in appendix C, section C1.4.1.2. Ratings are presented in appendix C, table C1.13.

4.4.2 Water Delivery Impact Reach Characteristic

The ratings for the Water Delivery Impact Reach Characteristic qualitatively evaluate how each reach impacts water delivery. The importance rating of water delivery for each reach is based upon water diversions and river flow seepage losses and gains. In the modeled reaches, river diversions are made from Angostura, Isleta, San Acacia Diversion Dams, and two Albuquerque Bernalillo County Water Utility Authority diversions (using surface and Ranney collectors). In the reaches from Cochiti Dam downstream to San Acacia Diversion Dam, irrigation return flows and riverside drain flows can be re-diverted into the MRGCD system. Downstream from San Acacia Diversion Dam, there are no main channel diversions, and river waters flow into Elephant Butte Reservoir. Seepage estimates have been reported between Cochiti Dam and the North Boundary of the Bosque Del Apache National Wildlife Refuge (S.S. Papadopulos and Associates, Inc. [SSPA] 2008). In the Cochiti Dam to Angostura Diversion Dam and Rio Puerco to San Acacia Diversion Dam Reaches, drain return flows exceed channel seepage losses. In all other reaches, channel seepage losses exceed drain return flows. It should be noted that, in the River Mile 78 to Elephant Butte Reservoir Reach, seeps have been observed in sections of recent degradation; but this is expected to stop when aggradation returns. Downstream from San Acacia Diversion Dam, irrigation returns and drainage waters are conveyed in the LFCC and enter the river within the Elephant Butte reservation boundary. During times when the river goes dry in the southern-most river reaches, water is pumped from the LFCC to the river to maintain RGSM habitat. The evaluation of the Water Delivery Impact Reach Characteristic for this plan does not include analysis of the water budget or a direct accounting in terms of Rio Grande Compact deliveries.

- Reaches rated of high importance for the Water Delivery Impact Reach Characteristic have one or more of the following properties:
- No diversions from the river. This is important as river waters flow into Elephant Butte Reservoir.
- Multiple diversions except for Velarde to Otowi Bridge where each diversion is generally less than 50 cfs.
- Flows that can be used for irrigation in multiple downstream reaches during low water supply years.
- Gains in flows from the riverside drainage system that can reduce downstream diversions.

Reaches from San Acacia Diversion Dam downstream to the Elephant Butte Reservoir are rated high importance for the Water Delivery Impact Reach Characteristic. Irrigation diversions are made from the LFCC in this reach. Irrigation return flows from the MRGCD's Socorro Division system flow into the LFCC, along with shallow ground water and land drainage flows.

Reaches rated medium importance for the Water Delivery Impact Reach Characteristic have one diversion location. Irrigation return and riverside drain flows can be re-diverted from the river and do not flow directly into Elephant Butte Reservoir.

Reaches rated low importance for the Water Delivery Impact Reach Characteristic do not have documented seepage loss rates and have either low amounts or no river diversions.

Note that the potential effects of the various strategies described in section 3.3 are evaluated for each strategy in each reach as part of the Engineering Effectiveness Evaluation Factor (Water Delivery Attribute) as described in section 4.6.

4.4.3 Infrastructure, Public Health, and Safety Reach Characteristic

The overall value of riverside infrastructure and facilities and public health and safety has three classifications:

- **Urban** land use areas would include municipalities with populations greater than 10,000. These municipalities have infrastructure such as roads, water and sewer and other utility lines, and homes and commercial development adjacent to the river. Potential flooding and public health and safety impacts would be the greatest in urban areas with their associated infrastructure and population.

- **Agricultural** land use areas include farms and ranches, which generally include irrigated croplands; with a sparse distribution of homes, barns, and other agricultural buildings. Pueblos, as well as State and national wildlife refuges, are included in the agricultural land use category. Wildlife refuges are included in agricultural land use when they contain irrigated croplands. Potential flooding and public health and safety impacts likely would occur but to a lesser degree than in urban lands.

- **Public** land use areas generally have no development other than to facilitate public uses. Elephant Butte Reservoir reservation is considered public land. Wildlife refuges are considered public land areas when no agriculture exists. For public lands, public health and safety concerns are minimal.

Because of the direct linkage between land use, infrastructure, and public health and safety, these three land use classifications (urban, agricultural, and public) are used to evaluate the Infrastructure, Public Health, and Safety Reach Characteristic.

Each classification has distinct differences in the value and types of infrastructure, as well as in public health and safety considerations.

Riverside levees would be the first infrastructure affected by lateral migration or peak flows. Note that riverside levees and drains/canals exist almost continuously along both sides of the river from Cochiti Dam to San Marcial, with the exception of the east side of the river between San Acacia Diversion Dam and about 10 miles downstream from San Marcial, along with a few other locations. Thus, levee infrastructure generally is not used to differentiate between the three classifications (urban, agricultural, and public lands). This report does not contain specific evaluation about the importance of various riverside infrastructures such as the LFCC or other large canals and levees that are operated and maintained by MRGCD. Other types of infrastructure to be affected are the riverside drains and canals.

Potential adverse public health and safety impacts are considered in this document, while potential water and economic losses are not included. Public health and safety issues arise when land adjacent to the levee is flooded as a result of levee failure. Levee failure can occur as a result of riverbank erosion, overtopping, piping, unstable foundation, and side slope instability. The possible consequences of levee failure include adverse public health and safety impacts, water loss, and economic loss. If a breach were to occur, river waters would flow into riverside drains and canals. When the capacity of downstream hydraulic structures is exceeded, adjoining land areas most likely will be flooded. Flooding would be even more significant in reaches where the river channel is perched above the valley floor. Inundation damage can occur to property such as homes, businesses, utilities, and transportation infrastructure. Public health and safety concerns also potentially include septic or sanitary sewer system failure, contamination of drinking water wells, utility failure, and inability to access homes and businesses.

4.4.4 Habitat Value and Need Reach Characteristic

Two federally endangered species are used to assess the importance of the Habitat Value and Need Reach Characteristic: Southwestern willow flycatcher, *Empidonax traillii extimus*, and Rio Grande silvery minnow, *Hybognathus amarus*. Both of these species have evolved in the Rio Grande system and require a properly functioning river and flood plain to thrive. The riparian obligate species (SWFL) and lotic species (RGSM) are assumed to represent the needs of other species that occupy the river system at this appraisal level of analysis.

Habitat maps, presence/absence survey data, nest monitoring data, and professional judgment were used to characterize reaches in terms of the importance of the Habitat Value and Need Reach Characteristic for the SWFL. Habitat value is determined by the presence (or absence) and extent of suitable SWFL habitat and can be thought of as the current condition. Additionally, higher value is assigned if this habitat is occupied by successfully breeding SWFLs. Habitat needs within a given reach are tougher to characterize because this characterization involves several factors and is determined by answering several questions:

- Is all suitable habitat within a reach occupied?
- Is currently occupied habitat decreasing in quality because of hydrology, age, or other factors?
- How close is newly developed suitable habitat to existing source SWFL populations, and how likely is it to be colonized by breeding SWFLs?
- How feasible is habitat creation within a given reach?

The ratings for the importance of the Habitat Value and Need Reach Characteristic for the RGSM were based upon current population levels or potential of the area to support a viable population of RGSM. Currently, RGSMs are present from Angostura Diversion Dam to the inflow to Elephant Butte Reservoir. There may be opportunities in the future to expand this range into other portions of the river if habitat conditions are appropriate. Higher value is placed upon currently occupied areas. For areas where RGSMs are not currently present, ecosystem assessment is based upon the expected native fishery within the area. Many of the areas have been altered from their historical condition, especially with respect to substrate and water temperature, which have a large impact on the composition of the fish fauna. Most native fisheries in the Southwest depend upon rivers with diverse habitats. Highly channelized reaches with low channel diversity provide very little habitat for most fish species. Specific questions for RGSM habitat value are similar to those presented for SWFL:

- What proportion of the reach provides suitable habitat for RGSM?
- Is all suitable habitat within a reach continuously occupied?
- What is the extent of drying within the reach?
- Is currently occupied habitat decreasing in quality because of hydrology, geomorphology, age, or other factors?
- How feasible is habitat improvement within a given reach?

4.5 Strategy Suitability

The first screening of strategies compared the effects of strategy implementation (see appendix C, section C1.6) to the reach geomorphic trends, reach characteristics, and modeling results of a reach. The intent was to focus evaluations on strategies that would be suitable because they counteract or modify trends of interest in a reach. There are 11 reaches and 6 possible strategies in each reach, giving 66 possible separate evaluations. After the suitability screening, there were 39 reach/strategy combinations to be evaluated, a 40-percent reduction. Table 4.8 in section 4.8 contains a summary of the suitability screening.

4.6 Geomorphic Effects of Strategy Implementation

The geomorphic effects of strategy implementation provide information to help assess the Engineering Effectiveness, Ecosystem Function, and Economics Evaluation Factors. Geomorphic effects of strategy implementation are discussed as reach-wide changes from baseline or existing conditions in:

- Support for natural channel processes under current water and sediment supplies
- The balance between sediment transport capacity and sediment supply
- Flood plain connectivity
- Planform type or stage[1] (Massong et al. 2010)

The geomorphology of a river results from physical processes, geologic and anthropogenic controls on those processes, and the history of changes, both natural and anthropogenic, within its watershed and channel. The effects of strategy implementation are estimated based on expected reach-based changes in processes as informed by controls, modeling indicators, historical trends, and professional judgment. Analysis results pertain to the next decade and have a moderate to high uncertainty because the future hydrology is unknown and uncertainty exists in system responses to the strategies. More detailed information on the geomorphic effects analysis can be found in appendix C, section C1.6.

Reach-specific geomorphic effects of strategy implementation are reported in chapters 5–15 for strategies that are recommended for further study and described in detail in appendix C. General strategy implementation geomorphic effects are described below.

[1] Stages are defined in the planform evolution model from Massong et al. (2010) and further described in appendix C, section C1.4.1.3. Also refer to the Unique Terms section located at the end of this document.

- **Promote Elevation Stability**

  This strategy tends to decrease channel and flood plain adjustments and episodic sediment transport because changes in bed elevation and temporary local sediment storage in the channel are locally minimized. Generally, little change in the attenuation of flood events in incised reaches, flood plain connectivity, or interaction between surface water and ground water is expected. If the bed is raised as a result of implementation, there may be an increase in flood plain connectivity and flood attenuation. When degradation is reduced or controlled and sediment transport capacity is still greater than sediment load, there is a possibility for increased lateral channel and flood plain adjustments at high flows. The sediment transport capacity and sediment supply should come into closer balance through the bed slope adjustment. Aggradational trends are addressed through implementing the following strategies: Reconstruct/Maintain Channel Capacity, Increase Available Area, and Manage Sediment.

- **Promote Alignment Stability**

  A general decrease in lateral channel and flood plain adjustments is expected with implementation of this strategy, but a temporary increase is possible if space is available for channel migration and lengthening. The attenuation of flood events in incised reaches and in the interaction between surface water and ground water should remain similar to existing conditions unless the channel migrates laterally—in which case, each could increase. If there is enough space to lengthen the channel, then the balance between sediment transport capacity and sediment supply could come closer, and episodic sediment transport could increase with streambank erosion.

- **Reconstruct and Maintain Channel Capacity**

  Little change is expected because the existing channel would be re-created. This strategy may help reduce future differential between bed and valley elevation in aggrading reaches.

- **Increase Available Area to the River**

  If the river is allowed to move as needed, the sediment transport capacity and sediment supply will come into closer balance. An increase in attenuation of flood events, surface water/ground water interactions, and channel and flood plain adjustments is expected. There is a possibility that the effective transport of water and sediment might decrease, especially in the short term as the channel lengthens and may evolve into a less hydraulically efficient form.

Table 4.8. Strategy Suitability Assessment and Recommendations

Strategy / Reach	Promote Elevation Stability	Promote Alignment Stability	Reconstruct /Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
Velarde to Rio Chama • Constructed alignment fairly stable • Migrating bends • Moderate incision not recent • Narrowing with resistant vegetation	Not suitable due to reach characteristics: low potential for new degradation	**Further study recommended**	Not suitable due to reach characteristics: loss of channel capacity not expected	**Further study recommended**	Not recommended: low effectiveness-to-cost ratio	Not suitable due to Reach Characteristics: no reach-wide imbalance in sediment transport capacity and load
Rio Chama to Otowi Bridge • Constructed alignment fairly stable • Migrating bends • Moderate incision • Narrowing with resistant vegetation	Not recommended: low effectiveness-to-cost ratio	**Further study recommended**	Not suitable due to reach characteristics: loss of channel capacity not expected	**Further study recommended**	Not recommended: low effectiveness-to-cost ratio	Not suitable due to Reach Characteristics: no reach-wide imbalance in sediment transport capacity and load
Cochiti Dam to Angostura Diversion Dam • Migrating bends – San Felipe • High incision • Low upstream sediment supply • Modeling shows both aggradation and degradation	**Further study recommended**	**Further study recommended**	Not suitable due to reach characteristics: loss of channel capacity not expected	**Further study recommended**	Not recommended: low effectiveness-to-cost ratio	Not suitable due to indicators: modeling results show both aggradation and degradation
Angostura Diversion Dam to Isleta Diversion Dam • Single channel • Low sediment load • Gravel bed channel • Potential for more incision and lateral migration • Upstream narrowing • Downstream bar formation • Many new restoration projects	**Further study recommended**	**Further study recommended**	Not suitable due to reach characteristics: loss of channel capacity not expected	Not suitable due to reach characteristics: urban development makes implementation so expensive as to be unfeasible	**Further study recommended**	**Further study recommended**
Isleta Diversion Dam to Rio Puerco • Narrowing through island and bank vegetation growth • Bank height increase due to deposition • Shifting toward single thread channel • Unknown potential for channel incision and lateral migration • Modeling shows meander belt fits between constraints, but there is little extra space	**Further study recommended**	Not suitable due to indicators: modeling results show meander belt fits between constraints	Not recommended: low effectiveness-to-cost ratio	**Further study recommended**	**Further study recommended**	**Further study recommended**
Rio Puerco to San Acacia Diversion Dam • Localized channel incision • Downstream lateral migration • Shifting toward single thread channel • Modeling results show mild future aggradation	Not analyzed because implemented through other strategies due to indicators: modeling results show mild aggradation	**Further study recommended**	Not suitable due to reach characteristics: loss of channel capacity not expected	**Further study recommended**	**Further study recommended**	Not suitable due to reach characteristics: only a mild, reach-wide imbalance in sediment transport capacity and load

Table 4.8. Strategy Suitability Assessment and Recommendations (continued)

Strategy / Reach	Promote Elevation Stability	Promote Alignment Stability	Reconstruct /Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
San Acacia Diversion Dam to Arroyo de las Cañas • Channel incision and lateral migration	**Further study recommended**	**Further study recommended**	Not suitable due to reach characteristics: loss of channel capacity not expected	**Further study recommended**	**Further study recommended**	Not recommended: Low effectiveness-to-cost ratio
Arroyo de las Cañas to San Antonio Bridge • Local narrowing through island and bank vegetation growth • Transition between upstream degradation and downstream aggradation – historically stable bed • Low potential for lateral migration • Channel filling at the downstream end • Modeling results show aggradation	Not analyzed because implemented through other strategies due to reach characteristics: reach over the long term is aggrading.	Not suitable due to reach characteristics: low potential for lateral migration	**Further study recommended**	Not suitable due to reach characteristics: low potential for lateral migration	Not suitable due to reach characteristics: historically stable bed	**Further study recommended**
San Antonio Bridge to River Mile 78 • Narrowing through island and bank vegetation growth • Plugs and potential for avulsion • Channel aggradation upstream and high temporary degradation downstream • Historical loss of channel capacity due to aggradation	Not analyzed because implemented through other strategies due to reach characteristics: reach over the long term is aggrading	Not suitable due to reach characteristics: reach over the long term is aggrading and only localized lateral migration.	Further study recommended	Further study recommended	Not suitable due to reach characteristics: reach over the long term is aggrading	Further study recommended
River Mile 78 to Elephant Butte Reservoir[1] • Recent channel degradation • Historical loss of channel capacity due to aggradation • Sediment plugs and potential for avulsion • Localized lateral migration • Limited upstream valley width • Limited flow conveyance underneath the railroad bridge • Temporary degradation currently	Not analyzed because implemented through other strategies due to reach characteristics: reach over the long term is aggrading	Not suitable due to reach characteristics: reach over the long term is aggrading and only localized lateral migration.	Further study recommended	Further study recommended	Not suitable due to reach characteristics: reach over the long term is aggrading	Further study recommended
Elephant Butte Reservoir to Caballo Reservoir • Tributary sediments decrease channel capacity • Reduction in hot springs flows • Urbanized near Williamsburg • Lower end is the fluctuating reservoir pool	Not suitable due to reach characteristics: low potential for new degradation	Further study recommended	Further study recommended	Not suitable due to reach characteristics: urban development makes implementation too expensive to be feasible	Not suitable due to reach characteristics: urban development makes implementation unfeasible	Not recommended: low effectiveness-to-cost ratio

[1]This reach is strongly influenced by the pool elevation of Elephant Butte Reservoir, which makes long-term results from reach-wide strategies difficult to predict.

- **Rehabilitate Channel and Flood Plain**

  In incised reaches, lowering bank line terraces would result in an increase in channel and flood plain adjustments, attenuation of flood events, surface water/ground water interactions, and episodic sediment transport (through channel and flood plain storage). A closer balance between sediment transport capacity and sediment supply at high flows is expected. Channel and flood plain variability should increase, but this may be temporary. There is a possibility that the effective transport of water and sediment might decrease, especially in the short term.

- **Manage Sediment**

  Balancing the sediment supply with the sediment transport capacity should, in the long term, result in a decrease in episodic sediment transport and channel and flood plain adjustments. If the reach is aggrading, removing sediment could increase effective transportation of water and sediment and might reduce flood plain connectivity. New areas of deposition would be created in the natural or constructed sedimentation basins. If the reach is degrading, adding sediment could increase the attenuation of flood events and channel and flood plain variability. Sediment augmentation could help preserve the ground water table.

4.7 Evaluation Factors

4.7.1 Engineering Effectiveness Assessment

Engineering effectiveness assessment is used to evaluate strategy duration and design life, level of confidence in being able to perform its intended functions, ability to deliver water, hydraulic (safe channel) capacity, adaptability to changing river conditions, and level of public safety. Many of the strategy evaluations depend upon the methods used. Where the majority of the methods were essentially the same type and one method was different for a given attribute; the majority of methods were used in the rating. If two or more methods are different than the majority, and these methods have an impact upon an attribute rating, the impact is noted in appendix C. Attributes used in this assessment are briefly described in table 4.5 and in further detail in appendix C, section C1.7. Attributes are assigned into two subevaluation factors. The first is strategy performance that describes strategy implementability and performance with respect to level of confidence, duration and design life, and adaptability. The second is river maintenance function that helps describes the degree a strategy meets the purpose of the Middle Rio Grande River Maintenance Program with respect to water delivery, hydraulic capacity, and public health and safety. Individual ratings for each attribute for each strategy in each reach are listed in the reach discussions in appendix C, chapters C2–C12.

Table 4.5. Engineering Effectiveness Evaluation Factor Attributes

Construction Location	Identifies the construction location: terrace, flood plain, bank line, or in the channel. Included here for general information only and is not a rated attribute.
Subevaluation Factor: Strategy Performance	Describes strategy implementability and performance with respect to level of confidence, duration and design life, and adaptability.
Ability to Implement Attribute (high, medium, low)	Assesses the overall ability to implement a strategy based upon access, ease or difficulty of obtaining land instruments, size, construction location, and overall scope of environmental effects (i.e., degree of disturbance).
Level of Confidence Attribute (high, medium, low)	Assesses the level or amount of information and documentation on design criteria, performance, case studies, and local geomorphic response.
Duration and Design Life Attribute (high, medium, low)	Qualitatively evaluates how long a strategy will meet its intended purposes (see chapter 4). This attribute is influenced by whether or not and how much a strategy achieves channel stability either with fixed features or by promoting dynamic equilibrium within current or relocated lateral constraints as influenced by reach characteristics.
Adaptability Attribute (high, medium, low)	Evaluates the ability of a strategy to be modified and/or added to at a later time (modularity). While all strategies can be modified or added to, at a later time, some are more difficult than others.
Subevaluation Factor: River Maintenance Function	Describes the degree that a strategy meets the purpose of the river maintenance program with respect to water delivery, hydraulic capacity, and public health and safety.
Water Delivery Attribute[1] (increase, decrease, no change)	Describes the qualitative potential changes to water delivery that could occur as a result of implementing a strategy by reach. Water delivery is affected by water surface evaporation, riparian zone evapotranspiration, and seepage. This attribute is rated as increasing when impacts for Indicator B: Wetted Area at 4,700 cfs, Indicator F2: Sinuosity: Strategy Sinuosity/Baseline Sinuosity, Indicator G: Width-Depth Ratio at 4,700 cfs, and Indicator J: Wetted Width at 4,700 cfs decrease. Conversely, water delivery is rated as decreasing when the wetted width, width-to-depth ratio, wetted area, and sinuosity increase.
Hydraulic Capacity Attribute (increase, no change)	Describes whether or not modeled 10,000-cfs flow is contained without overtopping the levees or going up to or over any identified infrastructure for reaches between Cochiti Dam and Elephant Butte Reservoir. The discharge used to qualitatively determine if the flow is contained is 5,000 cfs for Velarde to Rio Chama Reach, 7,500 cfs for Rio Chama to Otowi Bridge Reach, and 4,500 cfs for the Elephant Butte Dam to Caballo Reservoir Reach.
Public Health and Safety Attribute[2] (increase, no change)	Denotes whether a strategy results in the same or an increased level of public health and safety. Because all strategies must provide for public health and safety, a decrease is not rated.

[1.] The importance of water delivery impacts for each reach are not addressed in this attribute, as that is covered in the Water Delivery Impact Reach Characteristic for each reach.

[2] The degree of public health and safety that exists in a given reach is not addressed, as this is discussed using the Infrastructure, Public Health, and Safety Reach Characteristic for each reach.

General effects on the Engineering Effectiveness Evaluation Factor from each strategy are described below.

- **Promote Elevation Stability**

  Cross channel features are difficult to implement due to the number, type, and size of features and the level of environmental compliance required for implementation. For example, a cofferdam would be required during implementation along with dewatering, increasing the difficulty. Thus, the Ability to Implement Attribute would be rated lower.

  In general, the Level of Confidence Attribute is rated high because of the fixed features, such as riprap and sheet pile (when the gradient restoration facility method is employed). The Level of Confidence Attribute is rated lower for deformable riffles, but this is only one of many methods applicable to this strategy. The Duration and Design Life Attribute would be rated high—except in reaches where the modeled slope change is small, resulting in potential spacing of many miles. Lateral migration between structures may occur due to local erosion and deposition.

  Water Delivery Attribute under the Promote Elevation Stability would be rated no change since the width-to-depth ratio, wetted width, and sinuosity would remain the same as baseline. The width upstream may increase a small amount, depending upon the level of incision and upstream sediment deposition potential. The upstream sediment storage volume is small when compared to the annual sediment load for most reaches; thus, downstream channel bed degradation would not occur.

  In reaches where structure spacing would be many miles, there could be lateral migration between structures; therefore, additional structures or other strategies may need to be used at a later time. These structures are difficult to modify or add to at a later time. Thus, the Adaptability Attribute would be rated low.

  The Public Health and Safety Attribute would be rated no change or increase—depending upon reach characteristics. Increased public health and safety would be expected for reaches where fixing the local lateral river location reduces the potential for lateral migration.

- **Promote Alignment Stability**

  This strategy can generally be installed from the bank line. The amount of vegetation clearing is relatively low, only as needed to allow for equipment access along the bank. Landowners generally accept this strategy to prevent future loss of their land. Maintenance from the bank line also generally requires a lower level of environmental compliance than strategies that require equipment to work in flowing river waters. Therefore, this strategy has a high rating for the Ability to Implement Attribute.

Longitudinal bank protection methods have high ratings for both the Level of Confidence and Duration and Design Life Attributes as discussed in appendix A.

Transverse channel methods have medium ratings for the Level of Confidence Attribute. Transverse methods generally require more future maintenance than longitudinal bank protection methods (Duration and Design Life Attribute would be lower than for longitudinal bank protection methods). There is a moderate adaptability even with fixed features because of limited bank line access (Adaptability Attribute would be rated medium). Model results generally show that wetted perimeter, width-to-depth ratio, wetted width, and sinuosity remain about the same—resulting in a rating of no change for the Water Delivery Attribute.

The promising deformable bank line method has the lowest ratings for the Level of Confidence Attribute, because it has very little available design criteria (see appendix A).

Sediment deposition on the insides of stabilized bends has been noted by Niezgoda and Johnson (2006). This sediment deposition can reduce channel width by about 7 percent. The modeling results show slight width change and no width-to-depth ratio change because the model does not estimate width changes or local scour when bends are stabilized. If point bars form during lateral migration processes, the wetted width and hydraulic capacity could increase—resulting in a rating of increase for the Hydraulic Capacity Attribute.

For this strategy, the river channel would migrate laterally, increasing sinuosity, until infrastructure is approached and could be impacted unless the bank line is stabilized. For reaches where the sinuosity increases, the ratings for the Water Delivery Attribute would be decreased. Because of the low sinuosity and channel geometry changes computed by the model, hydraulic capacity remains the same as baseline for most reaches—resulting in a rating of no change for the Hydraulic Capacity Attribute.

Increased public health and safety would be expected for reaches where the bank line is fixed, thereby reducing the potential for future lateral migration—resulting in a rating of increase for the Public Health and Safety Attribute.

- **Reconstruct and Maintain Channel Capacity**

  Construction would be in the channel, bank, and flood plain. Thus, this strategy has lower ratings for the Ability to Implement Attribute than strategies using bank line construction. This strategy generally applies to reaches where incoming sediment supply exceeds transport capacity and the channel is aggrading (depositional). This sediment imbalance can be caused, in part, by an increase in the level of the Elephant Butte Reservoir water surface elevation.

  There are limited numbers and types of features for the methods used to implement this strategy. The Level of Confidence Attribute is rated medium, even though there are mobile features requiring ongoing maintenance, because of Reclamation's considerable experience. Confidence is higher for the complete channel reconstruction and longitudinal dike methods (see appendix A).

  When this strategy brings the river back into sediment transport balance, ratings are high for the Duration and Design Life Attribute. However, since sediment imbalance is usually the reason for implementing this strategy, unless the cause of the imbalance is addressed, ongoing maintenance will be required.

  Ratings for the Adaptability Attribute are high for mobile features. Since this strategy reconstructs and maintains channel capacity, there are no changes to the wetted area, sinuosity, width-to-depth ratio, or wetted width. The Hydraulic Capacity Attribute is maintained to the baseline condition, and there are no changes to the Public Health and Safety Attribute; thus, both attributes are rated as no change.

- **Increase Available Area to the River**

  Construction can be accomplished on the flood plain or terrace. This strategy requires land instruments to move infrastructure located outside the current levee. In many reaches, land use would need to change for infrastructure to be relocated, resulting in a low rating for the Ability to Implement Attribute. This strategy promotes dynamic equilibrium; however, there are limited post-project reports for levee relocation, and it is not likely that land would be available for the river to migrate throughout the full meander belt width. As a result, the ratings for Level of Confidence and Duration and Design Life Attributes are generally medium.

  Relocated infrastructure would be difficult to modify at a later time, resulting in lower ratings for the Adaptability Attribute. Point bars may form during future lateral migration, resulting in a greater wetted width and hydraulic capacity. Thus, the Hydraulic Capacity

Attribute would be rated as increase. These processes are not included in the SRH-1D modeling. The model shows low amounts, or no change, for wetted area, width-to-depth ratio, and wetted width. Thus, Water Delivery Attribute might be rated as decrease only when sinuosity increases occur. A potentially wider flood plain or inset flood plain for incised reaches creates additional flood storage—thus, potentially raising the rating for the Public Health and Safety Attribute to increase.

- **Rehabilitate Channel and Flood Plain**

  The channel bank and flood plain are the construction locations for this strategy. The Ability to Implement Attribute generally has low ratings because of the large riparian forest area that would have to be removed and the large quantities of excavation and disposal.

  For most of the methods used to implement this strategy, the Level of Confidence Attribute is rated as medium. Ratings for the Duration and Design Life Attribute are influenced by the length of time before sediment deposits in the excavation or second stage channel. This strategy will have greater duration in reaches with lower suspended sediment loads.

  The riverbed and banks can experience erosion and deposition and are, therefore, mobile. Due to these mobile features, this strategy has high ratings for the Adaptability Attribute. The wetted area, width-to-depth ratio, and wetted width would all increase, while the water surface elevation would decrease. Sinuosity would remain about the same as baseline. Thus, water delivery potentially would decrease (resulting in a decrease rating for the Water Delivery Attribute). Hydraulic capacity would increase (resulting in an increase rating for the Hydraulic Capacity Attribute). However, if 10,000 cfs (or other discharges for the nonmodeled reaches) is contained for the baseline condition (Indicator D: Containment of 10,000 cfs), then the rating would be no change for the Hydraulic Capacity Attribute. The Public Health and Safety Attribute would be rated increase because of the increased flow capacity and flood storage.

- **Manage Sediment**

  This strategy includes sediment augmentation in reaches that lack sediment and removal (settling basins) and in reaches that have an excess of sediment. Construction location for sediment sources and settling basins would be the bank, flood plain, and terraces. The location for sediment augmentation would be the channel.

  Ratings for the Ability to Implement Attribute are generally medium because of the relatively low numbers and types of features needed, recognizing that tree removal in the bosque would be necessary. For settling basins, ratings for the Ability to Implement Attribute are low, due to the numbers and types of features necessary to construct basins with inlet and outlet controls on a large river.

Sand-size augmentation has little field or lab data, design, or post-project monitoring, and there is little documentation concerning local geomorphic response. Settling basins have been used in a number of locations with success on irrigation canals, but not on a river channel. Thus, the rating for the Level of Confidence Attribute for most reaches is low.

The rating for the Duration and Design Life Attribute is high because this strategy promotes dynamic equilibrium. For settling basins, Monitoring and Evaluation, Frequency of Maintenance, Amount of Maintenance, Frequency of Adaptive Management, and the Amount of Adaptive Management Attributes are all rated high because settling basins fill with sediment over time. For sediment augmentation, Monitoring, Frequency of Adaptive Management, and Amount of Adaptive Management Attributes are all rated high because the location, method, timing, and amount of sediment augmentation most likely will need to be altered annually or every few years.

The rating for the Adaptability Attribute is high for mobile features and features with the ability to alter the size of augmentation or settling basins. Baseline hydraulic conditions would be maintained, so that the hydraulic capacity would not change.

Since baseline hydraulic conditions remain the same, the Public Health and Safety Attribute is rated no change.

4.7.2 Ecosystem Function Assessment

Similar to defining the Habitat Value and Need Reach Characteristic, two federally endangered species are used to assess the Ecosystem Function of a strategy: SWFL and RGSM. Both of these species have evolved in the Rio Grande system and require properly functioning riparian and lotic ecosystems to thrive.

If management strategies implemented promote habitat for both species, it is assumed that the other aspects of the river system will be functioning properly and will support the other species that depend on it. The following subsections explain how selected habitat attributes are used to predict impacts to each species and, in turn, to the ecosystem as a whole from various river management strategies. Table 4.6 lists the attributes used in the ecosystem function assessment. Individual ratings for each attribute for each strategy in each reach are listed in the reach discussions in appendix C, chapters C2–C12.

Table 4-6. Ecosystem Function Evaluation Factor Attributes

Subevaluation Factor: SWFL	
Variety of Successional Stages Attribute[1] (increase, no change, decrease)	Breeding habitat for the SWFL typically consists of early successional stage riparian habitat. This is judged based on Indicator A: Longitudinal Channel Slope Stability, Indicator F2: Sinuosity: Strategy Sinuosity/Baseline Sinuosity, and Indicator K1–K5: Bed Material.
Water Table Elevation Attribute (increase, no change, decrease)	River channel degradation can decrease habitat quality—either through reducing native vegetation or replacing natives with more drought-tolerant, exotic vegetation. Bed elevation changes indicate river channel aggradation or degradation and will determine if the river is increasing or reducing the amount of water available to flood plain riparian vegetation.
Flood Plain Width/Patch Availability Attribute[1] (increase, no change, decrease)	A wider flood plain promotes sediment and vegetation changes needed for the habitat diversity and edges that are important to high quality SWFL habitat. This is based on Indicator E1: Overbank Inundation: High-Flow Inundated Area/Channel Area, Indicator F2: Sinuosity: Strategy Sinuosity/Baseline Sinuosity, and Indicator I: Wetted Width at 4,700 cfs/Width Between Lateral Constraints
Flood Plain Elevation Attribute[1] (increase, no change, decrease)	A lower flood plain elevation would increase the opportunity for overbank flood events and the potential for scouring and deposition of sediment and regeneration of habitat. This is based on Indicator C: Bed Elevation Change. Indicator E2 Overbank Inundation: 4,700 cfs/ Overbank Inundation Discharge, and Indicator J: Wetted Width at 4,700 cfs.
Construction Impacts (Short-Term) Attribute[1] (high, medium, low)	Impacts to the riparian area and SWFL habitat may occur from clearing vegetation for access, staging areas, and the project area along the bank line, islands, and point bars.
Subevaluation Factor : RGSM	
Habitat Complexity Attribute (increase, no change, decrease)	RGSM require a variable mix of river habitats to survive, and their habitat needs change over the course of their development. This attribute is based on existing habitat complexity and the changes that are expected as a result of strategy implementation.
Flood Plain Connectivity and Frequency of Flooding Attribute (increase, no change, decrease)	This attribute quantifies flood plain connectivity and the ability for the river to be connected to backwaters and side channels during the spawning season (spring/summer) for the RGSM. This is based on Indicator C: Bed Elevation Change, Indicator E1: Overbank Inundation: High-Flow Inundated Area/Channel Area, Indicator E2: Overbank Inundation: 4,700 cfs/Overbank Inundation Discharge, and Indicator J: Wetted Width at 4,700 cfs
Sinuosity Attribute (increase, no change, decrease)	Indicator F2: Sinuosity: Strategy Sinuosity/Baseline Sinuosity represents the amount of sinuosity within each reach compared to the current conditions. It is assumed that greater sinuosity increases the opportunity for habitat to develop into quality RGSM habitat because of bank line movement, erosion, and deposition that creates areas of variable velocity and depth.
Construction Impacts (Short-Term) Attribute[1] (high, medium, low)	All work in the wet has both direct and indirect impacts to the riverine area. The degree of impact is a function of length of bank line or channel affected, number of river crossings, and type of heavy equipment.

[1]These factors are considered with habitat requirements to provide an overall rating.

4.7.2.1 Southwestern Willow Flycatcher

The SWFL depends on dense, structurally diverse, often-flooded stands of riparian vegetation in the Southwestern United States for its breeding habitat. Unfortunately, this type of habitat is often in short supply because of constraints that have limited high flows. The duration, frequency, magnitude, recession rate, and timing of high flows are all critical to the establishment and development of SWFL habitat.

All five of these elements must be in sync for vegetation to develop into suitable habitat:

1. **Duration.** Duration of overbank flooding must be for a period necessary to deposit new sediments, flush salts, and raise ground water levels.
2. **Frequency.** Floods must be frequent enough that the flows continue to replenish nutrients and provide water to the developing vegetation, without prolonged inundation that kills the developing vegetation.
3. **Magnitude.** Flood magnitude must be sufficient to mobilize sediment, both to scour decadent vegetation and to provide a sediment load to be deposited on the falling limb of the hydrograph.
4. **Recession Rate.** Recession rates following a flood must be such that the change in ground water availability is no greater than the root development of the seedling vegetation (generally less than 2 centimeters per day).
5. **Timing of High Flows.** Timing of overbank events is critical for the establishment of native vegetation. These should be generally late-May to mid-June when seed dispersal of native species (especially willow) is at the highest. Also, high flows following establishment should be avoided so that the subsequent flows do not scour and remove seedling vegetation.

6. **Timing of High Flows.** Timing of overbank events is critical for the establishment of native vegetation. These should be generally late-May to mid-June when seed dispersal of native species (especially willow) is at the highest. Also, high flows following establishment should be avoided so that the subsequent flows do not scour and remove seedling vegetation.

Aggrading river reaches are generally beneficial to SWFL habitat development. These reaches typically have increased frequency of overbank flooding, have greater flood plain connectivity, and maintain riparian vegetation by having higher ground water levels. An extremely aggraded reach perched above the historic flood plain does run the risk of a catastrophic levee breach or channel avulsion, which would lower ground water levels and have short-term adverse effects to the existing riparian vegetation. However, new riparian vegetation likely would become established, resulting in potential long-term benefits.

Analyzing strategy impacts to SWFL habitat using computer models is difficult at best and requires a significant amount of professional judgment. The attributes in table 4.6 were determined to be crucial to the presence of SWFL habitat and can be somewhat predicted by current hydrogeomorphic model outputs for the Rio Grande. However, in certain instances, no model indicators were able to predict impacts to various attributes. In these cases, biologists well versed in the habitat requirements of the SWFL used professional judgment.

General effects on SWFL from each strategy are:

- **Promote Elevation Stability**

  In reaches with a degrading or stable bed elevation, this strategy will essentially either prevent further incision from occurring or ensure that areas already likely to experience overbank flooding will continue to stay connected to the floodplain. Both actions benefit SWFL habitat. Conversely, in an aggrading reach, promoting elevation stability would stop the river from aggrading and essentially limit the potential for an increase in overbank flooding and floodplain connectivity.

- **Promote Alignment Stability**

  SWFLs require habitat that is constantly being created and destroyed. This strategy will armor the river banks to discourage lateral migration that will limit SWFL habitat in the future.

- **Reconstruct/Maintain Channel Capacity**

  In reaches that have already experienced incision, removing sediment would further decline native vegetative health and likely encourage exotic encroachment. By removing sediment in 'perched' areas (while ensuring the channel remains connected to the floodplain to allow for overbank flooding) and allowing the sediment to be deposited in downstream areas, this strategy potentially would help re-connect downstream incised areas back to the floodplain and stimulate new growth.

- **Increase Available Area to River**

  By increasing area available to the river, this strategy encourages river meandering, overbank flooding, and habitat creation and destruction that would benefit SWFL habitat.

- **Rehabilitate Channel and Flood Plain**

  Overall, this strategy would increase the width-to-depth ratio and encourage overbank flooding that, ultimately, should benefit SWFL habitat.

- **Manage Sediment**

  This strategy depends on site-specific details. In incising areas, this strategy encourages aggradation of the river system that could promote overbank flooding potential. In aggrading areas, this strategy could reduce channel realignment that would limit SWFL habitat in the future.

4.7.2.2 Rio Grande Silvery Minnow

Reaches outside of presently known RGSM territory include all areas north of Cochiti Dam and between Elephant Butte Dam and Caballo Dam. The area above Cochiti is within the historic range for RGSM, and RGSM have not been collected between Angostura and Cochiti Dams since 1995. RGSM were present but likely not abundant upstream of Cochiti due to larger substrate and cooler water temperatures than traditionally preferred by the species. The Service is evaluating the area north of Angostura Diversion Dam for potential reintroduction of RGSM. Assessment in these reaches is an indication of aquatic health for general fish and wildlife benefit only.

RGSM habitat needs vary over the course of their development. RGSM are pelagic spawners (spawning close to the shore) with semibuoyant eggs that are released into the water column. If low-velocity habitats are not abundant, RGSM eggs and larvae have the potential to drift long distances and be lost to reservoir areas with high levels of predatory fishes. Diversions and other dams often create barriers to upstream movement for these small fish. Upstream reaches may experience net losses in population if sufficient progeny are not maintained within the reach and drift downstream over the barriers. Fish augmentation and other management strategies within the collaborative program currently compensate for this net loss.

Larval stages of RGSM thrive in low-velocity habitats with high productivity, which are often provided in overbank areas during spring runoff. Currently, many of these areas do not remain inundated throughout larval development. Post larval and adult RGSM use a variety of habitats. They are most often collected in shallow, low velocity areas. There is likely an unknown upper level where particles in the water clog gills or harm RGSM. The effect of turbidity on RGSM health is not well understood. However, turbidity does affect primary productivity within the river, which is the food base for RGSM. RGSM habitat and biological preferences known include debris or shoreline habitats. The solid banks or shore provide some escape cover from predators and slow velocity microhabitats for resting and potential feeding.

In addition to the mathematically derived indicators in the strategy assessment, professional judgment by fish biologists, well versed in RGSM habitat needs, is also used to predict impacts. The resolution of the modeling was not sufficient to capture many of the interrelated parts of the habitat. Additional modeling is planned in more detailed reach analyses.

Attributes used in this assessment are briefly described in table 4.6 and in more detail in appendix C. General effects on RGSM from each strategy are:

- **Promote Elevation Stability**

  In reaches with a degrading or stable bed elevation, this strategy will essentially either prevent further incision or ensure that areas already likely to experience overbank flooding will continue to stay connected to the flood plain. Promoting elevation stability with grade control or other bank-to-bank structures probably would not change much of the RGSM habitat complexity. Channel-spanning features to promote elevation stability may impact upstream movement of RGSM. Any channel spanning features would need to be designed to allow upstream movement of RGSM. Minimizing aggradation could reduce channel complexity, depending on the strategy and method implemented.

- **Promote Alignment Stability**

  This strategy will fix the river to discourage lateral migration and, thus, will not improve and may reduce habitat complexity in the future. After implementation, the amount of sediment available from bank erosion potentially would be reduced, leading to local bed coarsening and potential downstream incision that could cause a decrease in downstream RGSM habitat.

- **Reconstruct and Maintain Channel Capacity**

  This strategy generally creates more uniform channel conditions reducing habitat complexity. The more efficient channel could help maintain flow continuity under low flow conditions reducing RGSM stranding. Overbank flooding would be reduced. By removing sediment in 'perched' areas (but keeping the channel connected to the floodplain to allow for overbank flooding) and allowing sediment to be deposited in downstream areas, this action would potentially help re-connect downstream incised areas back to the flood plain and reduce RGSM stranding.

- **Increase Available Area to the River**

  By increasing the area available to the river, this strategy encourages river meandering and provides area for overbank flooding. Overbank flooding provides important habitat for larval development. River meandering may increase sinuosity and overall habitat complexity for RGSM.

- **Rehabilitate Channel and Flood Plain Strategy**

  Overall, this strategy would increase the width-to-depth ratio and encourage overbank flooding which, ultimately, should benefit RGSM habitat by creating high productivity larval fish habitats that are inundated more often than unrehabilitated areas. There is the possibility that RGSM may become entrained on the flood plain when inundation subsides. Reconnection of abandoned side channels and backwaters could be positive for RGSM. Reduction of sediment supply to lower reaches may cause a narrower, deeper channel and decreased flood plain connectivity.

- **Manage Sediment**

  This strategy depends on site-specific details. In incising areas, depositional bars and islands may form downstream from augmentation sites. The potential change in bed material size would be greatest in the gravel-dominated bed reach where the sand-size portion of the bed material gradation would increase. In aggrading areas, reducing sediment load could reduce channel complexity.

4.7.3 Economics Assessment

An assessment of economics, in terms of cost,[1] was made and used to rate each strategy by reach. The "order of magnitude" cost of each method was estimated following Reclamation guidelines. The methods that would most likely be used to implement a strategy were the basis for the ratings for each strategy.

Implementation costs are for river maintenance construction, except sediment management (which includes an annual cost based upon annual sediment volume results from the SRH-1D model). Attributes used in this assessment are briefly described in table 4.7 and in further detail in appendix C. With the exception of implementation cost, ratings are based upon professional experience and judgment using the criteria in appendix C. Individual ratings for each attribute for each strategy in each reach are listed in the reach discussions in appendix C, chapters C2–C12. Note that for the economic attributes, "high" ratings mean more cost, and, thus, are not desirable. The potential reduction in future river maintenance costs resulting from implementing any of the strategies is not estimated as part of this economic assessment.

General effects on economics from each strategy are described below.

- **Promote Elevation Stability**

  This strategy has larger and more complex features relative to most other strategies. Also, as there is uncertainty in upstream and downstream distance and amount of effects, a numerical sediment transport model is recommended, resulting in a rating of high for the Planning and Design Attribute. Cross-channel fixed structures reduce opportunity for natural habitat development and sustainability requiring a high amount of environmental compliance, with a corresponding rating of high for the Environmental Compliance Attribute.

[1] As this report is not a NEPA or a Reclamation planning analysis, the ability to pay, unemployment in the region, and environmental justice aspects are not included in the economic analysis.

Table 4.7. Economics Evaluation Factor Attributes

Planning and Design Attribute (high, medium, low)	Factors that may increase or decrease planning and design costs including how the river will respond (e.g., the spatial and temporal range of potential channel responses; uncertainty in channel response; and the types, and sizes, etc., of features) and what is involved in the decisionmaking process (e.g., land ownership, government agencies, potential impacts, infrastructure, and biological significance).
Environmental Compliance Attribute (high, medium, low)	The degree of effort, analysis, and documentation required for a particular strategy to achieve environmental compliance.
Implementation Cost Attribute (high, medium, low)	Implementation costs of a strategy (including construction and annual sediment augmentation or removal costs). Appraisal level cost estimates were determined during a workshop held in Albuquerque, New Mexico, on August 12–14, 2009.
Monitoring and Evaluation Attribute (high, medium, low)	The amount of monitoring and evaluation necessary to make effective decisions regarding maintenance and adaptations.
Frequency of Maintenance Attribute[1] (high, medium, low)	How often maintenance work is anticipated. Frequencies will vary between strategies.
Amount of Maintenance Attribute[1] (high, medium, low)	The amount of recurring maintenance that would be required. Maintenance work can be anticipated. Maintenance restores channel to post-implementation conditions
Frequency of Adaptive Management Attribute[1] (high, medium, low)	The relative frequency of potential adaptive adjustments that may be needed to realize strategy objectives. The frequency of adaptive management is not known prior to project implementation.
Amount of Adaptive Management Attribute[1] (high, medium, low)	The relative magnitude of potential adaptive adjustments after strategy implementation. Adaptive management may change implemented strategy conditions and features. The quantity and type of adaptive management is not known prior to project implementation.

[1] See section 1.6 for discussion of the difference between maintenance and adaptive management.

The ratings for the Implementation Cost Attribute depend on the amount of slope change between the stable slope and baseline. With some uncertainty in channel response, the Monitoring and Evaluation Attribute is rated medium. For fixed nonerodible features, there is low frequency and amount of maintenance, so ratings are low for both the Frequency of Adaptive Management and Amount of Adaptive Management Attributes unless reach characteristics increase the ratings to medium. This strategy may reduce future maintenance by reducing future channel incision and potential associated lateral migration, which can impinge upon riverside infrastructure. There may need to be future structures added to a given reach after the channel response is known to adaptively manage this strategy. These economic attributes are rated low for fixed features, except in reaches that are biologically significant for the SWFL and RGSM.

- **Promote Alignment Stability**

  Reclamation has extensive experience with planning and design of longitudinal methods and less experience with transverse features. The Planning and Design Attribute is rated low when the geomorphic response and performance are relatively well understood and there are more simple features with more routine designs.

  Fixed features reduce future opportunities for habitat development and sustainability and have high environmental compliance costs. Medium environmental compliance costs are possible in reaches that are not significant for either the SWFL or RGSM. Also, work conducted below the mean high water mark adds to environmental compliance costs. Thus, the Environmental Compliance Attribute is rated high or medium under this strategy.

  The Implementation Cost Attribute is rated low or medium, depending upon the values for Indicator H1: Meander Width: Percent Fit of Length, which is used to determine the potential length of bank stabilization needed for each reach.

  Fixed features with low channel response uncertainty and high effectiveness require a low amount of monitoring unless implemented in a reach that is significant for the SWFL or RGSM (see appendix A for more detail). Thus, the Monitoring and Evaluation Attribute is rated low. Fixed features require low amounts of both frequency and amount of future maintenance; thus, the ratings for the Frequency of Maintenance and the Amount of Maintenance Attributes are low. The Frequency of Adaptive Management and Amount of Adaptive Management Attributes are rated low because there is a high amount of certainty with little variability, and strategies with fixed features (such as Promote Alignment Stability) are more difficult to modify at a later time than nonfixed feature strategies. This strategy is intended to reduce future maintenance by allowing some lateral migration when it is not threatening infrastructure. Downstream bank erosion still may occur that could require additional structures or other strategy implementation.

- **Reconstruct and Maintain Channel Capacity**

  This strategy is needed in reaches that have greater sediment supplies than sediment transport capacities, resulting in the channel capacity being reduced over time because of sediment deposition.

  Using a numerical sediment model is advised to improve the estimation of future channel response. The Planning and Design Cost Attribute is rated high because numerical modeling is needed to improve the certainty in estimating channel response and to maximize strategy benefits.

  The Environmental Compliance Attribute is rated high for this strategy because of the large amount of excavation required and the uncertainty of the channel response.

  The Monitoring and Evaluation Attribute is rated high for this strategy because it has mobile features and a higher likelihood of maintenance and adaptive management. The frequency of maintenance can be high, especially in the River Mile 78 to Elephant Butte Reservoir Reach, which is affected by changes in the reservoir water surface elevation. There is a high potential for erosion or sediment deposition in a reach that does not have sediment balance, requiring a high amount of maintenance. Thus, the Frequency of Maintenance and the Amount of Maintenance Attributes are rated high. The Frequency of Adaptive Management and Amount of Adaptive Management Attributes are rated high because of the dynamic nature of depositional reaches and because many methods associated with this strategy use the river to accomplish some of the work. This strategy promotes increased sediment transport capacity, thereby reducing channel aggradation and decreasing the potential need for future levee raising to maintain peak flow channel capacity.

- **Increase Available Area to the River**

  Infrastructure relocation generally requires a high amount of planning and design cost, especially if there are multiple landowners or government agencies involved. Thus, the Planning and Design Attribute is rated high. Conversely, the Environmental Compliance Attribute is rated low for this strategy because infrastructure relocation is accomplished in the flood plain or terraces and current channel and flood plain processes of lateral migration continue. The Implementation Cost Attribute ratings range from low to high, depending upon the value of Indicator H1: Meander Width: Percent Fit of Length. The Frequency of Maintenance, the Amount of Maintenance, the Frequency of Adaptive Management, and the Amount of Adaptive Management Attributes are all rated low with the infrastructure being relocated because future maintenance is reduced by allowing space for the channel to adjust as needed. However, the uncertainty that enough space can be acquired to permanently ensure that relocated levees will not be impacted by future lateral migration means monitoring is necessary, and additional strategies may need to be implemented.

- **Rehabilitate Channel and Flood Plain**

  A numerical sediment transport model is needed to determine the dimensions and elevations of flood plain lowering, resulting a high rating for the Planning and Design Attribute. The large amount of vegetation clearing in the riparian zone, coupled with the large earthwork quantities results in a high rating for Environmental Compliance and Implementation Cost Attributes.

  The Monitoring and Evaluation Attribute is rated medium for this strategy to account for some uncertainty in channel response and potential future sediment deposition in second stage channel created by excavation. This strategy encourages dynamic equilibrium; thus, the Frequency of Maintenance and Amount of Maintenance Attributes are rated low. This strategy may decrease future maintenance by reducing channel incision and potential associated lateral migration that can threaten riverside infrastructure. However, sediment deposition will occur over time in the newly created flood plain area during floods, and the presence of a new riparian zone could prevent excavation of these deposits to maintain the post-implementation flow capacity. This loss of capacity could require additional strategies to be implemented in the future.

  The Frequency of Adaptive Management Attribute is rated low because the adjustment to the vertical elevation of the lowered flood plain and/or width would occur only once. The Amount of Adaptive Management Attribute is rated medium because of the uncertainty of estimating the elevation of the lowered flood plain using both fixed bed and mobile bed numerical models. The river can scour during peak flows and later fill during the recession of the hydrograph, making estimating this elevation difficult. Once a suitable elevation is determined and additional excavation accomplished, future adaptive management cost would be low.

- **Manage Sediment**

  High planning and design costs are needed to carefully estimate the amount of sediment to be augmented or removed from a reach using a numerical model. In addition, the effects upon downstream reaches would need to be assessed. Thus, rating for the Planning and Design Attribute is high. Due to the level of uncertainty in channel response and biological effects, the Environmental Compliance Attribute would be rated high. The Implementation Cost Attribute ratings range from low to medium, depending upon the volume of sediment for removal or augmentation to achieve a balance between sediment transport supply and transport capacity. A high monitoring and evaluation cost is associated with uncertain channel response, leading to a rating of high for the Monitoring and Evaluation Attribute. Ratings for the Frequency of Adaptive Management and Amount of Adaptive Management Attributes are high for reaches with large volumes of sediment augmentation or where settling basins are needed for removal. As deposition occurs in settling basins, the inlet and outlet conditions change, potentially requiring extensive work to maintain suitable flow conditions to maximize the amount of deposition within each basin. The Frequency of Adaptive Management Attribute is rated high since the location of sediment augmentation or settling basins changes frequently. The amount of sediment augmentation or removal can vary considerably with flow conditions and channel response. For sediment augmentation, this strategy may reduce the future maintenance needs by decreasing future channel incision and potential associated lateral migration that could impinge upon riverside facilities. Careful monitoring would be needed since there is the potential for augmented sediments to contribute to loss of downstream channel capacity that could lead to future implementation of other strategies. For sediment removal, the concept is to reduce sediment supply so that the channel no longer deposits sediment. Consistent sediment removal may be difficult to achieve because sediment deposition rates will decrease over time as settling basins fills with sediment.

4.8 Summary of Strategy Recommendations

Table 4.8 shows a summary of the strategy assessment results by reach and identifies which strategies are recommended for further study or why a strategy was not suitable. Please note that reach prioritization for further study should include consideration of reach characteristics.

Strategies are judged to be not suitable for a certain reach when one or more of these situations exist:

- Strategies do not address the reach characteristics of concern.
- Modeled indicator results do not show the need for a strategy.
- Strategy implementation is simply not feasible within a reach.

In aggrading reaches, Promote Elevation Stability would be implemented through other strategies; thus, it is not rated there. The remaining suitable strategies for a reach are rated for the evaluation factors. Results are presented by strategy and summarized for each reach.

Index scores are developed for the ratios of subevaluation factors to cost, overall evaluation factors to cost, and total effectiveness to cost. Combining suitable strategies for all reaches, 100 is assigned as the largest score for each strategy and 0 as the smallest score. This linear indexing allows comparison of the ratios between reaches. These indexed results are summarized graphically for each reach. Within a reach, those strategies with low effectiveness-to-cost ratios (section 4.1.6.1.2) are eliminated from more detailed study. The remaining strategies are recommended for more detailed analysis.

Even though a strategy is excluded from more detailed analysis for a reach, an individual method within that strategy could still be feasible at a site-specific location. Further information on strategy assessment can be found in the reach chapters that follow and in appendices B (modeling and indicator results) and C (strategy assessment results).

5. Velarde to Rio Chama (RM 285 to RM 272)

5.1 Reach Characteristics

This upstream most study reach is approximately 13 miles long, with a riverbed slope of approximately 0.00224 (11.8 feet per mile) and an average channel width of 190 feet. Major tributaries in the reach are Truchas Arroyo, Palacio Arroyo, and Chinguague Arroyo. All these tributaries are ephemeral streams that supply gravel to the Rio Grande on a periodic basis. The Rio Grande has a low sand load with relatively clear water and essentially has unregulated perennial flow. The bed is mixed sand and gravel. A major feature of this reach is a narrow flood plain and riparian zone with a lack of well-formed or extensive flood plain and riparian zones. Within this reach, there are eight low-head dams that divert water for irrigation. Most of these dams are concrete and sheet pile structures with riprap aprons. Two bridges span the river in this reach. Habitat restoration activities in this reach include bioengineering and native vegetation planting near La Canova.

The reach is generally straight, with extensive historical channelization and bank stabilization. There are some sites in the reach where bank migration could damage irrigation canals and ditches. There has been a significant increase in bar deposition and vegetation encroachment between 1992–2007, particularly in the downstream three-quarters of the reach. Bank heights are moderately high, and the river channel is near the edge of the root zone, except in the recent deposition zones, which typically have lower banks. The potential for increased lateral channel migration in localized areas has increased because bed material of the channel is fairly coarse; therefore, bed stability is greater than bank stability, and the channel has become narrower with bar deposition, as documented in the 2007 aerial photos.

5.1.1 Channel Instability Reach Characteristic – Medium Instability

This reach was not modeled; therefore, channel instability is assessed through historical data and professional judgment and is rated medium. Without further data and analysis, the rate and extent of channel change (migration) is uncertain, but it appears that lateral migration could increase.

5.1.2 Water Delivery Impact Reach Characteristic – Low Importance

This reach has no documented seepage loss rates and low amounts of water diversions for local agriculture. Each of the eight diversion dams in this reach diverts less than about 50 cfs.

5.1.3 Infrastructure, Public Health, and Safety Reach Characteristic – Medium Importance

This reach has agricultural land with irrigated crops, orchards, and a sparse distribution of homes, barns, and other agricultural buildings. Although not part of the rating, it should be noted that this reach does not contain riverside levees (except some freeboard dikes) or drains. There are numerous irrigation canals along the river. Ohkay Owingeh Pueblo is along the southern portion of this reach.

5.1.4 Habitat Value and Need Reach Characteristic

5.1.4.1 Southwestern Willow Flycatcher – High Importance

Although not included in the critical habitat designation, several patches of moderately to highly suitable SWFL habitat exist within this reach, both inside and outside the Ohkay Owingeh. The small populations off the pueblo have not been able to sustain themselves and could be considered sinks (a breeding group that, due to its occupation of marginal habitat, does not produce enough offspring to maintain itself in coming years without immigrants from other populations). A small population of SWFL has persisted within suitable habitat on the Ohkay Owingeh for the past several years. However, as stated above, much of this reach is channelized, and habitat is lacking. Given that this population has persisted and could expand into newly created habitat, which currently is lacking, along with the sensitive nature of the population on the Ohkay Owingeh, this reach has a high importance rating for SWFL habitat value and need.

5.1.4.2 Rio Grande Silvery Minnow – Low Importance

Though there are historic records of RGSM from the lower portions of this reach, it likely was never abundant (Bestgen and Platania 1991). RGSM have not been documented in this reach for over 30 years. There is no "critical habitat" associated in this reach of the river. Ecosystem assessment for this reach is based on the potential to support RGSM if they were repatriated, as well as the current native fish. Due to these reasons, this reach would be considered a low priority for management for the RGSM.

5.2 Strategy Assessment Results

Three strategies were screened out as unsuitable due to reach characteristics and modeling results, leaving three strategies to be rated:

- Promote Alignment Stability
- Increase Available Area to the River
- Rehabilitate Channel and Flood Plain

Each of these strategies could address the issue of channel migration into riverside infrastructure. It should be noted that Increase Available Area to the River may require agencies other than Reclamation to acquire the land instruments. Modeling was not performed in this reach because current modeling data are not available, but an agreement to share data acquired by USACE is in progress.

The short discussions below summarize the reach specific strategy assessment results.[1] Figures 5.1–5.3 present the indexed scores of effectiveness divided by cost for the suitable strategies. More detailed assessment information, including weighted scores for each strategy, is presented in Appendix C: Strategy Assessment.

5.2.1 Promote Elevation Stability – Not Suitable

Historical trends do not show a recent tendency toward bed erosion, so this strategy is not suitable for this reach.

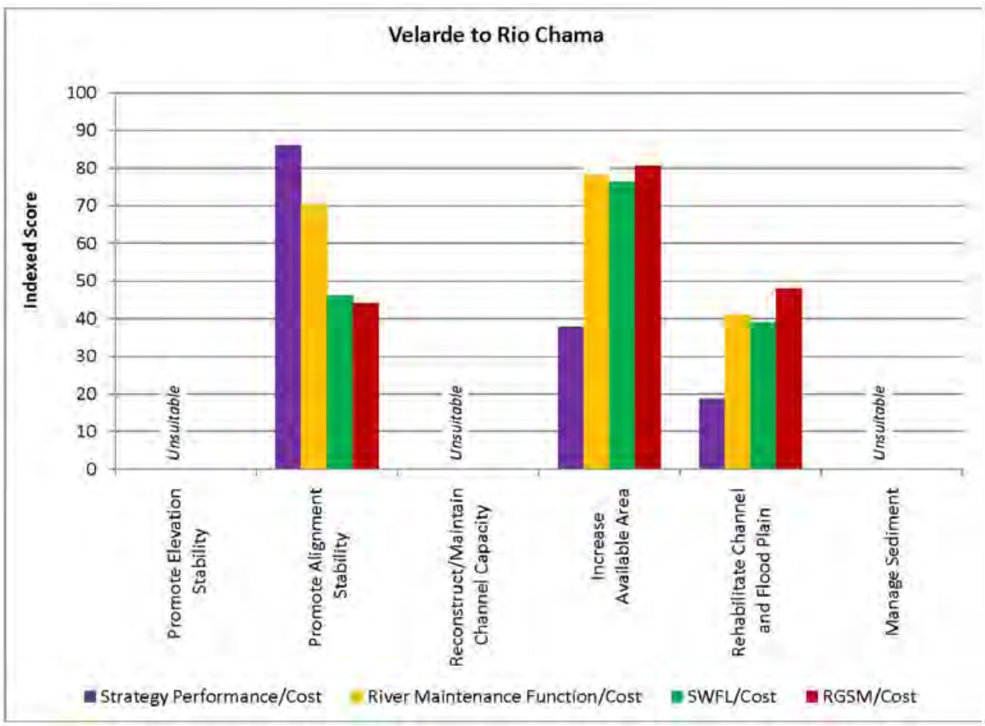

Figure 5.1. Velarde to Rio Chama Reach indexed effectiveness divided by cost scoring results by subevaluation factor

[1] Effects that are the same for a particular strategy and not affected by reach characteristics are summarized in chapter 4 of the main report and discussed in more detail in Appendix C, Section 1.7, Engineering Effectiveness Evaluation Factor; Section 1.8, Ecosystem Function Evaluation Factor; and Section 1.9, Economics Evaluation Factor.

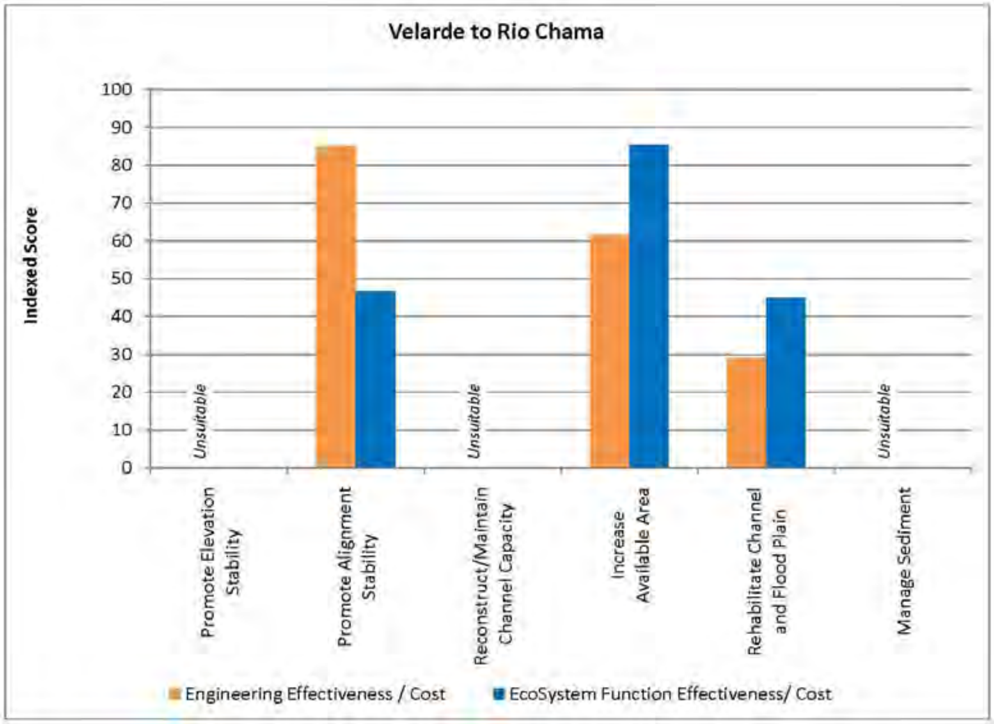

Figure 5.2. Velarde to Rio Chama Reach indexed effectiveness divided by cost scoring results by evaluation factor.

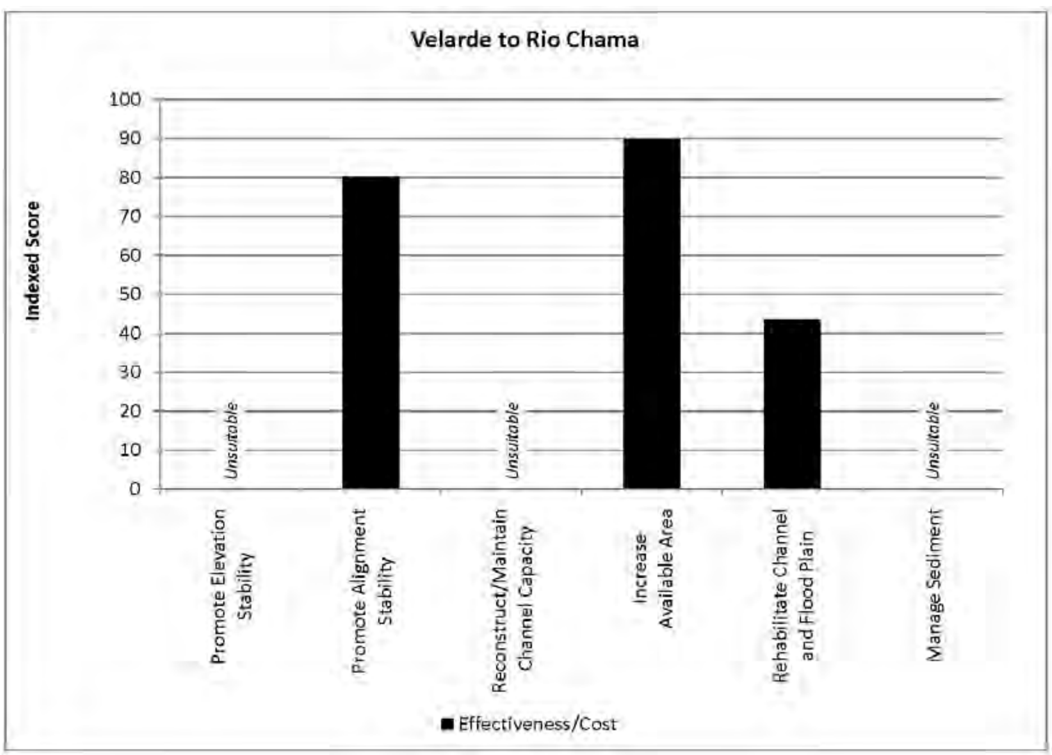

Figure 5.3. Velarde to Rio Chama Reach total effectiveness divided by cost indexed scoring results.

5.2.2 Promote Alignment Stability

- **Geomorphic Effects**

  Minimizing lateral migration in this reach could start local bed degradation with increasing bank height; as it appears. in certain sections, transport capacity may be greater than sediment load. The bed is fairly coarse, reducing the likelihood of local bed degradation. The stability of the bed material should be assessed in this reach before implementing this strategy.

- **Engineering Effectiveness Evaluation Factor**

  The small riparian zone and sport fishery reduce environmental compliance needs. Landowners readily approve bank stabilization to protect existing land. The likelihood of implementing other strategies in this reach at a later time is low. The low likelihood of future bed degradation increases the duration and design life.

- **Ecosystem Function Evaluation Factor**

  Promoting alignment stability decreases the erosion and deposition ability of the river, in turn decreasing the opportunity for a variety of successional stages needed for SWFL habitat. Native fish depend on diverse habitats. In general, the more confined the river, the less habitat diversity.

- **Economics Evaluation Factor**

  Multiple landowners would increase planning and design time, even though Reclamation has extensive experience with bank stabilization methods. A qualitative evaluation of potential sites resulted in a low rating for the Implementation Cost Attribute.

5.2.3 Reconstruct and Maintain Channel Capacity – Not Suitable

Historical trends do not show a tendency toward loss of channel capacity, so this strategy is not suitable for this reach.

5.2.4 Increase Available Area to the River

- **Geomorphic Effects**

  This strategy allows space for the channel to adjust its morphology as needed, which tends to increase natural channel processes. Continued lateral migration is possible as well as a possible short-term decrease of effective transport of water and sediment as the channel evolves.

- **Engineering Effectiveness Evaluation Factor**

  Most of the land is privately owned, and agricultural production extends nearly to the river banks; so land instruments may be difficult to obtain for this strategy without land purchase. The effectiveness for promoting dynamic equilibrium in this reach is difficult to assess, because it is unknown how close the river is to dynamic equilibrium—although visual observations indicate that it is fairly close to dynamic equilibrium, with lateral migration possible.

- **Ecosystem Function Evaluation Factor**

  There are positive impacts to SWFL habitat. Habitat availability in this reach would increase with this strategy.

- **Economics Evaluation Factor**

  The narrow riparian zone and relatively small amount of infrastructure for relocation would reduce implementation and environmental compliance costs and the need for adaptive management.

5.2.5 Rehabilitate Channel and Flood Plain – Not Recommended

This strategy is not recommended for further study because of the low effectiveness-to-cost ratio.

5.2.6 Manage Sediment – Not Suitable

Historical trends do not show a reach-wide imbalance in sediment transport capacity and sediment load, so this strategy is not suitable for this reach.

5.3 Recommendations

The trends of significance to river maintenance currently observed in this reach are:

- Channel narrowing
- Vegetation encroachment
- Bank erosion
- Coarsening of bed material

This reach is rated medium instability for the Channel Instability Reach Characteristic and medium importance for Infrastructure, Public Health, and Safety Reach Characteristics. The Water Delivery Impact Reach Characteristic is rated of low importance, as is the Habitat Value and Need Reach Characteristic for RGSM. The Habitat Value and Need Reach Characteristic is rated high importance for SWFL.

Two strategies have high effectiveness-to-cost ratios—Promote Alignment Stability and Increase Available Area to the River; these strategies should be analyzed in more detail. Reach-wide bank stabilization has a high score for the Engineering Effectiveness Evaluation Factor; the strategy is expected to perform well with a high degree of confidence and improve public health and safety. It will limit habitat renewal of riparian areas and, thus, could negatively impact the SWFL. If longitudinal methods are applied, it is expected that there will be little change to the fishery habitat.

As discussed in the Part 1 Report (Reclamation 2007), acquiring land to increase the available area for lateral migration (under Increase the Available Area to the River) may not be part of Reclamation's authority. Further research on the authority to purchase land or easements for this purpose and respective costs is needed. Increase the Available Area to the River also increases public health and safety and provides the opportunity for increased riparian habitat with little impact to the fishery present.

Rehabilitate Channel and Flood Plain has a lower effectiveness-to-cost ratio but may need to be reviewed again after more detailed modeling data become available. At this time, continued monitoring of the channel bank line with local projects to stabilize the banks as needed appears to be a reasonable course of action.

6. Rio Chama to Otowi Bridge (RM 272 to RM 257.6)

6.1 Reach Characteristics

This reach is approximately 14 miles long with a riverbed slope of approximately 0.00162 (8.6 feet per mile) and an average channel width of 310 feet. The river flows through the town of Española and three Native American pueblos. Four bridges cross the Rio Grande in this reach, including three within 1.5 miles in Española. The reach is perennial, with summer and fall flows that are higher than natural due to increased reservoir releases, including releases from the San Juan-Chama Project. There are three major tributaries: the Rio Chama, the Santa Cruz River, and the Pojoaque River. After 2003, Ohkay Owingeh Pueblo treated more than 100 acres of habitat with nonnative vegetation removal and native plantings.

This reach is highly channelized and incised, but it has not historically been prone to widespread lateral erosion. Extensive gravel mining in the 1980s resulted in the river bed being lowered. Degradation has progressed upstream in varying lengths since the conclusion of gravel mining operations. Continued bed lowering could initiate more channel migration. The channel planform is a slightly sinuous and generally single thread with sections of migrating bends and split channels.

There was an increase in bar deposition and vegetation encroachment between 1992–2007 in most of this reach but not to the same extent as the upstream reaches. Bank heights are high, and the riverbed is near or below the edge of the root zone except in the deposition zones, which have typically lower banks. Lateral migration appears to continue to be a less important process in this reach with fewer active banks observed except within the San Ildefonso Pueblo.

6.1.1 Channel Instability Reach Characteristic – Low Instability

The likelihood of reach-wide changes in channel slope, bed elevation, and bed elevation change are low. Several bends have been active since 1992 but appear to have local impacts. In general, the meander belt (since 1971) mostly fits between the infrastructure, and there is some space for adjustment; therefore, these two factors are rated as medium. The low rating for channel instability in this reach is based on historical trends and professional judgment.

6.1.2 Water Delivery Impact Reach Characteristic – Low Importance

This reach does not have documented seepage loss rates and has a low volume of water diversions. One temporary rock and brush dam diverts a small amount of irrigation water.

6.1.3 Infrastructure, Public Health, and Safety Reach Characteristic – High Importance

The city of Española lies within this reach, where there are levees, several bridges, and a sewer lift station. Ohkay Owingeh Pueblo is along the northern portion of this reach. Santa Clara and San Ildefonso Pueblos are also in this reach.

6.1.4 Habitat Value and Need Reach Characteristic

6.1.4.1 Southwestern Willow Flycatcher – Low Importance

Suitable SWFL habitat is lacking within this reach and is not likely to develop considering the channelized, degraded nature of the channel. Restoration efforts aimed at SWFL habitat would be costly in this reach and would be better conducted elsewhere. This reach is not included in the SWFL critical habitat designation.

6.1.4.2 Rio Grande Silvery Minnow – Low Importance

The last collection of RGSM in the Rio Chama was in 1949 (Service 1999), only 14 years after the closure of El Vado Reservoir. The last collection of RGSM above Cochiti Lake was in the late 1970s, less than 5 years after the closure of the reservoir in 1975. Fragmentation of habitats, higher and colder base flow releases for irrigation, and loss of habitat from channel incision have all influenced the species composition in both the Rio Chama and the Rio Grande. Suitable habitat may be present for juvenile and adult RGSM; however, the lack of low velocity habitats for larvae and young-of-the-year and the lack of contiguous sections of river for drifting eggs would limit the ability for the species to successfully complete its life cycle (Service 2005 [RGSM]). Ecosystem assessment for this reach is based on the potential to support RGSM if they were repatriated, as well as the current native fish fauna. Cochiti Dam still would block fish passage upstream into this reach. Strategies to improve fisheries should focus on improving habitat complexity for all native fishes.

6.2 Strategy Assessment Results

Four strategies were found to be suitable for this reach and, thus, were rated:

- Promote Elevation Stability
- Promote Alignment Stability
- Increase Available Area to the River
- Rehabilitate Channel and Flood Plain

Promote Elevation Stability could address the bed degradation and also might help reduce channel migration. Promote Alignment Stability, Increase Available Area to the River, and Rehabilitate Channel and Flood Plain could address the issue of channel migration into riverside infrastructure. Increase Available Area to the River and Rehabilitate Channel and Flood Plain also may reduce future degradation. It should be noted that Increase Available Area to the River may require outside agencies involvement to accomplish. The degree of strategy effect is not estimated for each suitable strategy because modeling was not performed in this reach. Current modeling data are not available for this reach, but an agreement to share data acquired by the USACE is in progress.

The short discussions below summarize the reach specific strategy assessment results.[1] Figures 6.1–6.3 present the indexed scores of effectiveness divided by cost for the suitable strategies. More detailed assessment information, including weighted scores for each strategy, is presented in Appendix C: Strategy Assessment.

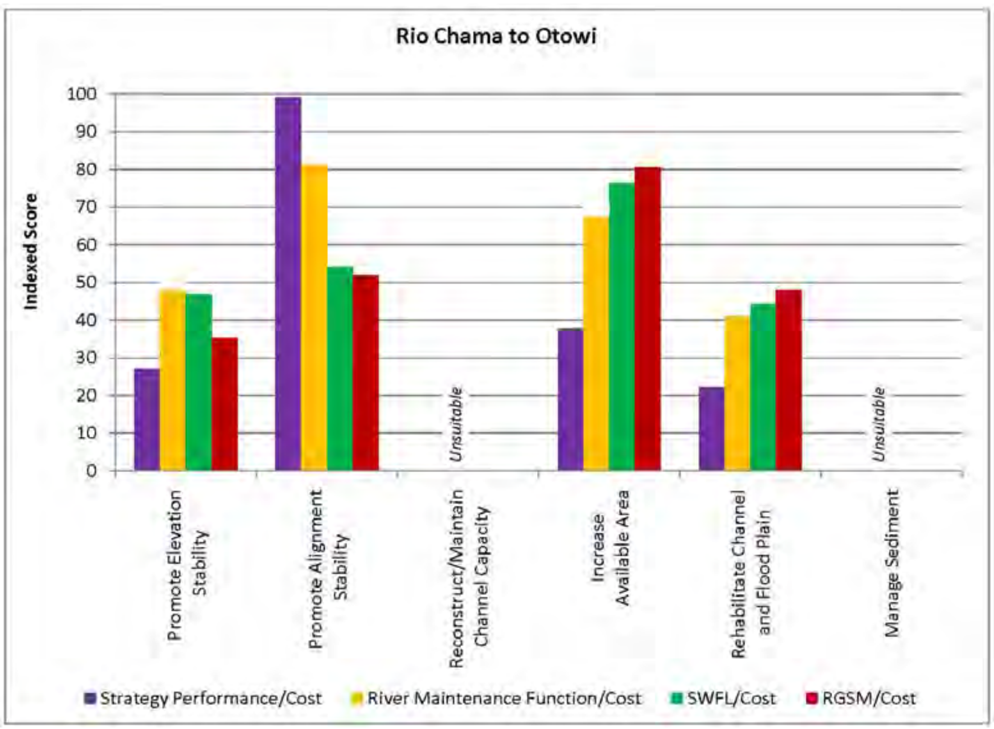

Figure 6.1. Rio Chama to Otowi Bridge Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

[1] Effects that are the same for a particular strategy and not affected by reach characteristics are summarized in the main report in chapter 4 and discussed in more detail in Appendix C, Section 1.7, Engineering Effectiveness Evaluation Factor; Section 1.8, Ecosystem Function Evaluation Factor; and Section 1.9, Economics Evaluation Factor.

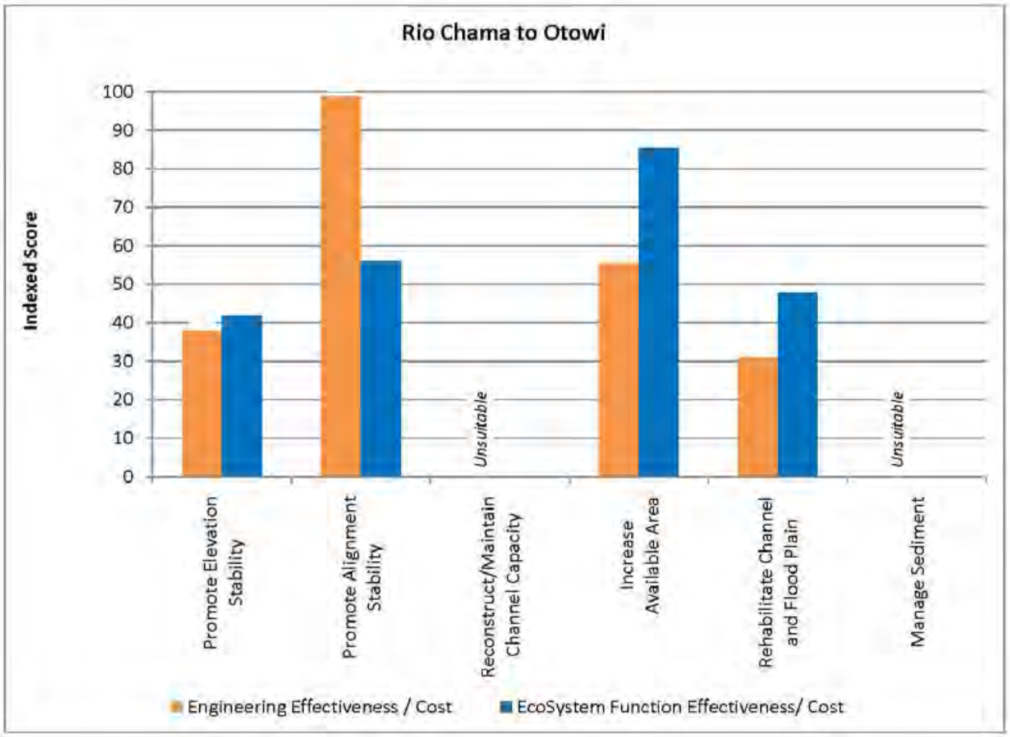

Figure 6.2. Rio Chama to Otowi Bridge Reach effectiveness divided by cost scoring results by evaluation factor.

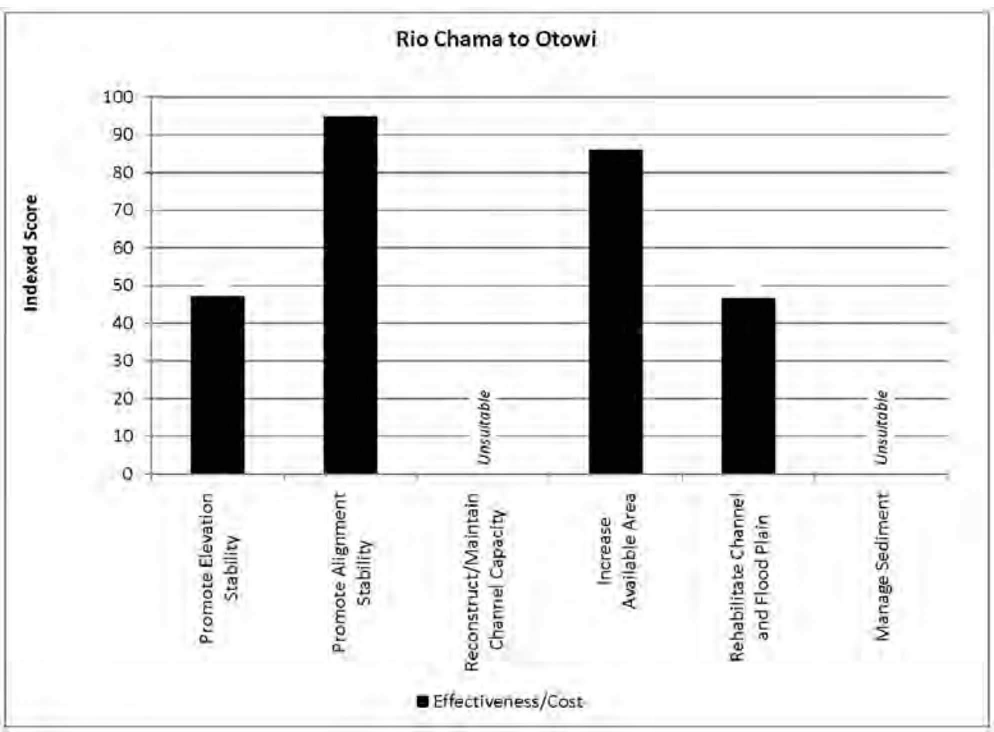

Figure 6.3. Rio Chama to Otowi Bridge Reach total effectiveness divided by cost indexed scoring results.

6.2.1 Promote Elevation Stability – Not Recommended

Promote Elevation Stability did not rate highly in this reach, so further study is not recommended unless new data show significant bed elevation changes on a reach-wide basis.

6.2.2 Promote Alignment Stability

- **Geomorphic Effects**

  Before implementing this strategy, more information is needed. If the channel incision increases bank height, then the potential for lateral migration may be high enough to warrant implementation. Local areas may require implementation that would have the same geomorphic effect as given in appendix C, section C1.6.

- **Engineering Effectiveness Evaluation Factor**

  Obtaining land instruments and environmental compliance are relatively straightforward. Bank protection/stabilization features have a high confidence level. The likelihood of the slope changing in the future is low, increasing the duration and design life.

- **Ecosystem Function Evaluation Factor**

  Alignment stability decreases erosion and deposition for regenerating SWFL habitat. Habitat complexity for native fishes would be decreased.

- **Economics Evaluation Factor**

  Multiple landowners, the city of Española, and three pueblos rate a medium for the Planning and Design Attribute. Maintenance and adaptive management needs would be low. A qualitative evaluation of potential sites resulted in a low rating for the Implementation Cost Attribute.

6.2.3 Reconstruct and Maintain Channel Capacity – Not Suitable

Historical trends do not show a tendency toward loss of channel capacity; therefore, this strategy is not suitable for this reach.

6.2.4 Increase Available Area to the River

- **Geomorphic Effects**

  Similar potential for channel migration as Promote Alignment Stability exists, but it is unknown how much space is needed. The rate of change may be slow enough or the area provided limited so that any increases in natural channel processes might not extend through the majority of the reach in the next decade.

- **Engineering Effectiveness Evaluation Factor**

  Undeveloped land exists in the pueblos where this strategy could be applied.

- **Ecosystem Function Evaluation Factor**

  SWFL habitat could improve with a meandering river. Meandering rivers tend to provide a variety of habitats for native fishes including low-velocity pools, riffles, and runs.

- **Economics Evaluation Factor**

  Multiple stakeholders mean planning costs would be high, but environmental compliance costs would be low. By relocating infrastructure away from the current active channel, maintenance and adaptive management would be low.

6.2.5 Rehabilitate Channel and Flood Plain – Not Recommended

Rehabilitate Channel and Flood Plain was shown to be highly effective for the ecosystem, but the cost is prohibitive through an urban reach. This strategy is not recommended for further study; however, local alternatives to improve habitat should be explored.

6.2.6 Manage Sediment – Not Suitable

Historical trends do not show a reach-wide imbalance in sediment transport capacity and sediment load; therefore, this strategy is not suitable for this reach.

6.3 Recommendations

The trends of significance to river maintenance currently observed in this reach are:

- Channel narrowing
- Vegetation encroachment
- Bank erosion
- Coarsening of bed material

This reach appears to be a bit more stable than the Velarde to Rio Chama Reach, so Channel Instability Reach Characteristic is rated low instability and the Water Delivery Impact as well as the Habitat Value and Need Reach Characteristics for both SWFL and RGSM also are rated with low importance. The Infrastructure, Public Health, and Safety Reach Characteristic is rated as high importance because the city of Española is in this reach.

Both Promote Alignment Stability and Increase Available Area to the River had high effectiveness-to-cost ratios and should be carried forward for further investigation. Even though Rehabilitate Channel and Flood Plain was highly effective for the ecosystem, the cost would be prohibitive; therefore, local alternatives to improve habitat should be explored. Promote Elevation Stability did not rate high for either Engineering Effectiveness or Ecosystem Function Evaluation Factors; therefore, further study is not necessary unless new data show significant bed elevation changes on a reach-wide basis.

At this time, continued monitoring of channel bank line and local projects to promote alignment stability as needed appears to be the most effective strategy. As discussed in the Part 1 Report (Reclamation 2007), increasing the available area for lateral migration (under Increase Available Area to the River) is probably useful but may not be part of Reclamation's authority. At this time, continued monitoring of the channel bank line with local projects to stabilize the banks as needed appears to be a reasonable course of action.

Rehabilitate the Channel and Flood Plain may need assessment after more detailed modeling data become available.

7. Cochiti Dam to Angostura Diversion Dam (RM 232.6 to RM 209.7)

7.1 Reach Characteristics

This reach is approximately 23 miles long with a riverbed slope of approximately 0.00137[1] (7.2 feet per mile) and an average channel width of 220 feet. At the upstream end of the reach is Cochiti Dam, a flood and sediment control dam, which began impounding water in 1973. Major tributaries, which are ephemeral, are Galisteo Creek and Tonque Arroyo. Galisteo Dam, also a flood and sediment control dam, was constructed on Galisteo Creek in 1970. This reach of river is comprised almost entirely of tribal lands, with infrastructure close to the river that includes drains, irrigation canals, roads, and buildings. Habitat restoration activities in this reach include terrace lowering and willow swale construction at the Santa Fe River confluence, nonnative vegetation removal at Santo Domingo and San Felipe Pueblos, and riparian area creation at the Pueblo de Cochiti. The historical oxbow in the Santo Domingo Pueblo also was reconnected.

A reduction of the Rio Grande's historical sediment load after closure of Cochiti Dam and (to a much lesser extent) Galisteo Dam has resulted in degradation and armoring of the riverbed and made the relatively erodible banks increasingly more vulnerable. Bed material is gravel/cobble with some sand. Sediment supply is now dependent solely on tributary and bank erosion sources.

This reach has the highest concentration of river maintenance sites anywhere on the Middle Rio Grande; the majority of active sites are concentrated in the narrow river valley near San Felipe Pueblo. The channel in this reach is moderately to highly incised. Sediment deposition at tributary confluences can act as a local bed control and cause erosion of the bank line opposite the tributary.

In general, the planform appears fairly stable, and the majority of the migrating bends are moving very slowly and tend to be moving downstream rather than laterally. This trend is expected to continue, creating a more stable channel. The tall banks in the San Felipe Pueblo area are an exception and are experiencing significant migration at some sites. This section of the valley is narrower than most of the rest of the reach, and infrastructure is close to the channel. The channel is currently in Planform Stages M5 (Sinuous thalweg channel) through M8 (Cutoff is now main channel).[2]

[1] The slope is calculated from the reduced number of cross sections in the Maintenance Plan model.

[2] See appendix C, section C1.4.1.3, for a description of the Middle Rio Grande Planform Evolution Model. Also refer to the Unique Terms section located at the end of this document.

7.1.1 Channel Instability Reach Characteristic – Medium Instability

If the channel is allowed to lengthen to flatten the slope, then less of the projected channel meander belt fits between the infrastructure and geologic constraints, and more of the available area is used. This makes the likelihood of infrastructure impact even greater. The meander belt analysis shows the area of most potential impact to infrastructure to be near San Felipe, approximately RM 212–217.

7.1.2 Water Delivery Impact Reach Characteristic – High Importance

During low-flow years, flows in this reach, which are diverted at Angostura Diversion Dam, can supply the bulk of irrigation water downstream as far as the Belen Division of the MRGCD. Seepage gains in this reach, from high ground water table within lands adjacent to the river (SSPA 2008), also reduce diversions at Angostura Diversion Dam during normal and high-flow years.

7.1.3 Infrastructure, Public Health, and Safety Reach Characteristic – Medium Importance

Lands along the river are mostly pueblo lands with some private ownership. Lands are used for both crops and grazing with very sparse distribution of homes and other agricultural buildings. Infrastructure in this reach includes the Cochiti, Santo Domingo, and San Felipe Pueblos; levees; and three bridges.

7.1.4 Habitat Value and Need Reach Characteristic

7.1.4.1 Southwestern Willow Flycatcher – Low Importance

Suitable SWFL habitat is lacking in this reach, and the highly incised channel and low sediment load present will not promote habitat development in the near future, without significant modification. In the long term, channel evolution may increase SWFL habitat. Lastly, this reach is outside of the critical habitat designation.

7.1.4.2 Rio Grande Silvery Minnow – Low Importance

Although a variety of management actions could improve the viability of Cochiti Dam to Angostura Diversion Dam Reach as RGSM habitat, this reach would be considered a low priority for management for the RGSM. Regardless of any management decision, it must be taken into account that the land base encompassing the Cochiti Dam to Angostura Diversion Dam Reach is primarily tribal-owned. Efforts must be fully supported by our pueblo partners to enhance the aquatic ecosystem in the Cochiti Dam to Angostura Diversion Dam Reach (Service 2008).

7.2 Strategy Assessment Results

Four strategies were found to be suitable for rating in this reach:

- Promote Elevation Stability
- Promote Alignment Stability
- Increase Available Area to the River
- Rehabilitate Channel and Flood Plain

Promote Elevation Stability, Promote Alignment Stability, Increase Available Area to the River, and Rehabilitate Channel and Flood Plain could address the issue of channel migration into riverside infrastructure. Rehabilitate Channel and Flood Plain would result in better reconnection of the currently incised channel to the flood plain, which would provide habitat benefits, as well as encourage growth of vegetation that would tend to stabilize the planform and reduce the sediment transport capacity of the flows that go overbank.

The short discussions below summarize the reach specific strategy assessment results.[1] Figures 7.1–7.3 present the indexed scores of effectiveness divided by cost for the suitable strategies. More detailed assessment information, including weighted scores for each strategy, is presented in Appendix C: Strategy Assessment.

7.2.1 Promote Elevation Stability

- **Geomorphic Effects**

  Model results indicate a small amount of aggradation might be expected in the lower portion of this reach. The upper end is bounded by Cochiti Dam, which releases clear water, resulting in a continuing potential for further degradation downstream from the dam. Flood plain connectivity may increase locally upstream of gradient restoration facilities if installed.

- **Engineering Effectiveness Evaluation Factor**

  Grade control would be needed to counteract incision and lateral migration. Model results show that the slope is decreasing. In the upper portion of the reach, the slope reduces as a result of channel bed degradation. The downstream portion near Angostura Diversion Dam was depositional. This downstream deposition reduces the effectiveness of this strategy for reach-wide application.

[1] Effects that are the same for a particular strategy and not affected by reach characteristics are summarized in chapter 4 of the main report and discussed in more detail in Appendix C, Section 1.7, Engineering Effectiveness Evaluation Factor; Section 1.8, Ecosystem Function Evaluation Factor; and Section 1.9, Economics Evaluation Factor.

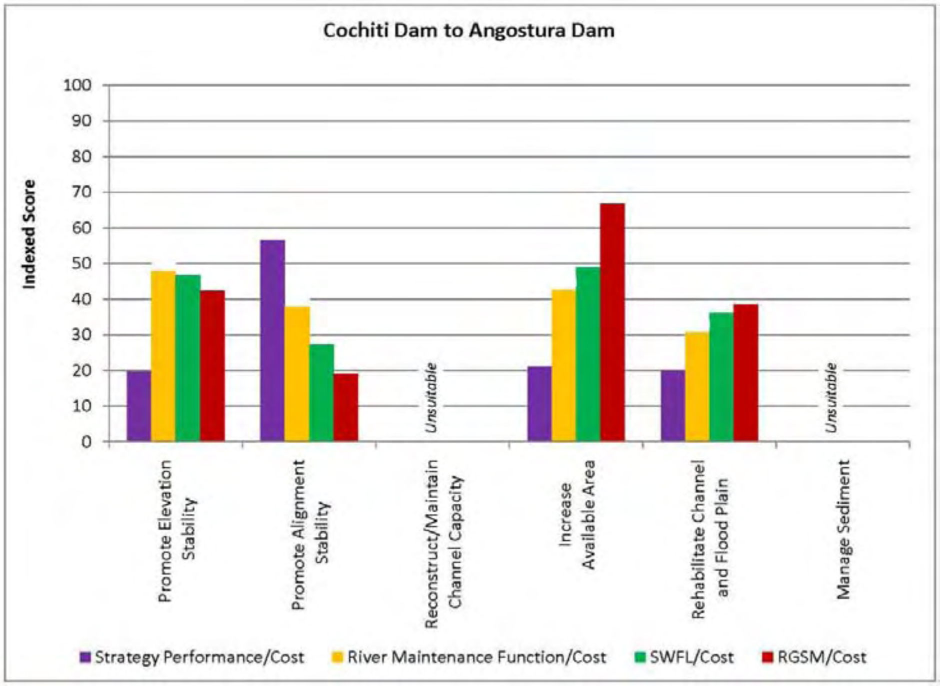

Figure 7.1. Effectiveness divided by cost indexed scoring results by subevaluation factor for the Cochiti Dam to Angostura Diversion Dam Reach.

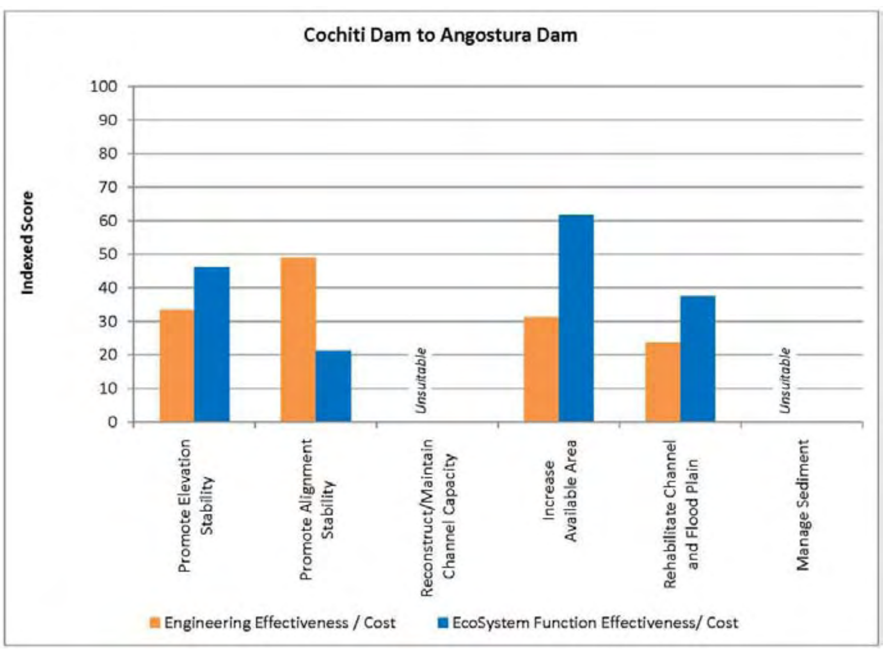

Figure 7.2. Effectiveness divided by cost indexed scoring results by evaluation factor for the Cochiti Dam to Angostura Diversion Dam Reach.

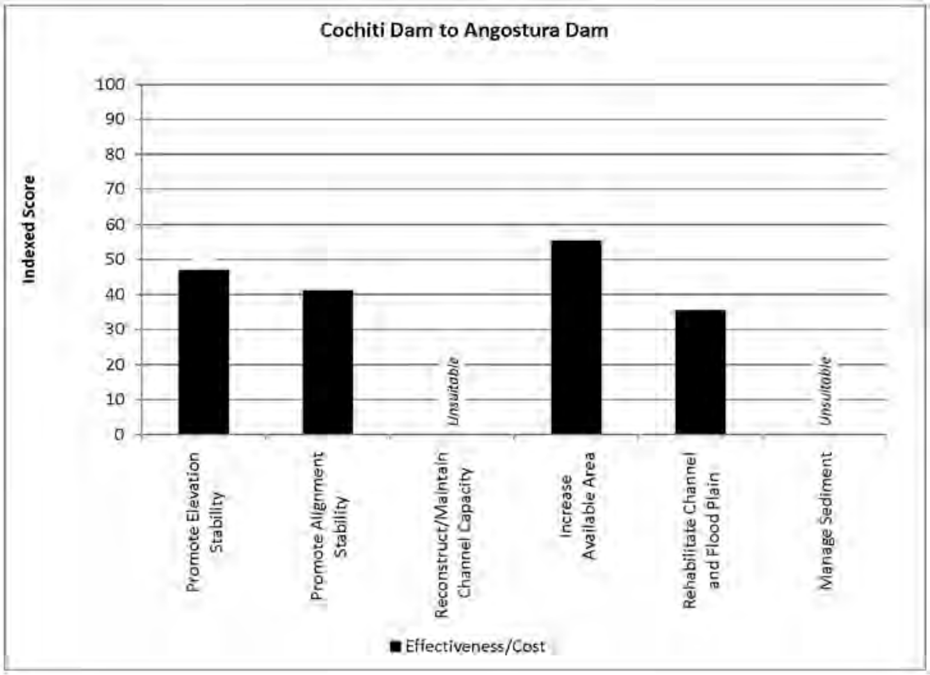

Figure 7.3. Total effectiveness divided by cost indexed scoring results for the Cochiti Dam to Angostura Diversion Dam Reach.

- **Ecosystem Function Evaluation Factor**

  Stabilizing the bed elevation at least would prevent further degradation of SWFL habitat in this reach. RGSM habitat would derive local benefit from greater flood plain connectivity and diversity of habitat if the bed elevation is raised by the structures.

- **Economics Evaluation Factor**

  While the rating for the Implementation Cost Attribute is medium, it is likely that this strategy only would be applied to the upper portion of the reach, thereby reducing implementation costs. However, another strategy likely would be needed in the downstream section. Land instruments may be difficult to obtain, and habitat improvement efforts may make environmental compliance time consuming.

7.2.2 Promote Alignment Stability

- **Geomorphic Effects**

  There is not much room to allow channel lengthening, and it appears more is needed on a reach basis than is available because most of the calculated meander belt in the reach is very close to or outside of the constraints. The channel likely would be stabilized mostly in the current alignment.

- **Engineering Effectiveness Evaluation Factor**

  This strategy should be easy to implement with a high degree of effectiveness.

- **Ecosystem Function Evaluation Factor**

  This strategy has a reduced ability for erosion and deposition needed for SWFL habitat. RGSM habitat complexity would be reduced.

- **Economics Evaluation Factor**

  Because of the large percentage of the calculated meander belt width that does not fit within the infrastructure, the implementation cost would be considered high on a reach basis.

7.2.3 Reconstruct and Maintain Channel Capacity – Not Suitable

Historical trends do not show a tendency toward loss of channel capacity; therefore, this strategy is not suitable for this reach.

7.2.4 Increase Available Area to the River

- **Geomorphic Effects**

  Should these expansions be implemented, it is possible that the percent of each Planform Stage M5 (Sinuous thalweg channel) through M8 (Cutoff is now main channel) within the reach might change, but it is not expected that there would be large areas of new stages develop. The opportunity for natural channel processes should increase as the river is given space to change its morphology as needed.

- **Engineering Effectiveness Evaluation Factor**

  The Ability to Implement Attribute is rated low because of the large land area requirement and the space required by the pueblos.

- **Ecosystem Function Evaluation Factor**

  Allowing the river to meander over a greater flood plain could create new and younger age classes of vegetation for SWFL through erosion and deposition of sediments. Opportunity for optimal RGSM and other native fish habitat and channel complexity would increase if this strategy is implemented.

- **Economics Evaluation Factor**

  Planning and design and implementation costs would be high because a large percentage of calculated meander belt length does not fit between the infrastructures, and corresponding long lengths of infrastructure would have to be moved. Environmental compliance costs would be lower because flood plain and river habitat would be minimally affected.

7.2.5 Rehabilitate Channel and Flood Plain – Not Recommended

This strategy has a low effectiveness-to-cost ratio and is not recommended.

7.2.6 Manage Sediment – Not Suitable

Even though there is the potential for aggradation in the downstream section of this reach, modeling results do not show a reach-wide imbalance in sediment transport capacity and sediment load. Therefore, this strategy is not suitable for this reach.

7.3 Recommendations

The trends of significance to river maintenance currently observed in this reach are:

- Bed material coarsening
- Channel narrowing
- Vegetation encroachment
- Bank erosion

The Channel Instability Reach Characteristic was rated as medium for instability; the Infrastructure, Public Health, and Safety Reach Characteristic was rated medium importance for this reach. The Habitat Value and Need Reach Characteristic for both SWFL and RGSM species was rated as low importance in this reach, as both habitat quality and use are very low for SWFL and RGSM. The Water Delivery Impact Reach Characteristic was rated as high importance because of the net gain of water in the reach.

Promote Elevation Stability, Promote Alignment Stability, and Increase Available Area to the River had the highest effectiveness-to-cost ratios; therefore, these strategies will go forward for more assessment in the next stage of investigation.

Promote Elevation Stability shows there is a potential need for grade control on the basis of only slope change criteria. The slope change is a result of channel bed lowering in the upstream portion of this reach and deposition in the downstream portion of this reach. Thus, it is not likely that Promote Elevation Stability would be a reach-wide strategy. Additional analysis would need to be done to determine if using Promote Elevation Stability in the upper portion of the reach affects sediment deposition in the lower portion of this reach.

Rehabilitate Channel and Flood Plain has a high cost and would be difficult to implement in this reach. Since much of the land is pueblo-owned and fish passage through Angostura Diversion Dam would be the last fish passage project constructed (Biological Opinion 2003 [Service 2003]); this strategy appears to be of lower impact—at least in the near term.

8. Angostura Diversion Dam to Isleta Diversion Dam (RM 209.7 to RM 169.3)

8.1 Reach Characteristics

This reach is approximately 40 miles long with a riverbed slope of approximately 0.00094[1] (5 feet per mile) and an average channel width of 390 feet. Angostura Diversion Dam, at the upstream end of the reach, diverts up to 650 cfs for irrigation. Major tributaries (all ephemeral) are the Jemez River, Arroyo de la Barranca, Arroyo de los Montoyas (Harvey Jones Channel), Calabacillas Arroyo, and Abo Wash. The Harvey Jones Channel outfall (Southern Sandoval County Arroyo Flood Control Authority [SSCAFCA]) collects flows from Montoyas Arroyo and the city of Rio Rancho and exits near RM 198. The Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) has two large outfalls in the reach. All three outfalls are into detention basins that are intended to reduce the amount of sediment reaching the river. Jemez Canyon Dam was originally both a flood and sediment control dam; but changes in operations beginning in 2000 have resulted in sediment pass through, and the sediment pool is no longer used. The sediment load in this reach was reduced due to sediment storage in Jemez Canyon Dam. Three gradient restoration facilities and one grade control sill were constructed on the Rio Grande in the early 2000s, beginning approximately a mile downstream from the Jemez River confluence to help address the trend of degradation caused by the reduction in sediment load.

Habitat restoration activities include wetlands construction; bar, island and bank lowering and destabilization; pond and backwater construction; ephemeral channel excavation; and removal of jetty jacks and non-native vegetation. The Minnow Sanctuary and various shelf and scallop projects have been constructed in this reach. Other habitat restoration activities include terrace lowering at Bernalillo and Santa Ana and Sandia Pueblos with removal of non-native vegetation and creation of riparian areas with native vegetation plantings. Multiple channels that flow at different discharges also were created at both pueblos.

This reach is highly urbanized and runs through Albuquerque and its suburbs in a narrow, well-defined floodway of managed Bosque. It contains subreaches with fairly distinct differences in channel planform and bed material size.

[1] The slope is calculated from the reduced number of cross sections in the Plan and Guide model.

From Angostura to north Albuquerque, the channel is in Planform Stages M4 (Narrow single channel) and M5 (Sinuous thalweg channel)[1] and may be moving toward M5 (Sinuous thalweg channel)/M6 (Migrating bend channel). The bed is generally gravel dominated. Islands are tall because of significant bed degradation, so any inundated areas are mostly along the channel margins. Moving downstream to about Bridge Street, the planform is in Stages 2 (Vegetating bar channel) to M5 (Sinuous thalweg channel) with more inundation of bars and islands, more split channels, and with an increasing percentage of sand in the bed. From Bridge Street to Isleta Diversion Dam, the planform is in Stages 1 (Mobile sand bed channel) through M4 (Narrow single channel) and generally sand bedded where deposition/bar formation can be an issue. In recent years, the reach has seen numerous habitat restoration projects ranging from non-native vegetation and Kellner jetty jack removal to construction intended to increase channel complexity. The cumulative effects of these projects are unknown at this time.

8.1.1 Channel Instability Reach Characteristic – Medium Instability

Although most of the factors used to rate channel instability are low, the very tight fit of the calculated meander belt within the constraints makes the channel instability more of a concern; and, thus, the rating is medium for this reach. Modeling results show that this reach is near its stable slope, and it appears that additional sediment from Jemez has at least slowed channel degradation and the downstream progression of the previously identified gravel transition zone. A potential exists for incision in this reach because the upstream subreach of the channel has narrowed, upstream sediment loads have decreased, and a few tributaries are in the reach. If the bed incises to below the vegetation root level (about 3–5 more feet), more lateral migration may start.

8.1.2 Water Delivery Impact Reach Characteristic – High Importance

The river losses from river seepage are about 2–3 cfs per mile at 500 cfs and increase for larger discharges (SSPA 2008). Drain return flows can be rediverted back into the MRGCD irrigation system. Water diversion infrastructures (Angostura Diversion Dam, Isleta Diversion Dam, and two water utility diversions), coupled with the seepage losses, result in a rating of high importance.

8.1.3 Infrastructure, Public Health, and Safety Reach Characteristic – High Importance

Infrastructure in this reach includes the cities of Bernalillo and Albuquerque, an Albuquerque drinking water project, diversion dams, levees, and bridges. The reach also includes the Albuquerque Bernalillo County Water Utility Authority's Ranney collectors. For Ranney collectors, there are two concerns:

[1] See appendix C, section C1.4.1.3, for a description of the Middle Rio Grande Planform Evolution Model. Also refer to the Unique Terms section located at the end of this document.

- Vertical incision removes covering bed material.
- Lateral migration may reroute the channel away from the collector.

This reach also includes the Sandia, Santa Ana, and Isleta Pueblos, waste water treatment plant outfalls, levees, bridges, the Corrales siphon, and utility crossings. MRGCD is studying the effects of the water utility diversions on irrigation at Isleta Diversion Dam.

8.1.4 Habitat Value and Need Reach Characteristic

Reclamation biologists have classified this reach as biologically significant for the RGSM.

8.1.4.1 Southwestern Willow Flycatcher – Low Importance

The river in this reach is outside the critical habitat designation. During the past decade, SWFL surveys in this reach have not documented territorial SWFL.

8.1.4.2 Rio Grande Silvery Minnow – High Importance

RGSM are common throughout this reach (Dudley and Platania 2011 and Reclamation data). It is unknown at this time whether the population would be self-sustaining without population supplementation. The lack of habitat diversity and low-velocity habitats above Highway 550 likely is a limiting factor for RGSM. This reach is rated high for the RGSM Habitat Value and Need Reach Characteristic because it is the least likely to go dry and has active management.

8.2 Strategy Assessment Results

Four strategies are potentially suitable for this reach:

- Promote Elevation Stability
- Promote Alignment Stability
- Rehabilitate Channel and Flood Plain
- Manage Sediment

Promote Elevation Stability could address the historical bed degradation that also might help reduce channel migration. Promote Alignment Stability, Rehabilitate Channel and Flood Plain, and Manage Sediment could address the issue of channel migration into riverside infrastructure. Terrace lowering and flood plain reconnection would help stabilize the channel by ensuring that the root level is at an appropriate elevation to help resist lateral erosion. An increase in sediment load could help provide a balance between the sediment supply and transport capacity and slow or prevent channel degradation.

The short discussions below summarize the reach specific strategy assessment results.[1] Figures 8.1–8.3 present the indexed scores of effectiveness divided by cost for the suitable strategies. More detailed assessment information, including weighted scores for each strategy, is presented in Appendix C: Strategy Assessment.

8.2.1 Promote Elevation Stability

- **Geomorphic Effects**

  Significant changes in channel processes and sediment balance are not anticipated. The upstream portion of the reach is incised with little overbank flooding, and modeling predicts a small slope change in the future, so the number of structures is low. A modest increase in flood plain connectivity, particularly in the lower portion of the reach, is possible if grade control structures raise the bed. A potential exists for incision in this reach because the upstream subreach of the channel has narrowed, upstream sediment loads have decreased, and a few tributaries are in the reach. If the bed incises to below the vegetation root level (about 3–5 more feet), more lateral migration may start.

- **Engineering Effectiveness Evaluation Factor**

  The expected slope change for this strategy is small, so this strategy is rated low overall for the Engineering Effectiveness Evaluation Factor in this reach. It is likely that another strategy would need to be implemented in addition to this strategy.

- **Ecosystem Function Evaluation Factor**

  Preventing channel lowering at least would prevent further degradation of SWFL habitat. RGSM habitat complexity would not change much.

- **Economics Evaluation Factor**

  The Implementation Cost Attribute is rated low because of the small amount of future slope change. The Monitoring and Evaluation, Amount of Maintenance, and Frequency of Adaptive Management Attributes are rated medium due to the biological significance of this reach for the RGSM.

[1] Effects that are the same for a particular strategy and not affected by reach characteristics are summarized in chapter 4 of the main report and discussed in more detail in Appendix C, Section 1.7, Engineering Effectiveness Evaluation Factor; Section 1.8, Ecosystem Function Evaluation Factor; and Section 1.9, Economics Evaluation Factor.

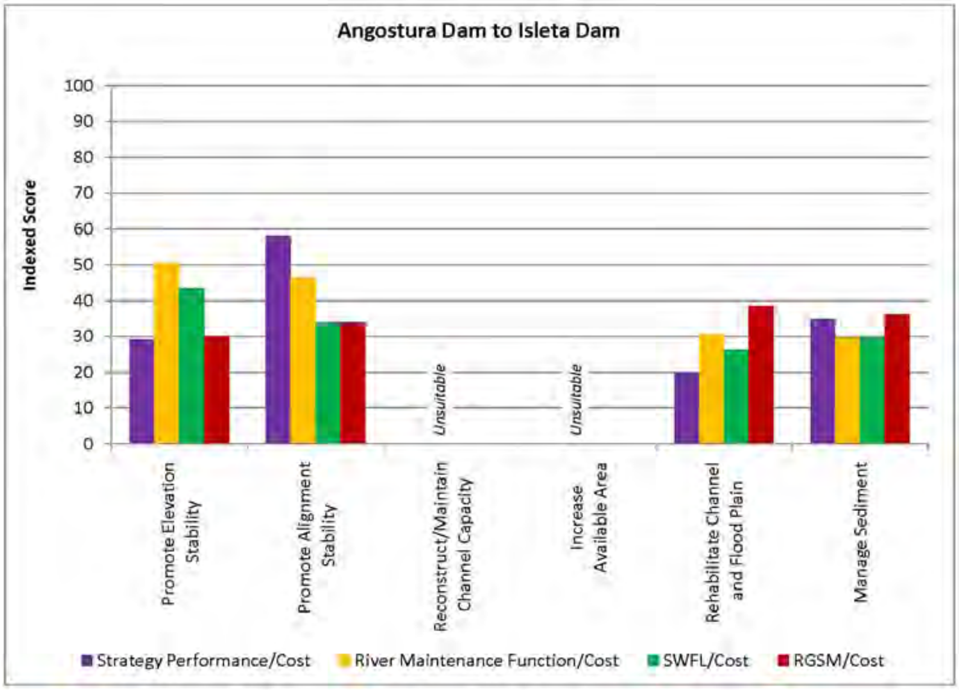

Figure 8.1. Angostura Diversion Dam to Isleta Diversion Dam Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

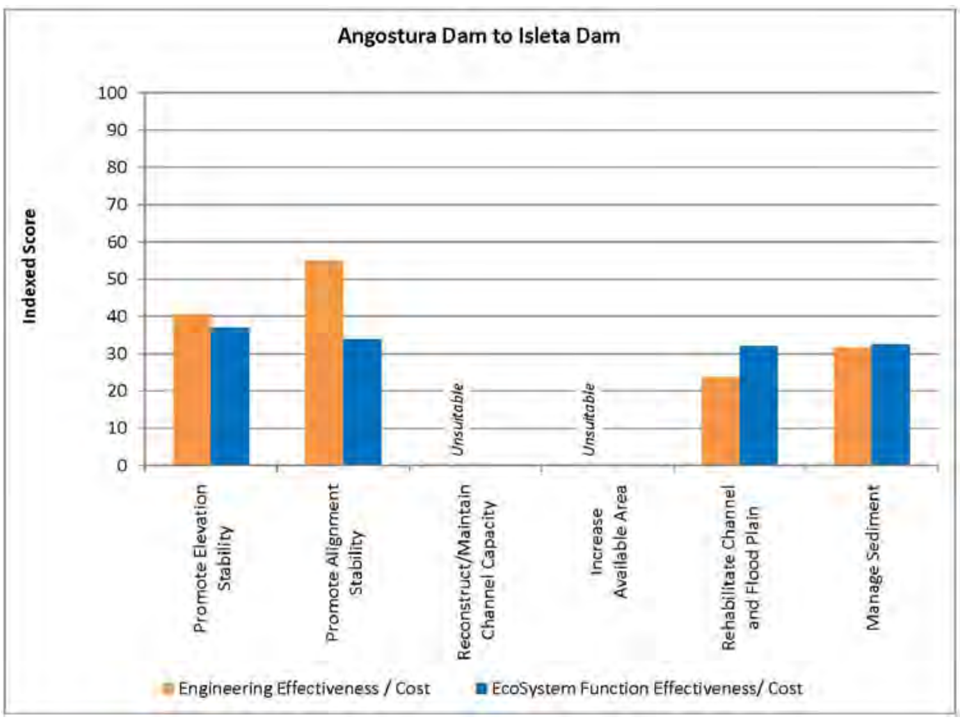

Figure 8.2. Angostura Diversion Dam to Isleta Diversion Dam Reach effectiveness divided by cost indexed scoring results by evaluation factor.

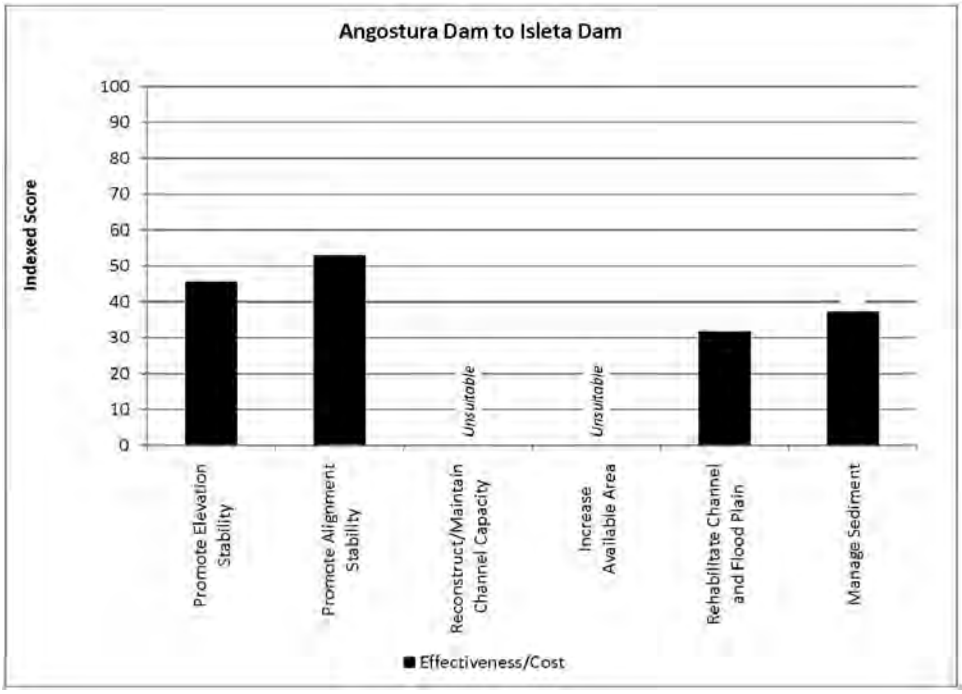

Figure 8.3. Angostura Diversion Dam to Isleta Diversion Dam Reach total effectiveness divided by cost indexed scoring results.

8.2.2 Promote Alignment Stability

- **Geomorphic Effects**

  The channel is near the stable slope according to the model results, and there is not much space to allow for lateral channel migration. Little change is expected in the balance of sediment load and transport capacity or flood plain connectivity if the strategy is implemented because the alignment would not change significantly.

- **Engineering Effectiveness Evaluation Factor**

  The slope change in the model results shows a relatively small amount of estimated change; yet half the length of the channel fits within the calculated meander belt. Thus, the river is laterally constrained, and this strategy might be needed for a large portion of the reach should lateral migration increase.

- **Ecosystem Function Evaluation Factor**

  No significant change to SWFL habitat would occur. RGSM habitat and opportunity for complexity would be reduced.

- **Economics Evaluation Factor**

  Since most of the land between the levees is project land, land ownership does not affect the cost of planning and design except on the Santa Ana, Sandia, and Isleta Pueblos. The high rating for the Implementation Cost Attribute is due to the large percentage of the channel length that does not fit between the infrastructures.

8.2.3 Reconstruct and Maintain Channel Capacity – Not Suitable

Historical trends do not show a tendency toward loss of channel capacity; therefore, this strategy is not suitable for this reach.

8.2.4 Increase Available Area to the River – Not Suitable

Although Increase Available Area to the River is not deemed suitable for this reach at this time due to difficulties in acquiring land in urban and pueblo settings, ways to overcome the difficulties should be investigated due to the very tight fit of the calculated meander belt within the existing constraints. This strategy would add an increased factor of safety for possible changes in hydrology and should supply additional RGSM habitat.

8.2.5 Rehabilitate Channel and Flood Plain

- **Geomorphic Effects**

  Much of the flood plain is disconnected in this reach. This strategy would reconnect flood plain and could reduce area needed for the meander belt because flow going overbank at lower discharges should reduce the energy of high flows. There are many habitat restoration projects ongoing in this reach that would need to be considered in any reach-wide flood plain rehabilitation.

- **Engineering Effectiveness Evaluation Factor**

  The 10,000-cfs water surface elevation after implementing this strategy would be lower than baseline. Both are contained, resulting in the no change rating for the Hydraulic Capacity Attribute. The sediment deposition rate in the overbank in this reach will be greater than in the Cochiti Dam to Angostura Diversion Dam Reach because there is a greater sediment supply from tributaries, notably from the Jemez River.

- **Ecosystem Function Evaluation Factor**

  SWFL habitat within this reach would not be affected or would be slightly improved. Opportunity for optimal RGSM habitat and channel complexity would increase.

- **Economics Evaluation Factor**

  The presence of three pueblos and higher environmental compliance costs increase planning and design costs.

8.2.6 Manage Sediment

- **Geomorphic Effects**

  Vegetation clearing (which makes bank-stored sediment available) appears to be creating a wider channel; but it is uncertain if this can be maintained by flows alone, and monitoring is needed.

- **Engineering Effectiveness Evaluation Factor**

  Sediment management in this reach involves adding sediment, which would reduce the tendency for future incision. In the upstream portion of this reach where the channel has already narrowed, lateral migration may still occur, and other strategies may be needed.

- **Ecosystem Function Evaluation Factor**

  Sediment management may build desirable point bar habitat for SWFL and RGSM. However, the patch size may not be large enough for SWFL. This reach has low sediment load, and increasing sediment could create islands and increased shoreline habitats for RGSM.

- **Economics Evaluation Factor**

  The Implementation Cost Attribute is rated low due to the volume of sediment needing to be added as estimated by the sediment model (Varyu et al., 2011).

8.3 Recommendations

The trends of significance to river maintenance currently observed in this reach are:

- Channel narrowing
- Vegetation encroachment
- Increased bank height
- Bank erosion
- Coarsening of bed material
- Incision or channel bed degradation

As this reach is highly urbanized, it has a high importance rating for the Infrastructure, Public Health, and Safety Reach Characteristic. The Channel Instability Reach Characteristic is rated as medium instability, and the Water Delivery Impact Reach Characteristic is rated as medium importance. This reach has a generally low value for both SWFL and RGSM habitat, but it rates as medium importance for the RGSM Habitat Value and Need Reach Characteristic due to ongoing RGSM population management in this reach.

Promote Elevation Stability, Promote Alignment Stability, Rehabilitate Channel and Flood Plain, and Manage Sediment should be studied in further detail for this reach. Promote Elevation Stability and Promote Alignment Stability have high effectiveness-to-cost ratios. The importance of this reach to RGSM means that Rehabilitate Channel and Flood Plain and Manage Sediment also should be considered because of the added value to the RGSM. Finally, even though it was not originally deemed suitable for this reach because of difficulties in acquiring land, Increase the Available Area to the River could be viable due to the very tight fit of the calculated meander belt within the existing constraints. This strategy would add an increased factor of safety for possible changes in hydrology and should supply additional RGSM habitat.

This reach has potential for adaptive management due to increasing sediment loads from Jemez Canyon Dam operational modifications. The cumulative effects of numerous habitat improvement projects on the sediment supply in the reach may be significant.

9. Isleta Diversion Dam to Rio Puerco (RM 169.3 to RM 127)

9.1 Reach Characteristics

This reach is approximately 42 miles long with a riverbed slope of approximately 0.00081[1] (4.3 feet per mile) and an average channel width of 350 feet. Isleta Diversion Dam, at the upstream end of the reach, has a combined diversion capacity of 1,070 cfs to the Peralta Main and Belen Highline Canals. This reach has one major tributary, Abo Arroyo (RM 139.5), which is ephemeral. Several riverside drains return flow to the river within the reach, but generally not substantial volumes.

Habitat restoration consisting of bank and island vegetation clearing, lowering, and destabilization; native vegetation plantings; and construction of bank complexity features has been completed at Isleta Pueblo and at the Los Lunas/Belen sites.

This reach is one of the least-studied reaches because it has had a fairly stable bed elevation and, until the recent drought, a fairly stable active channel width. As documented in 2001, numerous islands and bars have formed and attached to the banks in this reach, changing the planform from a wide, fairly straight active channel to a low-flow, single-threaded channel with some anastomosing character at high flows. Current areas with divided channel appear to have changed little since 2005. The active bars show some shifting, which may be due to the 2008 high flow. Many of the sparsely vegetated islands and bars deposited during the 2005 high flows are becoming more mature and thickly vegetated, and a significant number of high-flow side channels remain active and clear of vegetation. The extent of side channels decreases below Highway 6. There is ongoing mechanical vegetation clearing in select locations (e.g., near Belen); but most of the bars are more thickly vegetated, and the single channel character is growing. By Bernardo, the bars appear taller and the channel narrower with fewer active bars and side channels. The planform classification[2] is Planform Stages 3 (Main channel with side channels) to M5 (Sinuous thalweg channel) with very little Planform Stage 2 (Vegetating bar channel).

[1] The slope is calculated from the reduced number of cross sections in the Plan and Guide model.

[2] See appendix C, section C1.4.1.3, for a description of the Middle Rio Grande Planform Evolution Model. Also refer to the Unique Terms section located at the end of this document.

9.1.1 Channel Instability Reach Characteristic – Medium Instability

The Channel Instability Reach Characteristic overall rating is medium mainly because of the recent channel narrowing that could cause increased sediment transport capacity. There is uncertainty whether the effect would be in the vertical or horizontal direction. There is some room for channel migration; but in the area around RM 135–166 (downstream of Abo Arroyo to near Bosque Farms), the calculated meander belt is very close to or just outside the constraints at a few very constricted sites. Bank height increased through deposition in the flood plain along the channel edges through much of this reach in 2004 and 2005, and an alternating bar pattern has developed. There is potential for lateral migration because of the channel narrowing, and the modeling shows the stable channel slope is a bit flatter than existing conditions.

9.1.2 Water Delivery Impact Reach Characteristic – Medium Importance

River flows are diverted at Isleta Diversion Dam, which is the upstream boundary of this reach. Drain returns flow downstream into the Rio Puerco to San Acacia reach without being diverted, but return flows can be diverted at San Acacia Diversion Dam. This reach has a net loss of river flow to ground water through seepage from the channel. River seepage losses exceed drain return flows of approximately 2–3 cfs per mile at a 500-cfs river flow and increase for larger discharges (SSPA 2008). Since there is one downstream diversion point, this reach is rated as medium importance.

9.1.3 Infrastructure, Public Health, and Safety Reach Characteristic – High Importance

Infrastructure for this reach includes the town of Belen and the Isleta Pueblo. In addition, there are levees, bridges, and gas and power line crossings in this reach.

9.1.4 Habitat Value and Need Reach Characteristic

Reclamation biologists classified this reach as biologically significant for both SWFL and RGSM from Isleta Diversion Dam to New Mexico State Highway 49 bridge and U.S. Highway 60 bridge to Rio Puerco and for SWFL from about Abo Arroyo to U.S. Highway 60.

9.1.4.1 Southwestern Willow Flycatcher – High Importance

Small populations of SWFLs exist on the Isleta Pueblo and immediately upstream of the Rio Puerco. Most of this reach is unsuitable for SWFLs. The SWFL population on the Isleta Pueblo seems to be dwindling as habitat quality declines and other areas are colonized; this reach is rated high for the SWFL Habitat Value and Need Reach Characteristic.

9.1.4.2 Rio Grande Silvery Minnow – Medium Importance

RGSM are common in this reach (Dudley and Platania 2011 and Reclamation data). However, habitat quality is minimal. American Recovery and Reinvestment Act (ARRA) restoration work downstream through Belen has cleared vegetation and increased the potential for channel movement.

9.2 Strategy Assessment Results

Significant narrowing of the formerly wide, braided channel has occurred in recent years, creating a focused thalweg that could encourage rapid incision or lateral migration. This reach has been relatively stable in the past and, therefore, is among the least studied. Because less is known about how this reach may change in the future, five strategies were deemed potentially suitable for this reach. Promote Alignment Stability is unsuitable as a reach-wide strategy because analysis results show the meander belt generally fits within the constraints but is tight in the vicinity of Bosque Farms to downstream of Abo Arroyo. These areas of local constriction may require bank protection.

The short discussions below summarize the reach specific strategy assessment results.[1] Figures 9.1–9.3 present the indexed scores of effectiveness divided by cost for the suitable strategies. More detailed assessment information, including weighted scores for each strategy, is presented in Appendix C: Strategy Assessment.

9.2.1 Promote Elevation Stability

- **Geomorphic Effects**

  This strategy would reduce channel degradation supporting the existing riparian habitat but would not tend to support channel and flood plain adjustments and associated habitat renewal.

- **Engineering Effectiveness Evaluation Factor**

  The SRH1-D model shows the potential need for grade control in this reach. The amount of future slope change is fairly small. Therefore, if cross channel structures were implemented, it is likely that they would be spaced very far apart. Another strategy likely would be needed in this reach because of potential local lateral migration and the associated erosion and deposition of sediment.

[1] Effects that are the same for a particular strategy and not affected by reach characteristics are summarized in chapter 4 of the main report and discussed in more detail in Appendix C, Section 1.7, Engineering Effectiveness Evaluation Factor; Section 1.8, Ecosystem Function Evaluation Factor; and Section 1.9, Economics Evaluation Factor.

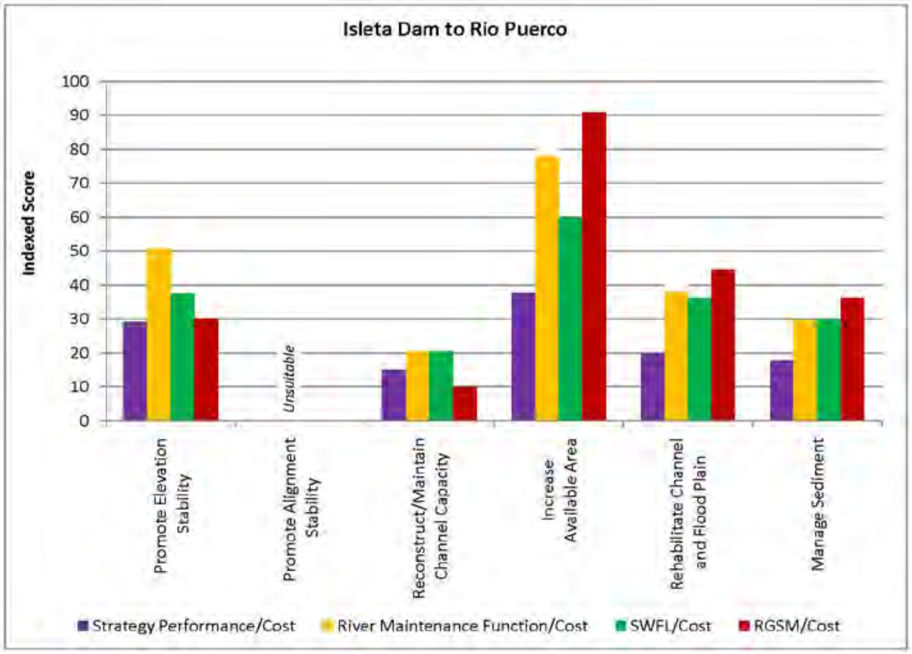

Figure 9.1. Isleta Diversion Dam to Rio Puerco Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

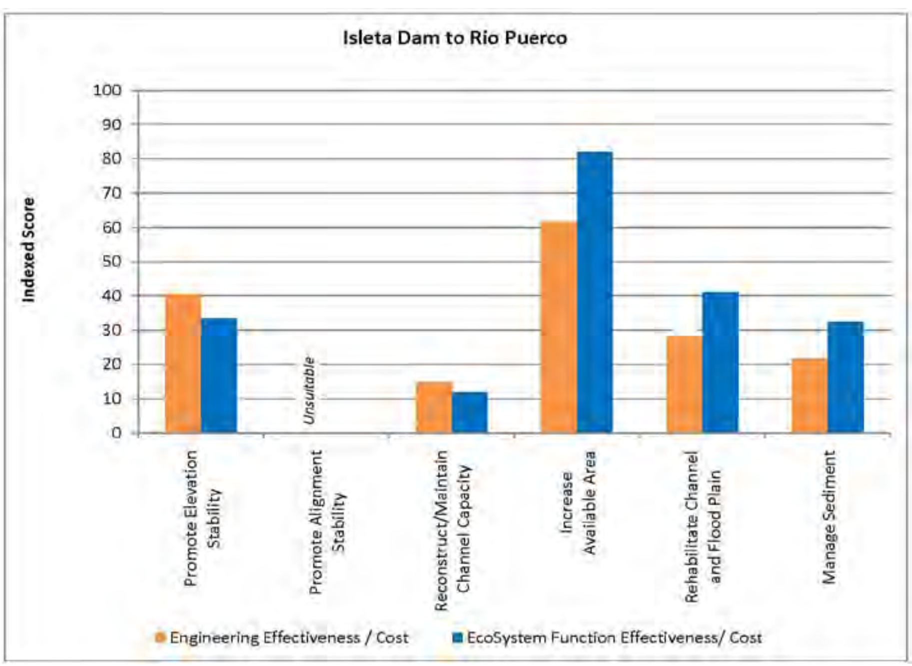

Figure 9.2. Isleta Diversion Dam to Rio Puerco Reach effectiveness divided by cost indexed scoring results by evaluation factor.

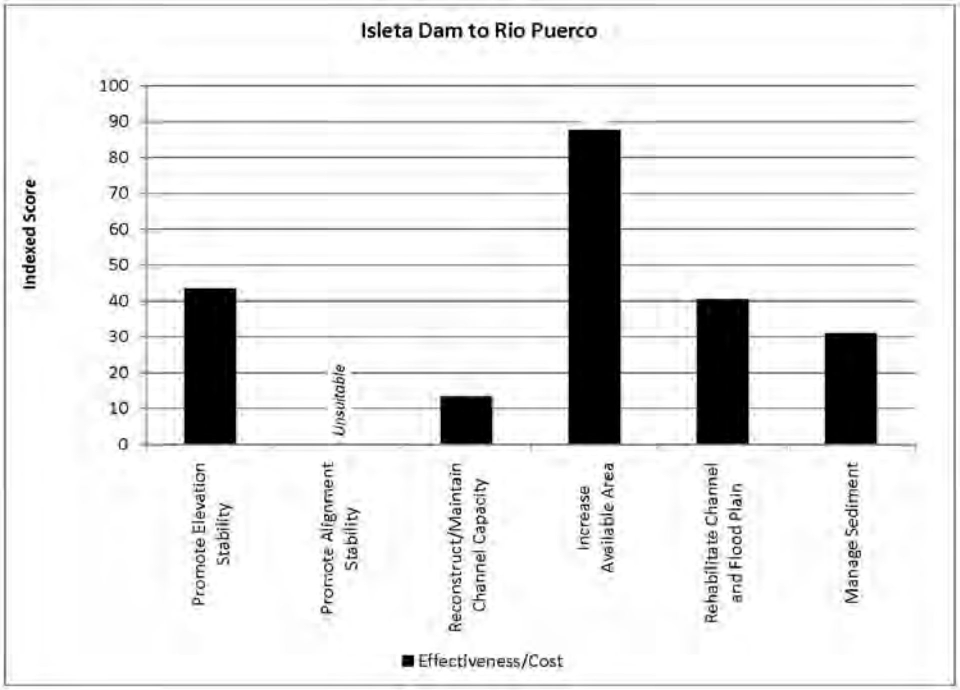

Figure 9.3. Isleta Diversion Dam to Rio Puerco Reach total effectiveness divided by cost indexed scoring results by evaluation factor.

- **Ecosystem Function Evaluation Factor**

  Promoting elevation stability in this reach likely would not have a great impact on SWFL habitat and probably would not change RGSM habitat complexity.

- **Economics Evaluation Factor**

  The Implementation Cost Attribute is rated low because of the fairly small amount of future slope change expected in this reach.

9.2.2 Promote Alignment Stability – Not Suitable

Analysis results show that the meander belt fits between the lateral constraints; therefore, this strategy is not suitable for this reach. Continued narrowing and development of a strongly meandering thalweg could change this condition thus there may be a need for local bank protection. If the change is widespread enough, the strategy may become suitable for this reach.

9.2.3 Reconstruct and Maintain Channel Capacity – Not Recommended

Since this strategy had a very low effectiveness-to-cost ratio, it is not recommended for further on a reach-wide basis; but it may still have value at specific locations.

9.2.4 Increase Available Area to the River

- **Geomorphic Effects**

  Opportunities for this strategy should be explored because the calculated meander belt is very close to the constraints for much of the reach, and much of the land outside the levee is agricultural. Channel narrowing creates the potential for future lateral migration and acquiring additional land along the channel is worth evaluating before land use changes.

- **Engineering Effectiveness Evaluation Factor**

  Analysis results show that nearly all of the calculated meander belt width fits within the infrastructure constraints; therefore, this strategy would not be considered applicable on a reach-wide basis. However, there are other reasons to explore future opportunities for implementing this strategy. Even with the presence of agriculture, lands, and urban development, enough available land area may exist for the river to approach dynamic equilibrium. However, acquiring the necessary land area may make this strategy difficult to implement.

- **Ecosystem Function Evaluation Factor**

  SWFL habitat could improve if river channel migration were to occupy newly available areas. Opportunity for optimal RGSM habitat and channel complexity would increase if the river is allowed to migrate and increase sinuosity.

- **Economics Evaluation Factor**

  The Implementation Cost Attribute is rated low based on analysis results; however, the cost may increase as canals and drains would need to be relocated in areas where the meander belt is very close to the constraints.

9.2.5 Rehabilitate Channel and Flood Plain

- **Geomorphic Effects**

  This strategy could reduce the potential for lateral migration in the future.

- **Engineering Effectiveness Evaluation Factor**

  Large sediment excavation volumes mean that the rating for the Ability to Implement Attribute is low.

- **Ecosystem Function Evaluation Factor**

  SWFL habitat may benefit from increasing overbank flooding. RGSM habitat complexity could increase.

- **Economics Evaluation Factor**

  As is common with this strategy, the large sediment volumes move the Implementation Cost Attribute rating to high, considering the required excavation volume needed to achieve overbanking during peak discharges.

9.2.6 Manage Sediment

- **Geomorphic Effects**

  If lateral migration increases as a result of channel narrowing, this strategy may be needed because the calculated meander belt is very close to the constraints for much of the reach. This strategy could reduce the potential for lateral migration in the future.

- **Engineering Effectiveness Evaluation Factor**

  SRH1-D model results show a sediment deficit in this reach. Model results show that the equilibrium slope is a bit flatter than baseline. Adding sediment could prevent a future decrease in channel slope.

- **Ecosystem Function Evaluation Factor**

  Impacts for SWFL depend on the type of sediment management. Adding sediment would be positive for RGSM by building desirable point bar habitat.

- **Economics Evaluation Factor**

  The Implementation Cost Attribute is rated low because of the smaller quantity of sediment needed per year.

9.3 Recommendations

The trends of significance to river maintenance currently observed in this reach are:

- Vegetation encroachment
- Channel narrowing
- Increased bank height
- Coarsening of bed material

Continuing these trends may cause the following additional trends to develop:

- Incision or channel bed degradation followed by
- Bank erosion

The time needed for these trends to develop is unknown, but the current rate of change does not support this as likely in the next decade or so. Additional investigations may change this conclusion.

The urban areas of Belen and Los Lunas result in a high rating for the Infrastructure, Public Health, and Safety Reach Characteristic. The Water Delivery Impact Reach Characteristic is of medium importance. The Isleta Diversion Dam to Rio Puerco Reach has been historically stable, and model results support a continuation of this trend at 2006 channel widths. Rapid narrowing in the last decade plus the moderately tight fit of the calculated meander belt within the constraints results in a rating of medium for channel instability in this reach. It is possible that bars and islands will continue to develop in this reach. The importance of the SWFL Habitat Value and Need Reach Characteristic is rated high because the reach is occupied by endangered species, and habitat is declining in quality. The importance of the RGSM Habitat Value and Need Reach Characteristic is rated medium because the reach is occupied by endangered species even though the habitat quality is low.

The high importance rating for SWFL Habitat Value and Need Reach Characteristic in this reach means that both Rehabilitate Channel and Flood Plain and Promote Elevation Stability also should be further considered for this reach because of the high habitat effectiveness-to-cost ratios. Manage Sediment had a high effectiveness-to-cost ratio for RGSM and should be studied further.

Reconstruct and Maintain Channel Capacity had a very low effectiveness-to-cost ratio and should not be investigated further on a reach-wide basis but may still have value at specific locations. Increase Available Area to the River should continue to be evaluated because it has the highest effectiveness-to-cost ratios and the potential for future lateral migration due to the channel narrowing.

The cumulative effect of numerous habitat improvement projects upstream of and in this reach may be significant and could lead to the need for adaptive management after future strategy implementation. Increasing sediment loads from Jemez Canyon Dam and habitat restoration projects may impact strategy effects over time.

10. Rio Puerco to San Acacia Diversion Dam (RM 127 to RM 116.2)

10.1 Reach Characteristics

The Rio Puerco to San Acacia Diversion Dam Reach is about 11 miles long and has a riverbed slope of approximately 0.00072[1] (3.8 feet per mile) and an average channel width of 250 feet. Major tributaries in the reach are: Rio Puerco (RM 126.5), Salas Arroyo (RM 126.5), Los Alamos Arroyo (RM 124), and Rio Salado (RM 118.5). The Rio Puerco and Rio Salado are ephemeral, but they contribute high sediment loads to the reach episodically, typically during summer monsoon season thunderstorms.

The bed material is primarily sand and gravel with gravel becoming a larger component of the bed material in this reach, especially downstream from the Rio Salado confluence where the tributary fan acts as major grade control. In general, the banks are high; but there are many inset flood plains with variable local bank heights. In the 2008 aerial photography, it appears that most of the islands and bars have attached to the banks. Vegetation is growing on these attached bars, setting up a narrow single-thread planform with increased potential for channel degradation and lateral migration. Downstream from the Rio Salado confluence, there has been significant planform change and lateral migration with some local incision in recent years.

10.1.1 Channel Instability Reach Characteristic – Medium Instability

The sediment modeling results for this reach predict a moderate amount of change in all the factors used to assess channel instability. This rating of medium instability depends on little change in the Rio Puerco and Rio Salado watersheds, so that incoming water and sediment loads would not vary much from existing levels.

10.1.2 Water Delivery Impact Reach Characteristic – High Importance

The drain return flows exceed river seepage when the flows are between 500–3,000 cfs (SSPA 2008). These gains are collected in Drain Unit #7. The flow in Drain Unit #7 reduces river diversions into the Socorro Main Canal by the same amount at San Acacia Diversion Dam. San Acacia Diversion Dam is the downstream boundary of this reach where flows are

[1] The slope is calculated from the reduced number of cross sections in the Plan and Guide model.

diverted into the MRGCD irrigation system. Because this is a gaining reach (where the river intercepts ground water flows and where drain return flows reduce downstream diversions), the water delivery impact is rated as high importance.

10.1.3 Infrastructure, Public Health, and Safety Reach Characteristic – Low Importance

This reach is primarily public lands (Sevilleta National Wildlife Refuge and Ladd S. Gordon Waterfowl Management Area-La Joya) and has little agricultural land use. Infrastructure in this reach also includes Drain Unit 7 Extension and levees.

10.1.4 Habitat Value and Need Reach Characteristic

Reclamation biologists have classified this reach as biologically significant for both SWFL and RGSM.

10.1.4.1 Southwestern Willow Flycatcher – High Importance

Similar to the Isleta Diversion Dam to Rio Puerco Reach, this reach has been occupied by resident SWFLs for the past several years, and much of this reach is included in the critical habitat designation. The SWFL population within this reach continues to expand into developing habitat and could become a significant source population for developing habitat upstream.

10.1.4.2 Rio Grande Silvery Minnow – Medium Importance

RGSM are present throughout this reach (Dudley and Platania 2011 and Reclamation data). Increases in channel complexity could increase the habitat diversity required to maintain RGSM within the reach. If fish passage is implemented at San Acacia Diversion Dam, the importance of this reach could move to a high importance rating for the RGSM Habitat Value and Need Reach Characteristic.

10.2 Strategy Assessment Results

Promote Alignment Stability and Increase Available Area to the River could address the potential for lateral migration in the downstream portion of the reach.

The short discussions below summarize the reach specific strategy assessment results.[1] Figures 10.1–10.3 present the indexed scores of effectiveness divided by

[1] Effects that are the same for a particular strategy and not affected by reach characteristics are summarized in chapter 4 of the main report and discussed in more detail in Appendix C, Section 1.7, Engineering Effectiveness Evaluation Factor; Section 1.8, Ecosystem Function Evaluation Factor; and Section 1.9, Economics Evaluation Factor..

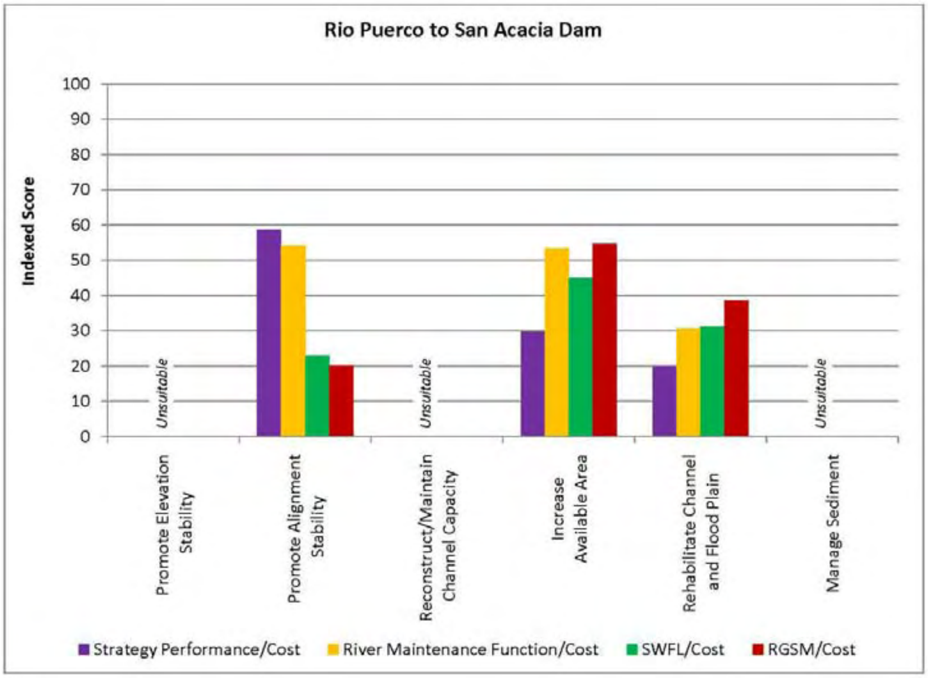

Figure 10.1. Rio Puerco to San Acacia Diversion Dam Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

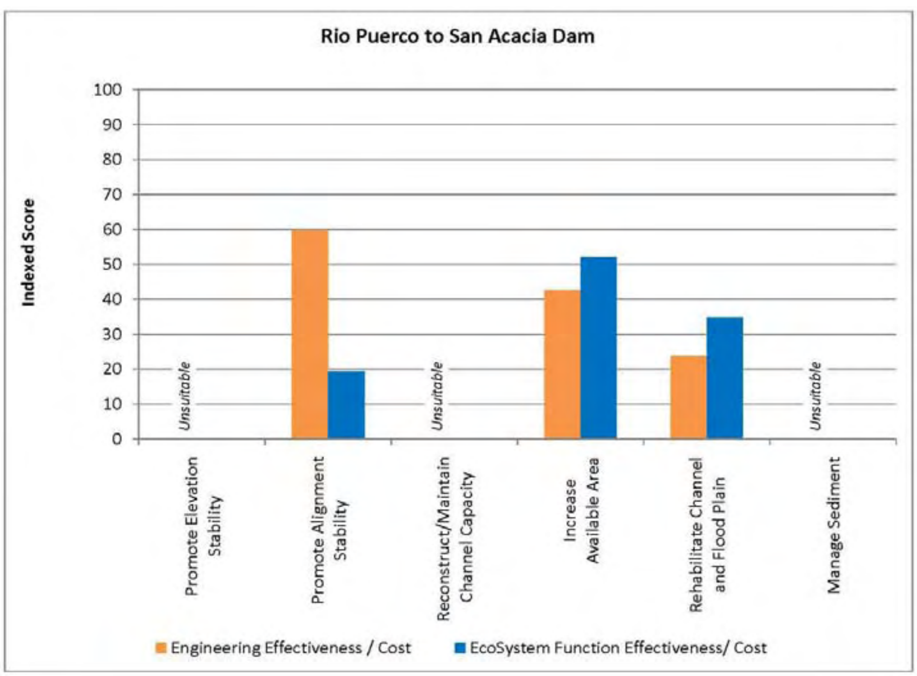

Figure 10.2. Rio Puerco to San Acacia Diversion Dam Reach effectiveness divided by cost indexed scoring results by evaluation factor.

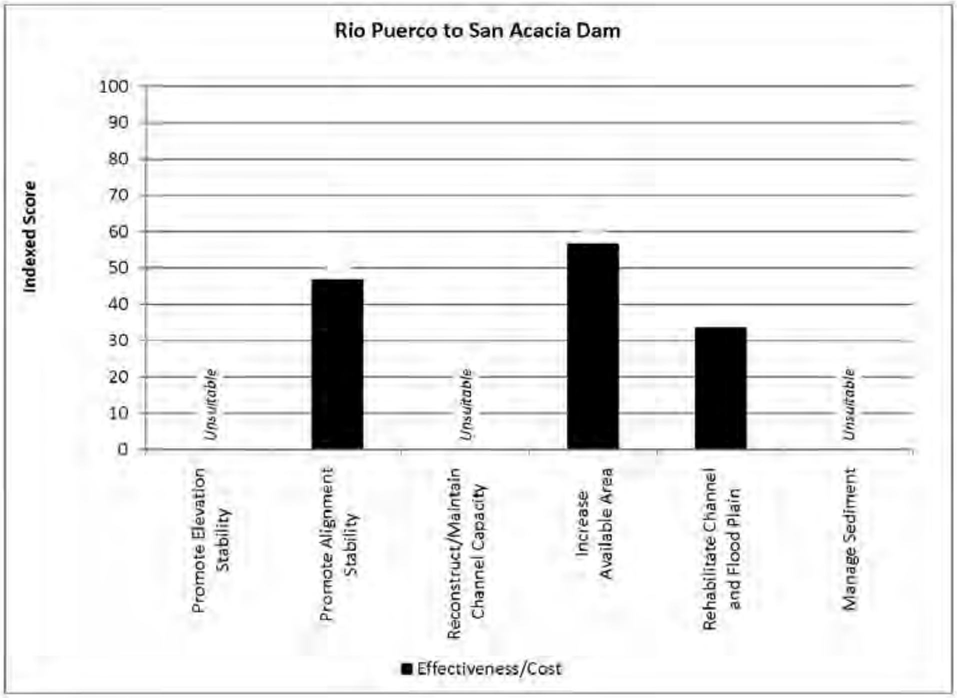

Figure 10.3. Rio Puerco to San Acacia Diversion Dam Reach total effectiveness divided by cost indexed scoring results.

cost for the suitable strategies. More detailed assessment information, including weighted scores for each strategy, is presented in Appendix C: Strategy Assessment.

10.2.1 Promote Elevation Stability – Not Analyzed

Modeling results indicate mild aggradation; therefore, this strategy was not analyzed because aggradation is addressed through other complementary strategies (see table C1.4 in appendix C for more information).

10.2.2 Promote Alignment Stability

- **Geomorphic Effects**

  If the channel continues to narrow, lateral migration may increase. There is some space to allow channel migration before bank stabilization is needed, so some channel and flood plain adjustments could occur bringing the sediment transport capacity and load closer to a balanced condition.

- **Engineering Effectiveness Evaluation Factor**

  The bed elevation change is small enough that the Level of Confidence Attribute is rated high.

- **Ecosystem Function Evaluation Factor**

  This strategy decreases the river's abilities for erosion and deposition and, thus, decreases regeneration of SWFL habitat. This strategy would reduce RGSM habitat and opportunity for habitat complexity and have high short-term construction impacts.

- **Economics Evaluation Factor**

  The reach is biologically significant for SWFL and RGSM, so the Planning and Design Attribute is rated medium. The Implementation Cost Attribute also is rated medium because about one-fourth of the meander belt width is outside of the lateral constraints.

10.2.3 Reconstruct and Maintain Channel Capacity – Not Suitable

Historical trends do not show a tendency toward loss of channel capacity, and modeling indicates that more than 4,700 cfs is contained in the channel. Therefore, this strategy is not suitable for this reach.

10.2.4 Increase Available Area to the River

- **Geomorphic Effects**

  Possible channel migration could increase attenuation of high-flow events, channel and flood plain adjustments, and episodic sediment transport with a possible decrease of effective transport of water and sediment, especially in the short term.

- **Engineering Effectiveness Evaluation Factor**

  This strategy could not be applied in the Sevilleta Bend portion of the reach because the valley is too narrow, but it could be applied in other subreaches.

- **Ecosystem Function Evaluation Factor**

  Allowing the river to meander over a greater flood plain could create new and younger age classes of vegetation through erosion and deposition, improving SWFL habitat. Opportunity for optimal RGSM habitat and channel complexity would increase.

- **Economics Evaluation Factor**

  A large amount of infrastructure would need to be moved over a quarter of the reach.

10.2.5 Rehabilitate Channel and Flood Plain

- **Geomorphic Effects**

  Even with the aggradation predicted by the modeling, this reach is still not connected to the flood plain at 4,700 cfs. This strategy would result in much more frequent flood plain inundation with wider, wetted width at high flows—resulting in attenuation of flood peaks.

- **Engineering Effectiveness Evaluation Factor**

  The Duration and Design Life Attribute is rated medium. Large volumes of sediment reduce the ability to implement this strategy. The Hydraulic Capacity Attribute is rated no change for this strategy. The rate of sediment deposition may be greater than the Angostura Diversion Dam to Isleta Diversion Dam Reach because of additional tributary sediment inflow.

- **Ecosystem Function Evaluation Factor**

  Habitat for SWFL in this reach likely would be improved by this strategy by providing increased overbank flooding. Increased flood plain area and connectivity to the flood plain creates more nursery habitat in flooding conditions, which would improve habitat for RGSM. It is a low construction impact, as work could impact the edge of the river-based RGSM nursery and adult habitats. However, the majority of work could be done from the bank line.

- **Economics Evaluation Factor**

  As is common with this strategy, the large sediment excavation volumes increase the Implementation Cost Attribute rating to high.

10.2.6 Manage Sediment – Not Suitable

Model results indicate a mild increase in reach average slope and channel aggradation. Historical trends show both significant aggradation and degradation over time; therefore, adding or removing sediment would not be advisable as a long-term strategy.

10.3 Recommendations

The trends of significance to river maintenance currently observed in this reach are:

- Channel narrowing
- Vegetation encroachment

- Increased bank height
- Incision or channel bed degradation (local)
- Coarsening of bed material

This reach is a gaining reach (from drains and river channel), reducing downstream river diversions, so the importance of the Water Delivery Impact Reach Characteristic is rated high. SWFL population continues to expand here because of the active river dynamics and could become a source for upstream expansion; thus, the SWFL Habitat Value and Need Reach Characteristic rating is high importance. RGSM are present, but the habitat quality is low; therefore, the RGSM Habitat Value and Need Reach Characteristic rating is medium importance. If fish passage is implemented, this reach could move to a high importance rating for the RGSM Habitat Value and Need Reach Characteristic. The Channel Instability Reach Characteristic is rated medium instability because most of the factors considered for this reach characteristic rating were classed as medium.

Increase Available Area to the River and Promote Alignment Stability had high effectiveness-to-cost ratios and should be further studied. Increase Available Area has a low effectiveness-to-cost ratio for strategy performance but high effectiveness-to-cost ratios for both the River Maintenance Subevaluation Factor and Ecosystem Function Evaluation Factor. Promote Alignment Stability has reach-wide impacts to the habitat, which means this strategy is likely a lower priority for future implementation because the SWFL Habitat Value and Need Reach Characteristic is rated as high importance in this reach. Rehabilitate the Channel and Flood Plain should continue to be investigated for local implementation because it is highly beneficial biologically, and this reach has strong habitat value and habitat needs.

11. San Acacia Diversion Dam to Arroyo de las Cañas (RM 116.2 to RM 95)

11.1 Reach Characteristics

This reach is about 21 miles long with a riverbed slope of approximately 0.00081[1] (4.3 feet per mile) and an average channel width of 270 feet. Major tributaries in the reach are all ephemeral: San Lorenzo Arroyo (RM 113), Arroyo Alamillo (RM 112), Arroyo de la Parida (RM 104.5), and Arroyo de las Cañas (RM 95). The city of Socorro also has the North Socorro Diversion Channel, a storm water runoff facility that exits to the river in the reach. San Acacia Diversion Dam can divert up to 283 cfs to the Socorro Main Canal. The LFCC also begins at San Acacia Diversion Dam and has a design capacity of 2,000 cfs. Surface water diversions to the LFCC were suspended completely in 1985, except for experimental operations. Habitat restoration activities in this reach include removing the western lateral river constraint by relocating the infrastructure setback over about 3 river miles. This has resulted in over 200 additional acres of lateral freedom for the river.

The channel bed is dominated by gravel, even though sand dunes often cover the gravel. Several arroyos have been reconnected to the Rio Grande by vegetation removal, which increased sediment supply; but vegetation is reestablishing in some areas. At nearly all of the tributary junctions, alluvial fans have developed that partially cover the Rio Grande's bed with gravel-sized and larger sediment and that can effectively act as grade control under average conditions (Bauer 2007).

Near San Acacia Diversion Dam, the bed has undergone at least 12 feet of degradation since the 1930s; this degradation has progressed downstream but decreases as it approaches Arroyo de las Cañas confluence, which appears to be relatively stable. The model predicts some aggradation near the confluence. Significant channel narrowing and lateral migration has occurred upstream of Escondida since the turn of the 21st century, and bed material has coarsened near San Acacia. There are still a few short sections of braiding (e.g., near RM 107). Two levee setbacks have made the historical meander belt available to the river, but there are still areas where it is cut off. There is new vegetation growing on the low bars; and on the higher bars, vegetation is maturing and thickening.

[1] The slope is calculated from the reduced number of cross sections in the Plan and Guide model.

The channel has straightened in several of the largest bends, steepening the locally overly lengthened/flattened slope in those bends.

11.1.1 Channel Instability Reach Characteristic – Medium Instability

Many bends are active in this reach, and the most active bends have moved to Planform Stages M7 (Migrating with cutoff channel) and M8 (Cutoff is now main channel),[1] straightening the channel. Channel narrowing continues with maturing vegetation on the inset flood plains, and the bars appear to be less active since 2005. This vegetation may reduce the potential for channel migration in the short term—even with the narrowing channel. Modeling predicts flattening of the reach slope with aggradation at the lower end. Virtually all of the calculated meander belt fits between the constraints but uses most of the available area so that there is little extra area to absorb any increase in channel migration. The Channel Instability Reach Characteristic in the San Acacia Diversion Dam to Arroyo de las Cañas Reach is, thus, rated as medium instability, based on historical trends and model results.

11.1.2 Water Delivery Impact Reach Characteristic – High Importance

The Water Delivery Impact Reach Characteristic is rated as high importance because river waters flow into Elephant Butte Reservoir without any diversions. San Acacia Diversion Dam is the terminal river diversion location for MRGCD. There are no major diversions from the Rio Grande below San Acacia Diversion Dam. Additional diversions from the LFCC into the MRGCD system occur in this reach. The LFCC becomes the low point in the valley a few miles downstream from Escondida Bridge. The net seepage loss to ground water in this reach is less than 0.5 cfs per mile at 500-cfs river flows (SSPA 2008).

11.1.3 Infrastructure, Public Health, and Safety Reach Characteristic – Medium Importance

Infrastructure in this reach includes agricultural cropland; sparse distribution of homes, barns, and other agricultural buildings; one bridge; and the town of Socorro. The LFCC and the west side levee, constructed and maintained by Reclamation, are in this reach. The LFCC is an important structure since the LFCC intercepts most of the river channel seepage losses, receives irrigation return flows, and delivers about a quarter of the total inflow to Elephant Butte Reservoir (San Acacia Workshop 2009).

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[1] See appendix C, section C1.4.1.3, for a description of the Middle Rio Grande Planform Evolution Model. Also refer to the Unique Terms section located at the end of this document.

11.1.4 Habitat Value and Need Reach Characteristic

11.1.4.1 Southwestern Willow Flycatcher – Low Importance

While this is included in the critical habitat designation, SWFL habitat is severely degraded, and no pairing or nesting has occurred during the past 14 years of surveying.

11.1.4.2 Rio Grande Silvery Minnow – High Importance

High RGSM population densities are found within this area. Drying makes maintaining channel connectivity and wetted habitats throughout the year a high priority.

11.2 Strategy Assessment Results

Five strategies are potentially suitable for this reach:

- Promote Elevation Stability
- Promote Alignment Stability
- Increase Available Area to the River (for areas of the river beyond the two existing levee setbacks)
- Rehabilitate Channel and Flood Plain
- Manage Sediment

Promote Elevation Stability could address the bed degradation that also might help reduce channel migration. Promote Alignment Stability, Increase Available Area to the River (for areas of the river beyond the two existing levee setbacks), and Rehabilitate Channel and Flood Plain could address channel migration into riverside infrastructure. An increase in sediment load could help reduce or prevent the tendency to erode sediment from channel bed and/or banks.

The short discussions below summarize the strategy assessment results.[1] Figures 11.1–11.3 present the indexed scores of effectiveness divided by cost for the suitable strategies. More detailed assessment information, including weighted scores for each strategy, is presented in Appendix C: Strategy Assessment.

[1] Effects that are the same for a particular strategy and not affected by reach characteristics are summarized in chapter 4 of the main report and discussed in more detail in Appendix C, Section 1.7, Engineering Effectiveness Evaluation Factor; Section 1.8, Ecosystem Function Evaluation Factor; and Section 1.9, Economics Evaluation Factor.

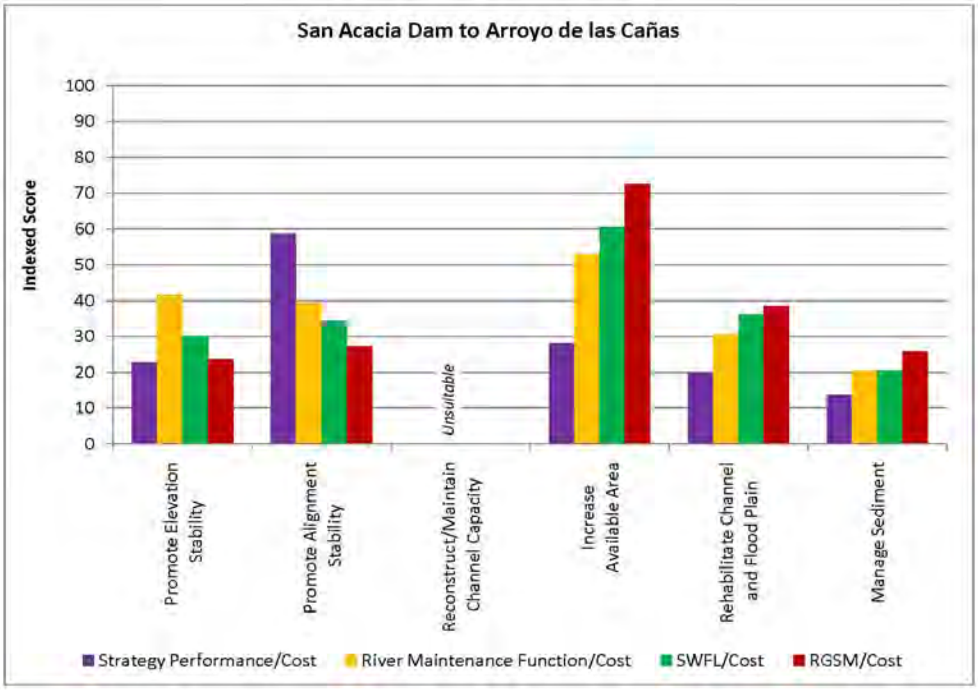

Figure 11.1. San Acacia Diversion Dam to Arroyo de las Cañas Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

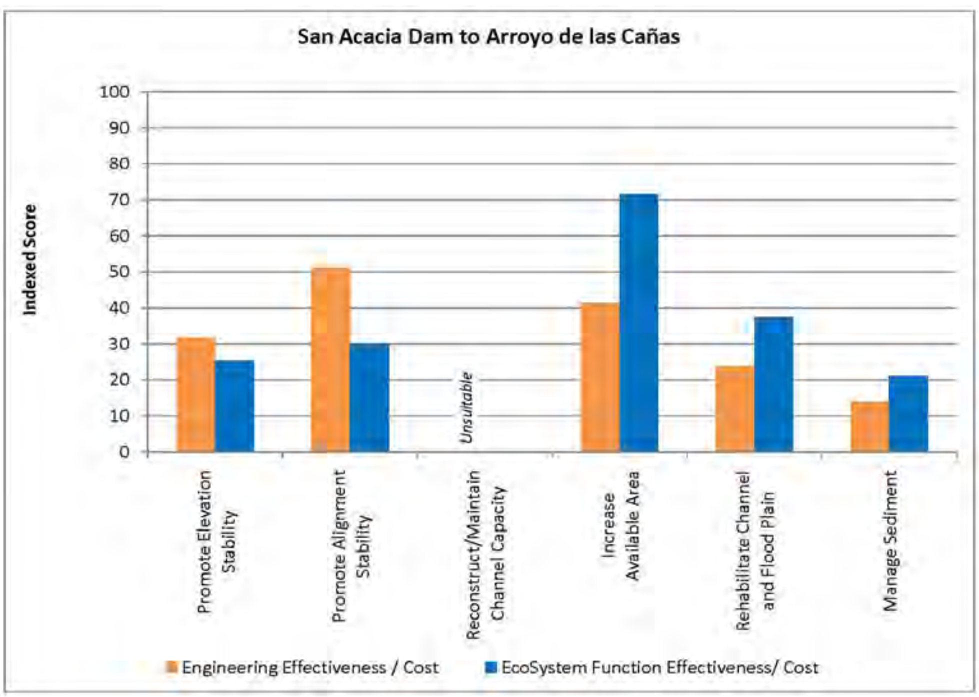

Figure 11.2. San Acacia Diversion Dam to Arroyo de las Cañas Reach effectiveness divided by cost indexed scoring results by evaluation factor.

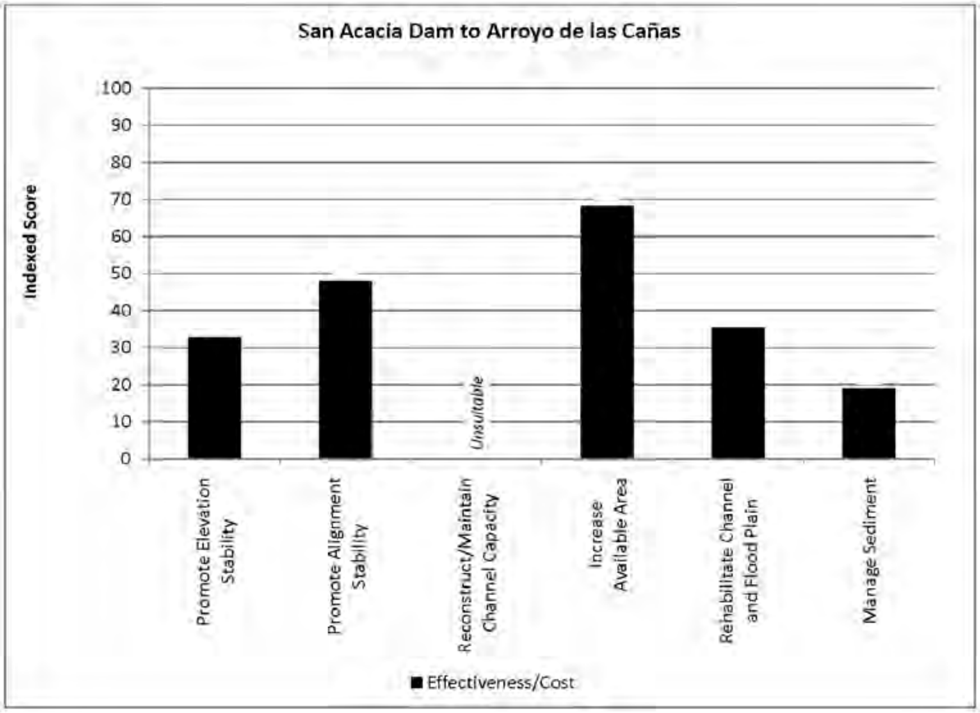

Figure 11.3. San Acacia Diversion Dam to Arroyo de las Cañas Reach total effectiveness divided by cost indexed scoring results.

11.2.1 Promote Elevation Stability

- **Geomorphic Effects**

  This strategy could be necessary for the upper portion of this reach, especially if fish passage is constructed at the San Acacia Diversion Dam. This reach is incised enough that flood plain connectivity and attenuation of flood peaks are unlikely to change.

- **Engineering Effectiveness Evaluation Factor**

  The riverbed elevation will be held constant in the vicinity of each structure. Long spacing between structures means this strategy is unlikely to meet river maintenance goals without implementing another strategy.

- **Ecosystem Function Evaluation Factor**

  No impact on SWFL or RGSM habitat. The entrance elevation to the fish passage structure would need to be stable to permit RGSM use. Bank-to-bank construction would be a high, short-term impact for RGSM.

- **Economics Evaluation Factor**

  Implementation cost is rated medium because of the fairly small amount of future slope change in this reach.

11.2.2 Promote Alignment Stability

- **Geomorphic Effects**

  This reach has actively migrating large bends but does not have much space to accommodate more channel migration except in the levee setback areas. Alignment stability would reduce the channel and flood plain adjustments.

- **Engineering Effectiveness Evaluation Factor**

  The small potential slope change and percent of the channel outside of the meander belt width indicate that this strategy can be used with confidence in this reach.

- **Ecosystem Function Evaluation Factor**

  The river's capacity for erosion and deposition would decrease, decreasing SWFL habitat. Within this reach, lateral migration would be allowed, if there is room within the infrastructure. Minimal change to RGSM habitat and opportunity for complexity would take place if some lateral migration is possible.

- **Economics Evaluation Factor**

  This reach is rated medium for the Implementation Cost Attribute because a portion of the length of the meander belt width is calculated to be outside of the limits of the lateral constraints.

11.2.3 Reconstruct and Maintain Channel Capacity – Not Suitable

Historical trends do not show a tendency toward loss of channel capacity; therefore, this strategy is not suitable for this reach.

11.2.4 Increase Available Area to the River

Note that this strategy applies to portions of the river that have not already been setback.

- **Geomorphic Effects**

  The modeling shows flattening of the slope, so this strategy may continue to be useful—even though levee setbacks have already been implemented for two areas in this reach. This strategy would probably not decrease the potential degradation by much immediately below the San Acacia Diversion Dam.

- **Engineering Effectiveness Evaluation Factor**

  Because the calculated meander belt width is not completely within the infrastructure, this strategy would be effective.

- **Ecosystem Function Evaluation Factor**

  A more dynamic river system would positively impact SWFL habitat. Opportunity for optimal RGSM habitat and channel complexity would increase.

- **Economics Evaluation Factor**

  The Planning and Design and Environmental Compliance Attributes are rated high due to infrastructure relocation design, which in this reach consists primarily of the LFCC.

11.2.5 Rehabilitate Channel and Flood Plain

- **Geomorphic Effects**

  Because much of this reach is incised, this strategy would result in more frequent flood plain inundation and would provide a wider wetted width at high flows.

- **Engineering Effectiveness Evaluation Factor**

  Overall engineering effectiveness is rated low because the slope change predicted by the model is small.

- **Ecosystem Function Evaluation Factor**

  This strategy could have a positive impact on SWFL habitat from the increased likelihood of overbank flooding. Opportunity for optimal RGSM habitat and channel complexity would increase.

- **Economics Evaluation Factor**

  Implementation costs are high for this strategy.

11.2.6 Manage Sediment – Not Recommended

This strategy has a low effectiveness-to-cost ratio and so is not recommended for further reach-wide study.

11.3 Recommendations

The trends of significance to river maintenance currently observed in this reach are:

- Vegetation encroachment
- Increased bank height
- Bank erosion

- Incision or bed degradation
- Bed material coarsening

This reach has been one of the most active in terms of channel changes for the last couple of decades, and two levee setback projects have been implemented. The Channel Instability Reach Characteristic is rated as medium instability for the future because there is more space for the channel to adjust; and, based on the modeling, the rate of change is decreasing. The Infrastructure, Public Health, and Safety Reach Characteristic is rated as medium importance because most of the reach is agricultural. The Water Delivery Impact Reach Characteristic is rated as high importance because there are no diversions into MRGCD's system in this reach. The SWFL Habitat Value and Need Reach Characteristic is rated as low importance, but the RGSM Habitat Value and Need Reach Characteristic importance is rated as high importance. Leakage through the dam provides a permanent water source, and fish tend to congregate below the dam. Fish passage would only increase habitat value as a corridor.

Promote Elevation Stability, Promote Alignment Stability, Increase Available Area to the River, and Rehabilitate Channel and Flood Plain should be further analyzed, but reservations on each are noted. Promote Elevation Stability has a higher River Maintenance Function Subevaluation Factor effectiveness-to-cost ratio, but is rated lower for both Ecosystem Function and Engineering Effectiveness Evaluation Factors. Promote Alignment Stability has a very high effectiveness-to-cost ratio for the Engineering Effectiveness Evaluation Factor but a much lower score for the Ecosystem Function Evaluation Factor. At this time, Increase Available Area to the River has the highest effectiveness-to-cost ratio, but this may change with more information on the cost of conservation easements or land purchase. Rehabilitate Channel and Flood Plain has high scores for both the Ecosystem Function Evaluation Factor and the River Maintenance Function Subevaluation Factor, but the strategy ranks low for the overall Engineering Effectiveness Evaluation Factor.

Manage Sediment has a low effectiveness-to-cost ratio compared to the other suitable strategies and, therefore, should not be considered in further analyses.

12. Arroyo de las Cañas to San Antonio Bridge (RM 95 to RM 87.1)

12.1 Reach Characteristics

This reach is about 8 miles long with a riverbed slope of approximately 0.0008[1] (4.3 feet per mile) and an average channel width of 320 feet. Major tributaries (all ephemeral) in the reach are: Arroyo de las Cañas (RM 95), Brown Arroyo (RM 94) and "Bosquecito" Arroyo (RM 87). The LFCC is the low point in the valley in this reach, and the Rio Grande is perched above the flood plain, particularly at the downstream end of the reach. Water is pumped from the LFCC to the river as needed during the summer months to maintain flow in the river. The pump station location in this reach is near Neil Cupp (RM 90).

The channel in this reach has been historically stable in bed elevation, but recently channel filling has been documented, especially at the lower end. Significant channel narrowing due to vegetation growth has occurred in the wider sections since the turn of the 21st century, with additional bank line bar and island attachment between 2005–2009. It appears that an alternating bar/thalweg pattern may be developing, opening the door to possible future bank erosion. This reach has a predominantly sand bed channel.

12.1.1 Channel Instability Reach Characteristic – Medium Instability

Recent channel aggradation extending upstream of the lower end of reach has been documented. This reach has more variability in widths than captured in the model cross sections (variability was minimized to help model convergence) that could affect sediment transport and deposition volumes. The rest of the factors for the Channel Instability Reach Characteristic fell into the medium range.

12.1.2 Water Delivery Impact Reach Characteristic – High Importance

This reach is rated high because river waters flow into Elephant Butte Reservoir without any diversions. San Acacia Diversion Dam is the terminal river diversion location for MRGCD. There are no major diversions from the Rio Grande below San Acacia Diversion Dam. Additional diversions from the LFCC into the MRGCD system occur in this reach. The LFCC is the low point in the valley in this reach. The net seepage loss to ground water in this reach is less than 0.5 cfs per mile at 500-cfs river flows (SSPA 2008).

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[1] The slope is calculated from the reduced number of cross sections in the Plan and Guide model.

12.1.3 Infrastructure, Public Health, and Safety Reach Characteristic – Medium Importance

This reach contains irrigated agricultural croplands with sparse distribution of homes, barns, and other agricultural buildings. One bridge is located near San Antonio. The LFCC and the levee, maintained by Reclamation, are parallel to the river in this reach. The LFCC is an important structure since the LFCC intercepts most of the river channel seepage losses, receives irrigation return flows, and delivers about a quarter of the total inflow to Elephant Butte Reservoir (San Acacia Workshop 2009).

12.1.4 Habitat Value and Need Reach Characteristic

12.1.4.1 Southwestern Willow Flycatcher – Low Importance

Even though this reach is included in the critical habitat designation, no SWFL pairing or nesting has occurred during the past 14 years of surveying.

12.1.4.2 Rio Grande Silvery Minnow – High Importance

This reach is of high priority for RGSM due to the high population densities within this area. Habitat improvement work may be needed in this reach to maintain channel connectivity and wetted habitats throughout the year because of the likelihood of drying.

12.2 Strategy Assessment Results

Two strategies are potentially suitable for this reach:

- Reconstruct and Maintain Channel Capacity
- Manage Sediment

These strategies could address the recent channel filling and reduction in hydraulic capacity.

The short discussions below summarize the strategy assessment results.[1] Figures 12.1–12.3 present the indexed scores of effectiveness divided by cost for the suitable strategies. More detailed assessment information, including weighted scores for each strategy, is presented in Appendix C: Strategy Assessment.

[1] Effects that are the same for a particular strategy and not affected by reach characteristics are summarized in chapter 4 of the main report and discussed in more detail in Appendix C, Section 1.7, Engineering Effectiveness Evaluation Factor; Section 1.8, Ecosystem Function Evaluation Factor; and Section 1.9, Economics Evaluation Factor.

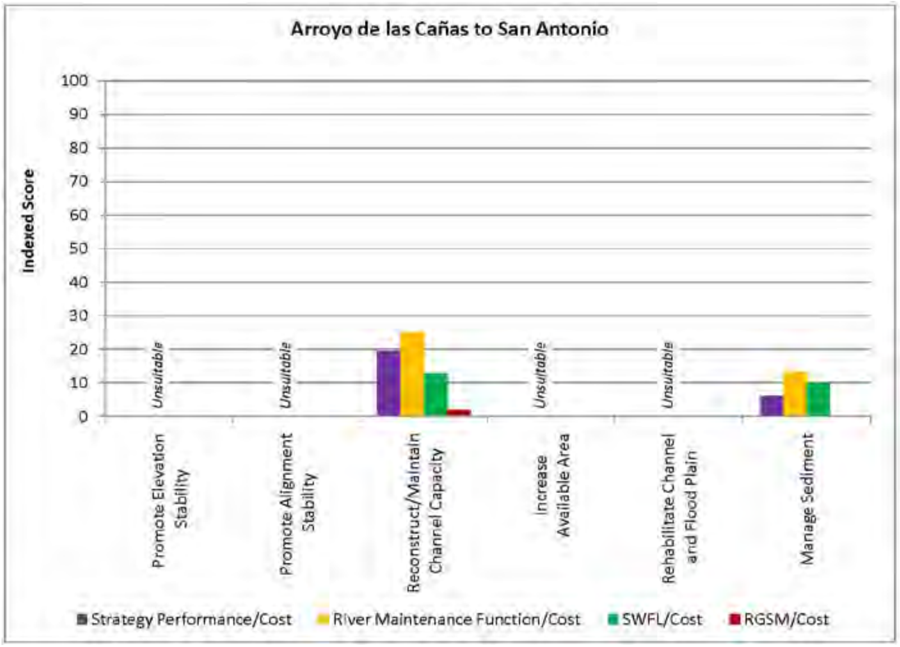

Figure 12.1. Arroyo de las Cañas to San Antonio Bridge Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

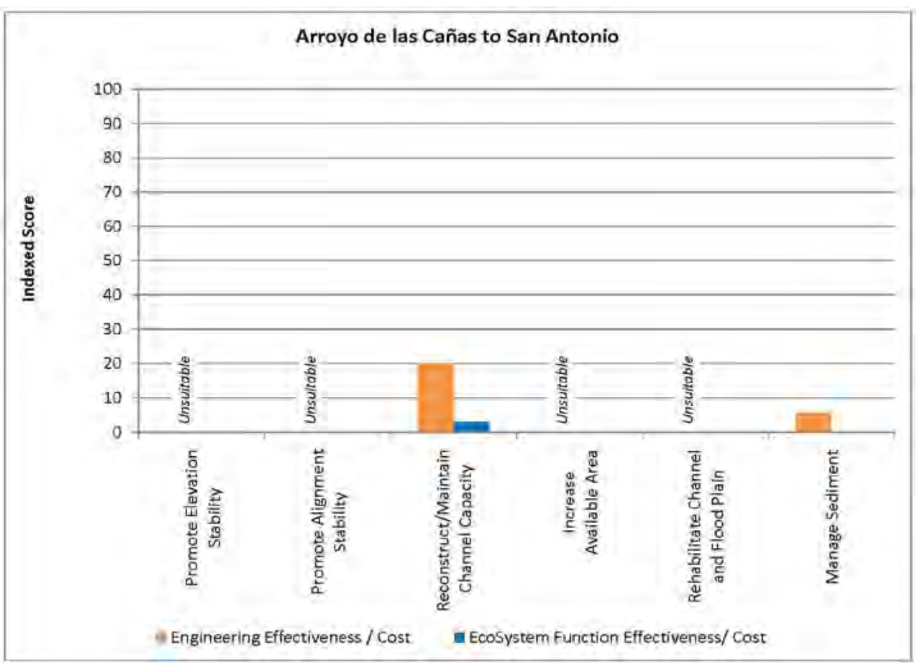

Figure 12.2. Arroyo de las Cañas to San Antonio Bridge Reach effectiveness divided by cost indexed scoring results by evaluation factor.

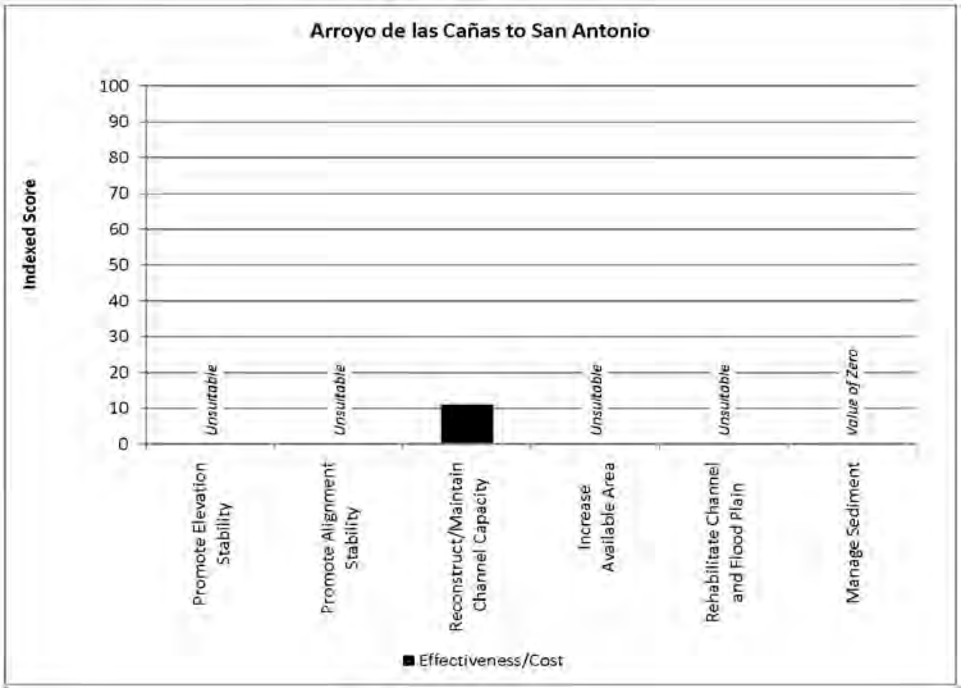

Figure 12.3. Arroyo de las Cañas to San Antonio Bridge Reach total effectiveness divided by cost indexed scoring results.

12.2.1 Promote Elevation Stability – Not Analyzed

Grade control, gradient restoration facilities, and rock sills are applicable for reaches where the channel is degrading. Modeling results show aggradation; therefore, this strategy was not analyzed because aggradation is addressed through other complementary strategies (see table C1.4 in appendix C for more information).

12.2.2 Promote Alignment Stability – Not Suitable

Historical trends and modeling results do not show a tendency toward lateral migration; therefore, this strategy is not suitable for this reach. However, local bank stabilization may be needed (e.g., after the 2005 spring runoff bank erosion was noted upstream of Arroyo Cañas).

12.2.3 Reconstruct and Maintain Channel Capacity

- **Geomorphic Effects**

  This strategy would simply re-create the existing channel, so the geomorphic effects would be small. This reach has been aggrading, which could result in a need to reestablish channel capacity.

- **Engineering Effectiveness Evaluation Factor**

  This could be an important strategy for this reach because modeling results show high rates of aggradation in the future. However, duration and design life is relatively short; and frequent maintenance is required. Continued aggradation makes the levee increasingly vulnerable to overtopping. Continued levee raising increases the level of potential damage to the riverside infrastructure.

- **Ecosystem Function Evaluation Factor**

  Overall, this strategy would not change SWFL habitat significantly from existing conditions. If management activities are taken that allow aggradation, benefits to SWFL habitat would occur. If the channel were altered to maintain capacity, overbank flooding likely will decrease, reducing the availability of flood plain habitat to RGSM.

- **Economics Evaluation Factor**

  The Planning and Design and Environmental Compliance Attributes are rated high because this reach is biologically significant for the RGSM. The Implementation Cost Attribute is rated medium because of the number and types of methods applicable to this reach.

12.2.4 Increase Available Area to the River – Not Suitable

Historical trends and modeling results do not show a tendency toward lateral migration; therefore, this strategy is not suitable for this reach. Should continued aggradation result in a significantly perched channel, this rating may change to create space for possible channel relocation.

12.2.5 Rehabilitate Channel and Flood Plain – Not Suitable

Modeling results show aggradation; therefore, this strategy is not suitable for this reach.

12.2.6 Manage Sediment

- **Geomorphic Effects**

  A closer balance between sediment supply and transport capacity would tend to maintain the channel in current configuration.

- **Engineering Effectiveness Evaluation Factor**

  Given the high volume of sediment removal predicted by the model, the Ability to Implement Attribute is rated low. In addition, with the high volume of sediment and the limited use of settling basins on river channels, the Level of Confidence and Duration and Design Life Attributes are medium.

- **Ecosystem Function Evaluation Factor**

  This strategy would not change SWFL habitat significantly from existing conditions. Managing sediment by removal would be negative for RGSM because it would reduce habitat complexity.

- **Economics Evaluation Factor**

  The Implementation Cost Attribute is rated high due to the volume of sediment needing to be removed as estimated by the sediment model (Varyu et al. 2011).

12.3 Recommendations

The trends of significance to river maintenance currently observed in this reach but which appear to be declining in effects are:

- Channel narrowing
- Vegetation encroachment

Recent arroyo reconnections and aggradation extending upstream of the San Antonio Bridge to RM 78 Reach contribute to these trends:

- Aggradation (developing trend)
- Perched channel (potential trend)
- Channel plugging (potential trend)

This reach has been historically stable. Both recent observations and modeling show aggradation; however, there is uncertainty about the amount. The rest of the rating factors for the Channel Instability Reach Characteristic falls in the medium range, so this reach is rated as medium instability overall for the Channel Instability Reach Characteristic. The importance of the Water Delivery Impact Reach Characteristic is rated high because there are no diversions from the river into the MRGCD irrigation system. The reach is mostly agricultural lands, so the importance of the Infrastructure, Public Health, and Safety Reach Characteristic is medium. Although the habitat appears to be good for SWFL, rarely have resident SWFLs been documented in this reach, and no pairing or nesting has occurred during the past 14 years of surveying. Therefore, this reach is rated as low importance for the SWFL Habitat Value and Need Reach Characteristic. This is an important reach for RGSM and, thus, has high importance ratings for the RGSM Habitat Value and Need Reach Characteristic.

None of the strategies identified for this reach have a high effectiveness-to-cost ratio due to high costs, but Reconstruct and Maintain Channel Capacity and Manage Sediment are recommended for further investigation. Currently, LFCC is the low point in the valley in this reach, and continued aggradation could create a perched condition within the floodway in this reach. More study is needed to better predict the rate and amount of aggradation and evaluate the idea of channel realignment. Promote Elevation Stability, Promote Alignment Stability, Increase Available Area to the River, and Rehabilitate Channel and Flood Plain are currently not suitable for this reach. Due to the potential for continued channel aggradation, strategies may need adaptive management after implementation.

13. San Antonio Bridge to River Mile 78 (RM 87.1 to RM 78)

13.1 Reach Characteristics

This reach is about 9 miles long with a riverbed slope of approximately 0.00069[1] (3.6 feet per mile) and an average channel width of 230 feet. Water is pumped from the LFCC to the river as needed during the summer months to maintain flow in the river. The pump station is located near the north boundary of the Bosque Del Apache National Wildlife Refuge (BDANWR) (RM 84). Habitat restoration in the BDANWR channel area includes vegetation clearing and native planting and bank/bar destabilization.

This reach has been gradually aggrading since the 1930s, with a recent increase in the rate of aggradation. The channel is perched above the edges of the flood plain defined by the mesa and LFCC Levee—in some sections by several feet. The LFCC is generally the valley thalweg. However, there are isolated locations on the east side of the river with lower elevation than the LFCC bottom. Bank heights are low, and the flood plain, along with recently formed islands, is flood prone at relatively low flows. During the 2008 spring runoff, a sediment plug formed in the main channel of the river, just downstream from RM 81. After the runoff, a pilot channel, approximately 25 feet wide, was excavated through the plug, and excavated spoil material was placed on the west side of the channel to form a spoil berm. The river widened the pilot channel excavation fairly quickly. The lower end of this reach appears currently to be the approximate transition point between an aggradational bed upstream and a degradational bed downstream. The degradation is moving gradually upstream and is a result of the lowered level of the Elephant Butte Reservoir since the late 1990s.

In the last few years, the reach has responded to the recent drought with a significant reduction in channel width because of vegetation encroachment. This is likely a result of several years of relatively low peak flows during the spring runoff, possibly combined with higher cohesiveness in the banks material in these areas. Mid-channel bars isolated from the low flows also are becoming vegetated. During the 2005 runoff recession, many of the side channels filled in, became vegetated, and are now attaching the islands to the banks. High flows since 2005 were not able to erode these features; in fact, the main channel rapidly decreased in width and now flows around these stable features, similar to conditions seen

[1] The slope is calculated from the reduced number of cross sections in the Plan and Guide model.

near Belen. There are, however, isolated bends between RM 78 and RM 83 that continue to migrate. These appear to be following the M series of the planform stages,[1] generally in M5 (Sinuous thalweg channel)/M6 (Migrating bend channel) with a M7 (Migrating with cutoff channel) bend just downstream from the plug at RM 81. Most of the rest of the reach is in Planform Stages 3 (Main channel with side channels) to A5 (Aggrading plugged channel) and would be moving to A6 (Aggrading avulsed channel) without maintenance.

13.1.1 Channel Instability Reach Characteristic – High Instability

The perched nature of the channel and predicted aggradation are the main reasons that the Channel Instability Reach Characteristic is rated high for this reach. The 2008 plug illustrates the strong potential for channel avulsion.

13.1.2 Water Delivery Impact Reach Characteristic – High Importance

This reach is rated high for the importance of the water delivery impact because river waters flow into Elephant Butte Reservoir without any diversions.
San Acacia Diversion Dam is the terminal river diversion location for MRGCD. There are no major diversions from the Rio Grande below San Acacia Diversion Dam. Additional diversions from the LFCC into the Bosque Del Apache National Wildlife Refuge occur in this reach. The net seepage loss to ground water in this reach is less than 0.5 cfs per mile at 500-cfs river flows (SSPA 2008).

13.1.3 Infrastructure, Public Health, and Safety Reach Characteristic – Medium Importance

This reach has irrigated agricultural cropland and sparse distribution of homes, barns, and other agricultural buildings. The bridge at San Antonio and the Bosque del Apache National Wildlife Refuge are located in this reach. The LFCC and LFCC Levee (constructed and maintained by Reclamation) run parallel to the river in this reach. The LFCC intercepts most of the river channel seepage losses, receives irrigation return flows, and delivers about a quarter of the total inflow to Elephant Butte Reservoir (San Acacia Reach Workshop 2009).

13.1.4 Habitat Value and Need Reach Characteristic

13.1.4.1 Southwestern Willow Flycatcher – High Importance

During the 2010 breeding season, 35 SWFL territories were documented in this reach, and newly developed habitat has become occupied. This population, given its high nest success rates and rapid increase in numbers, is a very important population and could act as a source for colonization of incoming habitat.

[1] See appendix C, section C1.4.1.3, for a description of the Middle Rio Grande Planform Evolution Model. Also refer to the Unique Terms section located at the end of this document.

13.1.4.2 Rio Grande Silvery Minnow – High Importance

As there are high population densities within this area and a likelihood of drying, habitat actions to maintain channel connectivity and wetted habitats throughout the year would be a high priority.

13.2 Strategy Assessment Results

Three strategies are potentially suitable for this reach:

- Reconstruct and Maintain Channel Capacity
- Increase Available Area to the River
- Manage Sediment

Most of this reach is actively aggrading. Reconstruct and Maintain Channel Capacity and Manage Sediment would be effective in minimizing the aggradation through removing sediment aggradation in the channel. Increase Available Area to the River would allow space for the channel to avulse to a lower elevation and deposit sediment as occurred historically.

The short discussions below summarize the strategy assessment results.[1] Figures 13.1–13.3 present the indexed scores of effectiveness divided by cost for the suitable strategies. More detailed assessment information, including weighted scores for each strategy, is presented in Appendix C: Strategy Assessment.

13.2.1 Promote Elevation Stability – Not Analyzed

Historical trends do not show a recent tendency toward bed erosion over the entire reach; therefore, this strategy was not analyzed because aggradation is addressed through other complementary strategies (see table C1.4 in appendix C for more information).

13.2.2 Promote Alignment Stability – Not Suitable

Historical trends do not show a recent tendency toward lateral migration; therefore, this strategy is not suitable for this reach. However, the perched channel condition for most of the reach means there is a distinct possibility of avulsion. If the channel moves near the levee, bank stabilization of the new alignment may be required.

[1] Effects that are the same for a particular strategy and not affected by reach characteristics are summarized in chapter 4 of the main report and discussed in more detail in Appendix C, Section 1.7, Engineering Effectiveness Evaluation Factor; Section 1.8, Ecosystem Function Evaluation Factor; and Section 1.9, Economics Evaluation Factor.

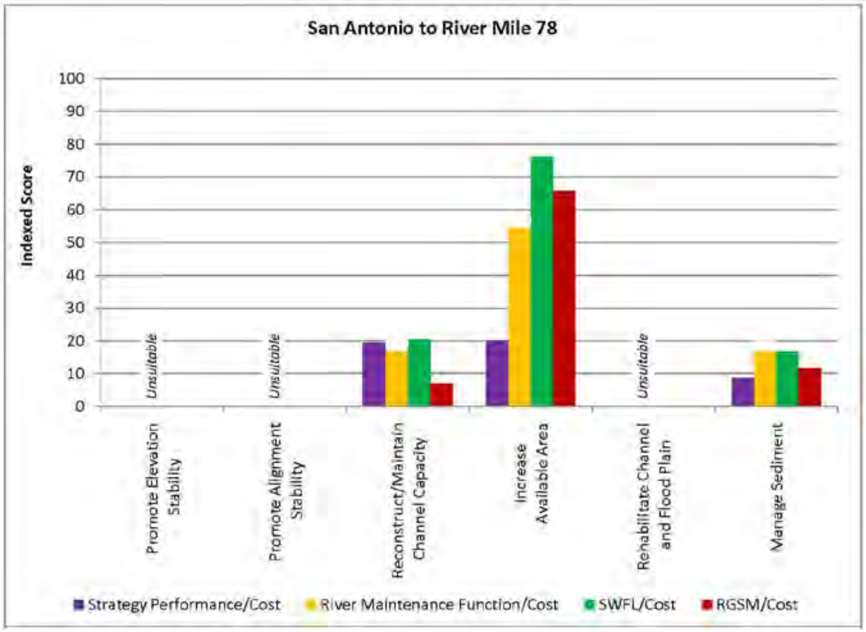

Figure 13.1. San Antonio Bridge to River Mile 78 Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

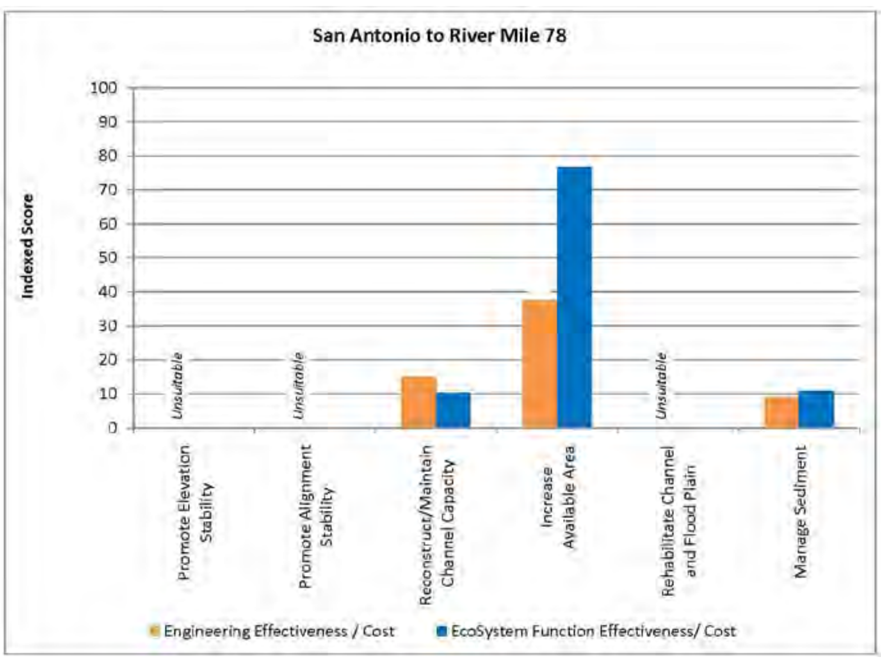

Figure 13.2. San Antonio Bridge to River Mile 78 Reach effectiveness divided by cost indexed scoring results by evaluation factor.

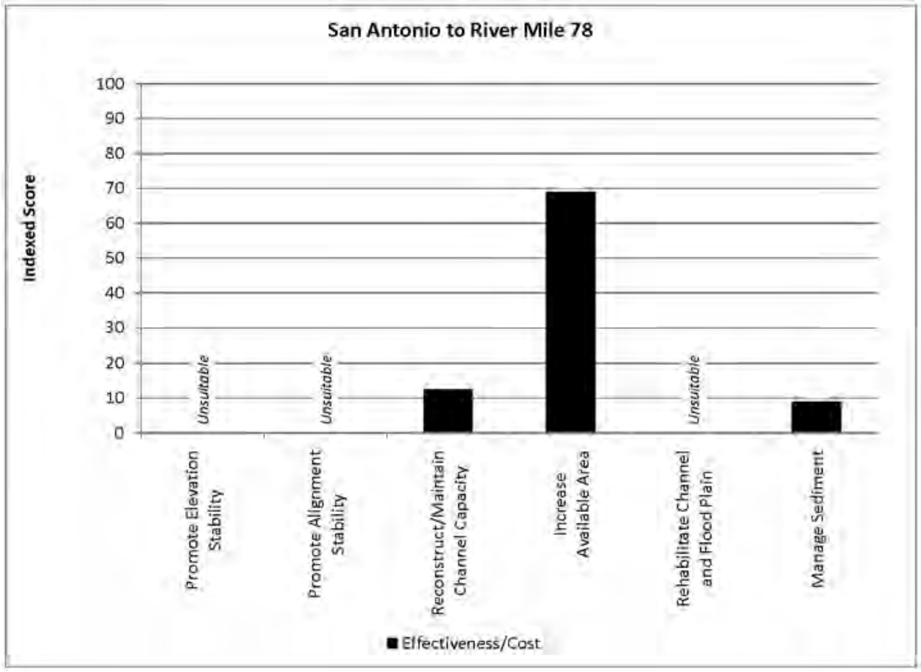

Figure 13.3 San Antonio Bridge to River Mile 78 Reach total effectiveness divided by cost indexed scoring results.

13.2.3 Reconstruct and Maintain Channel Capacity

- **Geomorphic Effects**

  Reconstructing the previous channel in the current alignment decreases the opportunity for channel and flood plain adjustments. This strategy does not appear to be a long-term solution for this reach and likely would have to be repeated.

- **Engineering Effectiveness Evaluation Factor**

  This strategy is important if the current channel alignment is to be maintained because of the large amount of sediment accumulation with accompanying loss of channel capacity. Maintaining channel capacity allows peak flows to safely pass through the reach without damaging riverside infrastructure. The channel plugging with sediment over 10s of miles would likely increase evaporation and seepage losses and negatively affect water delivery. These methods have mobile features, which promote dynamic equilibrium for a limited time. This strategy, however, is not a long-term solution; and, given the long-term aggradational trend of the river, continuing to raise the levees increases the risk of levee failure and associated damage to riverside infrastructure and land use.

- **Ecosystem Function Evaluation Factor**

  SWFL impacts will depend on site locations and will need site assessments. RGSM habitat complexity may decrease, again depending on location.

- **Economics Evaluation Factor**

  The Planning and Design Attribute is rated high because the river response is uncertain, implementation is often conducted in the river channel, and this reach is biologically significant for the RGSM. The Implementation Cost Attribute is rated medium because of the number and types of methods applicable to this reach. Maintenance requirements likely are to be high.

13.2.4 Increase Available Area to the River

- **Geomorphic Effects**

  In this reach, setting the levees back would allow the channel to avulse to the low elevation along the existing levee without eroding the toe over the long term. In the long term, it is expected that the balance between sediment load and transport capacity would become closer and that flood plain connectivity would increase because the channel has more space to adjust its morphology. How long it would take to form a competent channel in the new alignment and what measures would best encourage that formation need to be researched.

- **Engineering Effectiveness Evaluation Factor**

  Because there are opportunities to add sediment storage area in an aggrading reach, this strategy should be considered for future implementation.

- **Ecosystem Function Evaluation Factor**

  This strategy would be beneficial to SWFL habitat by allowing the river to aggrade and potentially move into a larger flood plain. There is little tendency for river meandering in this reach, so there would be no change to RGSM habitat unless the river avulsed. For that case, until a competent channel is formed, there may be a temporary increase in RGSM stranding

- **Economics Evaluation Factor**

  The meander belt width falls within the infrastructure constraints, resulting in a low rating for the Implementation Cost Attribute. However, should the river avulse to the west and the levee fail, there would be potentially significant costly damage to the LFCC and levee infrastructure. Moving the river to the west, likewise, would involve potentially significant expenses to move these infrastructures or reinforce them, but the costs are likely to be lower with a controlled implementation.

13.2.5 Rehabilitate Channel and Flood Plain – Not Suitable

Historical trends show a long-term trend of aggradation; therefore, this strategy is not suitable for this reach. Local implementation of terrace lowering could help address the degradation in the lower end of the reach.

13.2.6 Manage Sediment

- **Geomorphic Effects**

  Long term, this reach has an excess of sediment load, so reducing sediment should bring the sediment load and transport capacity more into balance and help maintain the channel morphology. However, it would not increase flood plain connectivity in the currently degraded locations.

- **Engineering Effectiveness Evaluation Factor**

  Given the volume of sediment needing to be removed from this reach estimated by the SRH 1-D model, the ability to implement is rated low. The relatively large amount of sediment to be removed would have a large impact upon the channel.

- **Ecosystem Function Evaluation Factor**

  Impacts would be site-specific for SWFL, but removing plugs and decreasing aggradation would negatively impact existing and developing SWFL habitat. Removing sediment would create low habitat complexity and be a negative effect on RGSM.

- **Economics Evaluation Factor**

  The Implementation Cost Attribute is rated medium, even though the sediment volume is high, because removing sediment costs less than other strategies.

13.3 Recommendations

Under historically more frequent conditions, there is an excess of sediment supply as compared to transport capacity and long-term trends of:

- Aggradation
- Channel plugging with sediment
- Perched channel

The formation of sediment plugs has been observed to cause the following local trends of significance to river maintenance downstream from the plug within this reach. These trends tend to return to preplug conditions once a direct connection, like a pilot channel, is made between the upstream and downstream river sections.

- Increased bank height
- Incision or channel bed degradation
- Bank erosion
- Minor coarsening of bed material

Changes in the upstream sediment supply or the Elephant Butte Reservoir level may affect the ability to return to preplug conditions.

Two trends currently observed that may or may not reverse when water and sediment loads increase and the reservoir pool rises are:

- Channel narrowing
- Vegetation encroachment

This reach is rated of high instability for the Channel Instability Reach Characteristic due to its perched nature, high sediment load, and responses to fluctuations in Elephant Butte Reservoir pool elevation. The importance of the Water Delivery Impact Reach Characteristic is rated high because there are no diversions from the river into the MRGCD irrigation system and river waters flow directly into Elephant Butte Reservoir. The majority of land use is agricultural; thus, the rating for the importance of the Infrastructure, Public Health, and Safety Reach Characteristic is medium. Riparian habitat within this reach, for the most part, has been unsuitable for breeding SWFLs, with the exception of two new patches adjacent to the 2008 sediment plug at RM 81 that is rated medium for the SWFL Habitat Value and Need Reach Characteristic. Because of the high RGSM population densities within this reach and the likelihood of drying, there is a high importance rating for the RGSM Habitat Value and Need Reach Characteristic.

Because of the perched nature of this reach and the high effectiveness-to-cost ratio of Increase Available Area to the River, continued study of this strategy is recommended, even though the calculated meander belt fits within the constraints. The recent sediment plug and general channel filling mean that Reconstruct and Maintain Channel Capacity will continue to be needed in this reach. A new channel alignment should be considered as part of this strategy in this reach due to the perched nature of the current alignment. Manage Sediment should be investigated further because planned deposition basins to reduce sediment load could provide new habitat and extend the life of Elephant Butte Reservoir.

Suggestions have been advanced for the need of Promote Elevation Stability in the downstream end of the reach. These techniques likely are to be difficult to successfully implement over the long term in a historically aggrading and perched section and should be thoroughly evaluated before any local implementation. Due to the long-term trend of channel aggradation with periods of degradation, adaptive management will improve the ability of strategies to properly function. Downstream effects, such as significant changes in base level control, are also suitable for adaptive management.

14. River Mile 78 to Elephant Butte Reservoir (RM 78 to RM 46)

14.1 Reach Characteristics

This reach is about 32 miles long with a riverbed slope of approximately 0.00063[1] (3.3 feet per mile) and an average channel width of 130 feet. The location of the downstream end of the reach (and its slope) varies greatly according to the reservoir pool elevation. The full pool elevation of the reservoir is 4,407 feet using the local Elephant Butte Dam project datum, which is elevation 4,452.5 in the NAVD 88 datum. At full pool, the water surface intersects the current riverbed thalweg at approximately RM 64. When the pool is lower, Reclamation generally maintains the channel down to about RM 46, and the New Mexico Interstate Stream Commission maintains the rest of the channel downstream. The upper portion of the reach has no arroyos with direct inflow to the river. The lower portion of the reach does have several drainages, which can contribute significant flows during local thunderstorms, including: Milligan Gulch (RM 63), Quates Canyon (RM 61), Silver Canyon (RM 54.5), and Nogal Canyon (RM 52). The Rio Grande is perched, and the LFCC is the low point in the valley through most of this reach, except downstream from the Ft. Craig Bridge. Water is pumped from the LFCC to the river as needed during the summer months to maintain flow in the river. The pump station locations are at the south boundary of the BDANWR (RM 74) and near Ft. Craig (RM 64). The LFCC reconnects with the Middle Rio Grande at RM 54.7. Levees confine the floodway to about the eastern third of the valley above the reconnection (RM 60), and the access road that continues downstream also creates a degree of confinement.

Extensive long-term aggradation and rapid short-term degradation are the most defining characteristics of this reach. The base level lowering effects of the low pool elevation of Elephant Butte Reservoir this past decade have significantly contributed to the current degradation, but historical trends show that the reach most likely will return to aggradation. Much of the reach has been channelized through cohesive material and remains narrow.

Several bends with active lateral migration have set up near RM 78, RM 64, and RM 60. There have been several small breaches in the temporary channel near RM 47, and the main flow appears to be running along the western edge of the flood plain near the mesa. The channel falls into

[1] The slope is calculated from the reduced number of cross sections in the Plan and Guide model.

Planform Stages M5(Sinuous thalweg channel) to M7 (Migrating with cutoff channel)[1] through most of the reach, but there have been plugs at various locations over time.

Model results show that the stable slope is flatter than the existing slope and predict aggradation downstream and degradation upstream. These results depend on the reservoir pool staying below the Narrows, and aggradation is expected to begin when the reservoir pool begins to fill up. The meander belt generally does fit within the constraints. However, there is not much space between the meander belt and the constraints in this upstream subreach. Downstream, the unused space between the geologic constraints is quite large.

14.1.1 Channel Instability Reach Characteristic – High Instability

This reach is strongly influenced by the pool elevation of Elephant Butte Reservoir. In the past, the reservoir's water surface level has risen fairly rapidly when the drought periods ended; and this is expected to happen again. Additionally, climate change scenarios (Gangopadhyay and Pruitt 2011) show runoff below the median for this area; therefore, historical trends may not be directly applicable.

14.1.2 Water Delivery Impact Reach Characteristic – High Importance

This reach is rated high because waters flow into Elephant Butte Reservoir without any diversions. During periods of channel aggradation, seepage from the river channel into the LFCC is significant because the flood plain elevation is higher than the LFCC. Recent channel degradation has reduced the Rio Grande floodway bed elevation relative to the LFCC. It is likely that the seepage losses from the river to ground water have decreased, while the LFCC continues to convey flow in the downstream direction. However, this reach is aggradational over the long term, which has the potential for long-term high seepage loss rates.

14.1.3 Infrastructure, Public Health, and Safety Reach Characteristic – Low Importance

Most of the lands in this reach are public lands or the Armendaris Ranch in the Elephant Butte Reservoir reservation boundary. Bosque del Apache National Wildlife Refuge, the San Marcial Railroad Bridge, the LFCC, and levees are the notable infrastructure in this reach. The LFCC delivers about a quarter of the total valley flow to Elephant Butte Reservoir (San Acacia Workshop 2009).

[1] See appendix C, section C1.4.1.3, for a description of the Middle Rio Grande Planform Evolution Model. Also refer to the Unique Terms section located at the end of this document.

14.1.4 Habitat Value and Need Reach Characteristic

Reclamation biologists classified this reach as biologically significant for both SWFL and RGSM.

14.1.5 Southwestern Willow Flycatcher – High Importance

This reach contains the largest breeding population of SWFLs within the subspecies' range and is an important stronghold for the subspecies. Very little of the high quality habitat in this reach is associated with the river itself because of severe degradation of the channel, particularly in the downstream portion of the reach. The current high quality habitat will be lost when the reservoir pool rises and inundates it.

14.1.5.1 Rio Grande Silvery Minnow – Medium Importance

Seasonally, RGSM are abundant in this reach (Dudley and Platania 2011 and Reclamation data). Generally, RGSM in this reach are considered to be lost to the reservoir pool. Habitat projects that contribute to channel complexity in this reach would aid in decreasing the number of eggs and larvae that drift into the reservoir.

14.2 Strategy Assessment Results

Three strategies are potentially suitable for this reach due to the wide range of possible geomorphology responses and high instability of this reach:

- Reconstruct and Maintain Channel Capacity
- Increase Available Area to the River
- Manage Sediment

It should be noted that there is a high degree of uncertainty of the sustainability of any of the strategies. Methods from Promote Elevation Stability, Promote Alignment Stability, and Rehabilitate Channel and Flood Plain may be considered for local implementation in this reach if the pool of Elephant Butte remains very low.

The short discussions below summarize the strategy assessment results.[1] Figures 14.1–14.3 present the indexed scores of effectiveness divided by cost for the suitable strategies. More detailed assessment information, including weighted scores for each strategy, is presented in Appendix C: Strategy Assessment.

[1] Effects that are the same for a particular strategy and not affected by reach characteristics are summarized in chapter 4 of the main report and discussed in more detail in Appendix C, Section 1.7, Engineering Effectiveness Evaluation Factor; Section 1.8, Ecosystem Function Evaluation Factor; and Section 1.9, Economics Evaluation Factor.

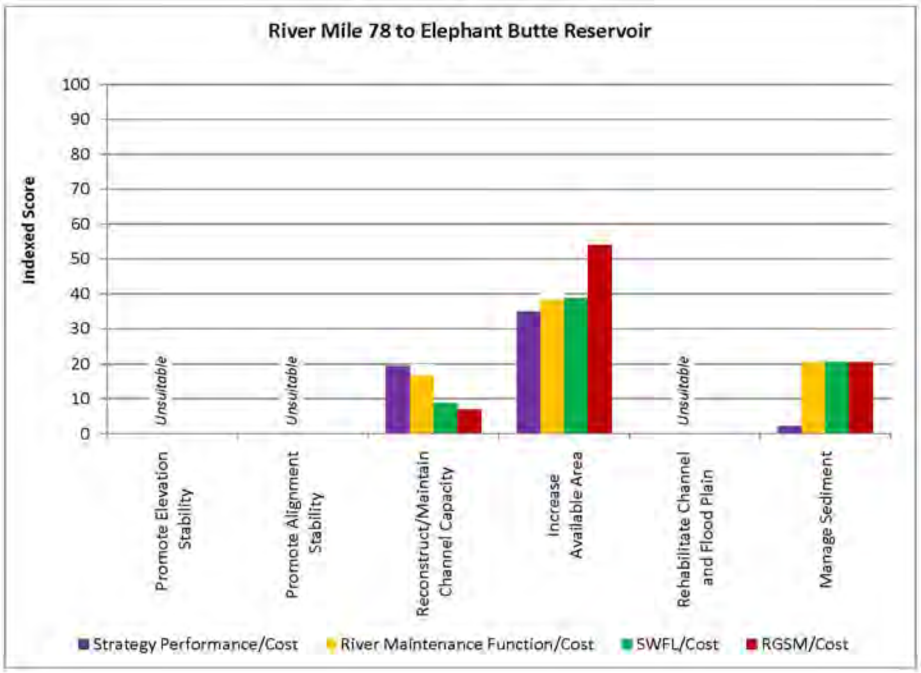

Figure 14.1. River Mile 78 to Elephant Butte Reservoir Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

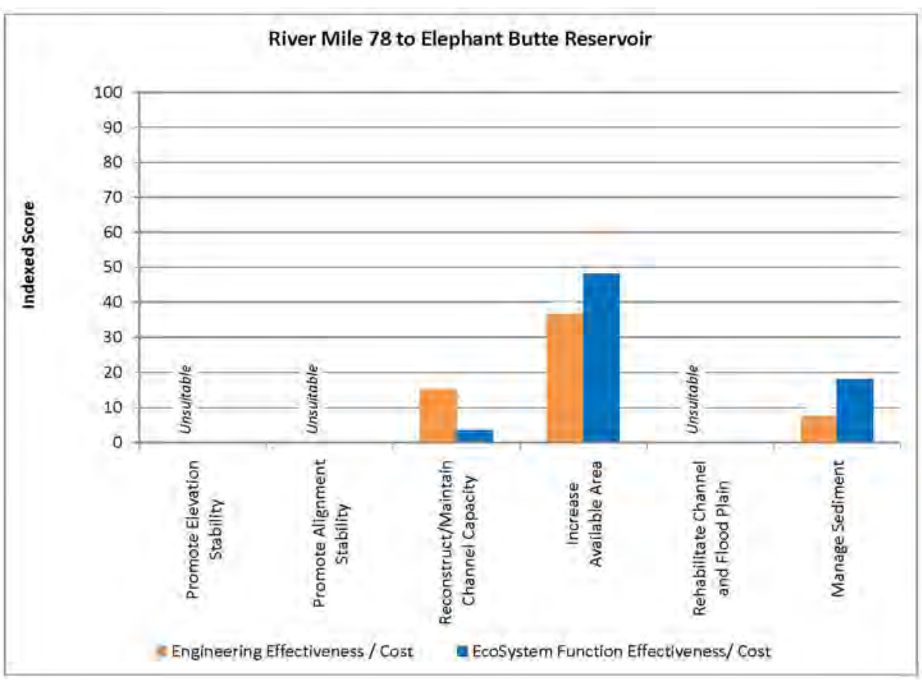

Figure 14.2. River Mile 78 to Elephant Butte Reservoir Reach effectiveness divided by cost indexed scoring results by evaluation

factor.

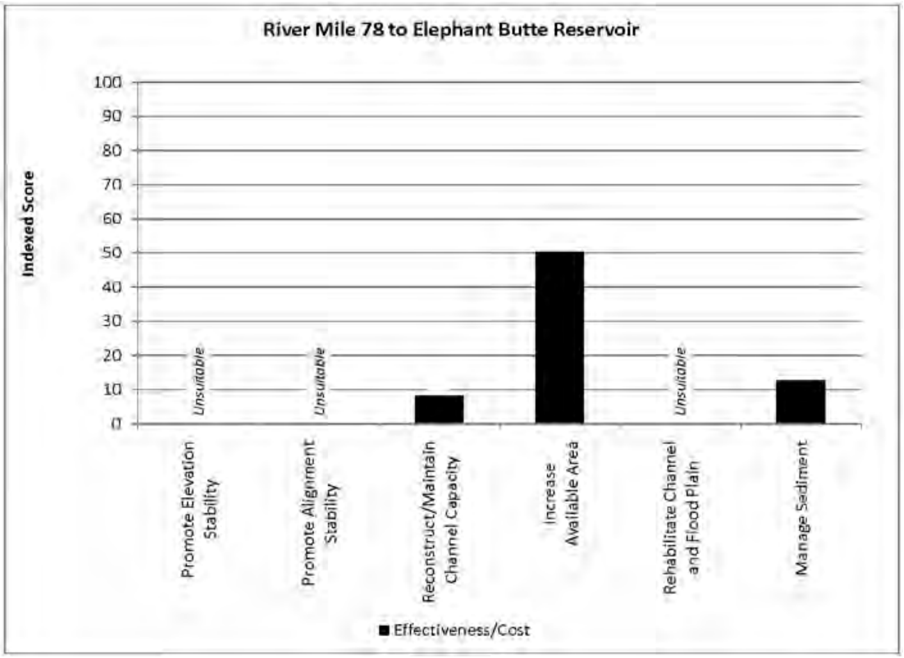

Figure 14.3. River Mile 78 to Elephant Butte Reservoir Reach total effectiveness divided by cost indexed scoring result.

14.2.1 Promote Elevation Stability – Not Analyzed

Over the long term, this reach has been aggrading with periods of degradation. Placing grade control structures in a reach with these long-term conditions can be problematic; therefore, this strategy was not analyzed because aggradation is addressed through other complementary strategies (see table C1.4 in appendix C for more information).

14.2.2 Promote Alignment Stability – Not Suitable

This strategy is not effective due to the high likelihood that the bank protection measures would be inundated with sediment in the long term. Bank stabilization installations might be used effectively in the upper part of the reach where aggradation amounts are lower or for sites like the Fort Craig bend where the channel is actively migrating into the pump site and LFCC.

14.2.3 Reconstruct and Maintain Channel Capacity

- **Geomorphic Effects**

  There should be little change to the geomorphology, because this strategy is to re-create the existing channel under aggrading conditions.

- **Engineering Effectiveness Evaluation Factor**

Reconstruct and Maintain Channel Capacity is important due to the long-term aggrading tendency of this reach. While this strategy works to increase sediment transport capacity, a single action probably will not completely achieve this objective. Regular maintenance generally is needed.

- **Ecosystem Function Evaluation Factor**

  Removing sediment to reduce aggradation and preventing overbank flooding would be a detriment to SWFL and RGSM habitat.

- **Economics Evaluation Factor**

  Few features are included in this strategy, but the Planning and Design and the Environmental Compliance Attributes are rated high because of uncertain river responses and the biological significance of the reach.

14.2.4 Increase Available Area to the River

- **Geomorphic Effects**

  The major constrictions in this reach are the Tiffany Levee, the LFCC Levee (also known as the San Marcial Levee), and the San Marcial Railroad Bridge. Less than 10 percent of the calculated meander belt does not fit within the constraints that occurs in this area. Much of the rest of the reach is in the Elephant Butte Reservoir pool reserve, which generally has only the geologic constraints of the mesas. It appears that only the area near the Tiffany Levee and San Marcial Railroad Bridge would need to be modified to make this strategy work (figure 14.4).

- **Engineering Effectiveness Evaluation Factor**

  The LFCC and levees confine about 10 miles of this reach (downstream from the San Marcial Railroad Bridge) to less than a third of the valley width. While analysis results indicate that the calculated meander belt lies within the lateral constraints, this reach should receive special consideration for activating this large, disconnected flood plain. This strategy would promote dynamic equilibrium as much as possible in a long-term aggrading reach.

- **Ecosystem Function Evaluation Factor**

  This strategy would be generally positive for SWFL but needs to be accompanied by sediment management that promotes aggradation in the severely degraded downstream portion of this reach. Opportunity for optimal RGSM habitat and channel complexity would increase.

Figure 14.4. Area near San Marcial Railroad Bridge and Tiffany Levee.

- **Economics Evaluation Factor**

  The Implementation Cost Attribute is rated low because the calculated meander belt width fits within the lateral constraints. However, in view of the comments under the Engineering Effectiveness Evaluation Factor for this strategy, this reach should receive special consideration for this strategy. If infrastructure were relocated, the cost likely would be high because of the LFCC and LFCC Levee. However, future maintenance costs would be very low.

14.2.5 Rehabilitate Channel and Flood Plain – Not Suitable

Historical trends show a long-term trend of aggradation; therefore, this strategy is not suitable for this reach.

14.2.6 Manage Sediment

- **Geomorphic Effects**

  Theoretically, this strategy could result in balancing the sediment load and transport capacity of the reach and reduce the rate of capacity loss in Elephant Butte Reservoir when aggradation returns. A study of climate change effects may be needed to determine how long a sediment management strategy would provide benefits.

- **Engineering Effectiveness Evaluation Factor**

  Based upon model results, this strategy would be sediment augmentation while the reservoir is low. However, adding sediment to a reach that has long-term aggradation and is immediately upstream of a reservoir would not be advisable. Thus, this strategy in the form of sediment augmentation to the delta of Elephant Butte Reservoir does not apply, but sediment removal should be considered.

- **Ecosystem Function Evaluation Factor**

  Sediment management, consisting of augmentation, could improve SWFL and RGSM habitat in downstream portions of this reach. But settling basins to remove sediment would have the opposite effect without very careful implementation. This strategy is very site-specific and is confounded by the model assumption that Elephant Butte Reservoir will remain low. Removing sediment would create low habitat complexity and be a negative effect on RGSM.

- **Economics Evaluation Factor**

  The Implementation Cost Attribute is rated low because the amount of sediment calculated by the sediment model to bring the reach into sediment balance is small. However, adding sediment to the delta of a reservoir is not advisable. Implementation costs for removing sediment have not been estimated.

14.3 Recommendations

This reach is strongly influenced by the pool elevation of Elephant Butte Reservoir. Under the current water and sediment loads, the pool is quite low and not expected to rise far in the near term. This base level lowering has led to the following current trends that are anticipated to be temporary:

- Increased bank height
- Incision or channel bed degradation
- Bank erosion
- Coarsening of bed material

Two trends currently observed that may or may not reverse when water and sediment loads increase and the pool begins to fill are:

- Channel narrowing
- Vegetation encroachment

Under historically more frequent conditions, there is an excess of sediment supply as compared to transport capacity and long-term trends of:

- Aggradation
- Channel plugging with sediment
- Perched channel

This reach is rated of high instability for the Channel Instability Reach Characteristic and of high importance of the Water Delivery Impact Reach Characteristic due to the significant effect that the pool elevation of Elephant Butte Reservoir exerts on the channel morphology, the proximity of the LFCC and Tiffany Levees, and the location of the San Marcial Railroad Bridge. Because river waters flow into Elephant Butte Reservoir without diversion, the importance of the Water Delivery Impact Reach Characteristic in this reach is rated high. Most lands in this reach are public land or part of the Armendaris Ranch, and the importance of the Infrastructure, Public Health, and Safety Reach Characteristic is rated low. This reach contains the largest breeding population of SWFLs within the subspecies' range and is an important stronghold. Therefore, the importance of the SWFL Habitat Value and Need Reach Characteristic is rated high. RGSM population losses to the reservoir pool could be reduced with more complex habitat in this reach; therefore, the rating for importance of the RGSM Habitat Value and Need Reach Characteristic is medium.

Reconstruct and Maintain Channel Capacity, Increase Available Area to the River, and Manage Sediment had high effectiveness to cost ratios. Manage Sediment has a high effectiveness-to-cost ratio only because a relatively small amount of sediment augmentation is calculated by the model to bring the reach into sediment balance during this period where the pool of Elephant Butte is low. However, as stated above, it is not advisable to add sediment to a reservoir delta. Thus, this strategy in the form of sediment augmentation to the delta of Elephant Butte Reservoir does not apply, but sediment removal should be considered when conditions change.

The high ratings for multiple reach characteristics, the changing hydrology, and fluctuations in the pool elevation of Elephant Butte Reservoir mean it is difficult to select a single long-term, reach-wide maintenance strategy. The reach will need to be adaptively managed as it responds to the changing conditions. It is recommended that a wide range of possible conditions be further investigated, and the reach may need to be subdivided for better analysis.

15. Elephant Butte Dam to Caballo Reservoir (RM 26.6 to RM 12)

15.1 Reach Characteristics

The Elephant Butte to Caballo Reach is approximately 15 miles long with a riverbed slope of approximately 0.0006 (3.2 feet per mile) and an average channel width of 150 feet. The reach has the following major tributaries: Cuchillo Negro Arroyo, Mescal Arroyo, Arroyo Hondo, and Palomas Arroyo. The amount of sediment that can be conveyed by these tributaries is quite large; for example, during the 2006 monsoon season, the Mescal Arroyo and the Cuchillo-Negro Arroyo brought in enough sediment to block the Rio Grande.

As an apparent result of the low sediment supply downstream from Elephant Butte Dam and the sediment excavation when the arroyos block the channel, the channel appears to be slightly incised. The bank line is stable throughout the reach, and only some of the banks are lined with riprap. The planform of this reach is predominately a single channel with an alternating thalweg. There are isolated instances of point bars and split channels.

Reclamation constructs a temporary dike across the river (located at RM 21.4) during the winter (when flow is shut off) to raise the stage in the river, which reduces ground water flow into the river and increases the temperature of the ground water for the bath houses. Sediment accumulates from tributary arroyos, and Reclamation annually excavates sediment deposits to restore the 5,000-cfs channel capacity.

15.1.1 Channel Instability Reach Characteristic – Medium Instability

The degree of potential channel change is hard to estimate because modeling was not performed in this reach. Historical trends indicate that few slope and planform changes are expected, but the volume of sediment deposited in the reach by tributaries and the tight fit of the channel within the lateral constraints make the Channel Instability Reach Characteristic rating medium.

15.1.2 Water Delivery Impact Reach Characteristic – Medium Importance

This reach has no documented loss rates and no water diversions for irrigation or other uses. The rating is medium in this reach because the river is the corridor to deliver water for diversions south of Caballo Reservoir such as the Elephant Butte Irrigation District, city of El Paso, Texas, etc.

15.1.3 Infrastructure, Public Health, and Safety Reach Characteristic – High Importance

The population of the city of Truth or Consequences is below the 10,000-population threshold for a high rating, However, urban development lies along the river in this reach, and there are homes, roads, and other infrastructure along the west bank of the river in this reach. One bridge is located within the reach. Elephant Butte Dam is the upper reach boundary. Caballo Reservoir stores water during the nonirrigation season while power is being produced at Elephant Butte Dam.

15.1.4 Habitat Value and Need Reach Characteristic

15.1.4.1 Southwestern Willow Flycatcher – Low Importance

Although bird surveys have not been conducted, the lack of suitable SWFL habitat is obvious.

15.1.4.2 Rio Grande Silvery Minnow – Low Importance

RGSM are native to this reach but have not been collected since before 1950. The quality of habitat for native fish in this reach is variable and determined by the flows from Elephant Butte Dam. Water temperatures for much of the reach are colder than optimal for RGSM. The reach is shorter than what would be optimal for RGSM to complete their life cycle without drifting into Caballo Reservoir. A 1987 survey found eight of the expected eighteen native fish present in the reach (Propst et al. 1987). Most fish were nonnative. There is a small recreational fishery seasonally supported below the dam for trout, walleye, and catfish. Priority for other native fish is also low.

15.2 Strategy Assessment Results

Three strategies are potentially suitable for this reach:

- Promote Alignment Stability
- Reconstruct and Maintain Channel Capacity
- Manage Sediment

Each could help address the alignment and capacity concerns of the reach.

The short discussions below summarize the strategy assessment results.[1] Figures 15.1–15.3 present the indexed scores of effectiveness divided by cost for the suitable strategies. More detailed assessment information, including weighted scores for each strategy, is presented in Appendix C: Strategy Assessment.

15.2.1 Promote Elevation Stability – Not Suitable

Historical trends do not show a recent tendency toward bed erosion, and there is a low potential for new degradation; therefore, this strategy is not suitable for this reach.

15.2.2 Promote Alignment Stability

- **Geomorphic Effects**

  Reclamation places riprap bank protection for property developed before 1985 in the cities of Truth or Consequences and Williamsburg. This strategy would continue the trend of preventing bank erosion using riprap to protect homes and other infrastructure along the river.

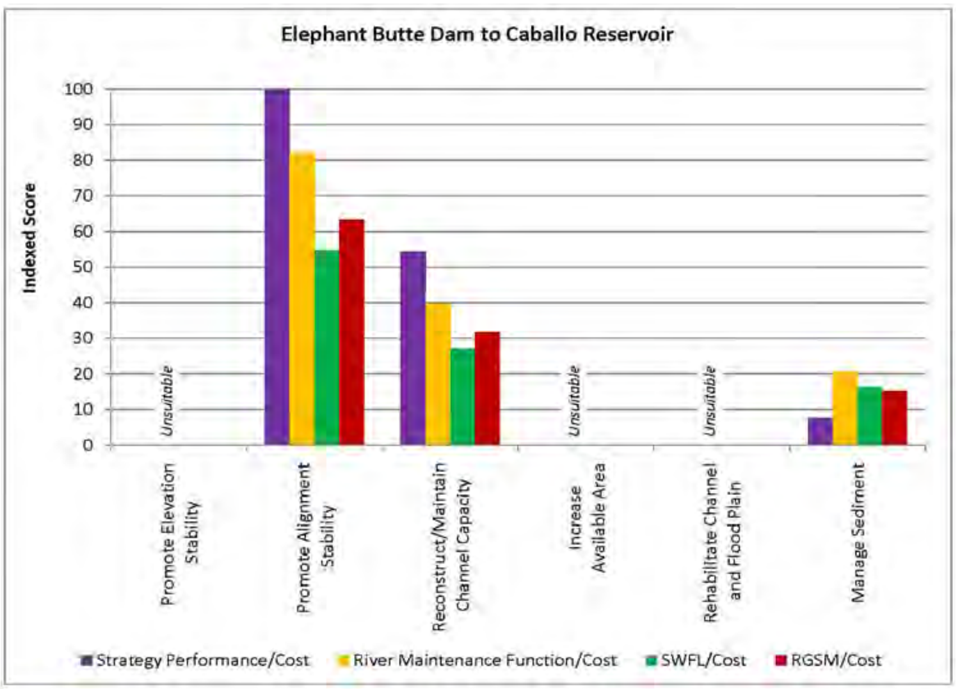

Figure 15.1. Elephant Butte Dam to Caballo Reservoir Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

[1] Effects that are the same for a particular strategy and not affected by reach characteristics are summarized in chapter 4 of the main report and discussed in more detail in Appendix C, Section 1.7, Engineering Effectiveness Evaluation Factor; Section 1.8, Ecosystem Function Evaluation Factor; and Section 1.9, Economics Evaluation Factor.

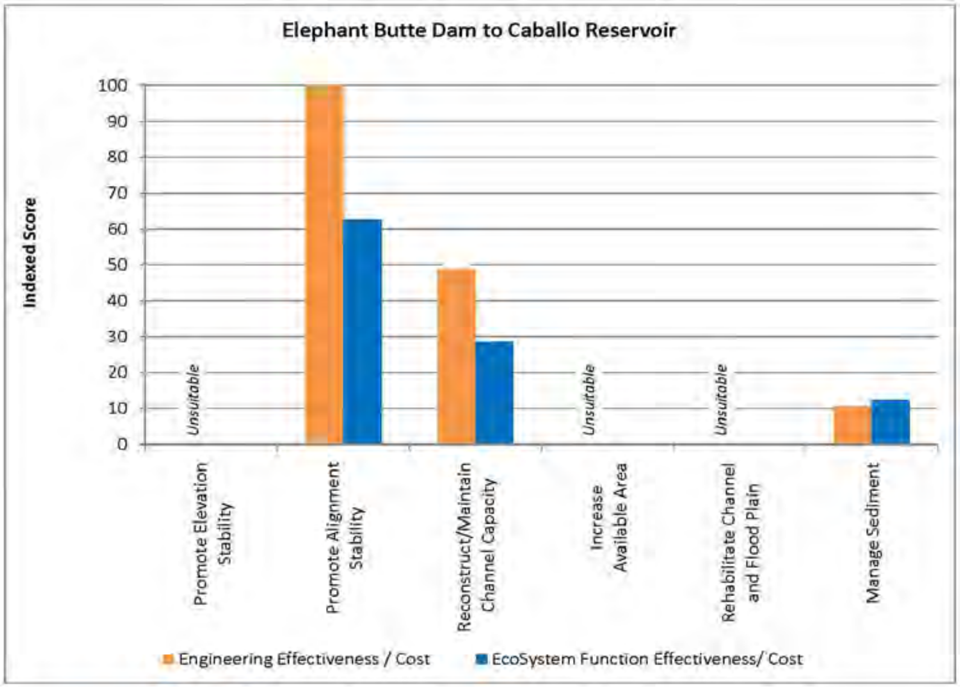

Figure 15.2. Elephant Butte Dam to Caballo Reservoir Reach effectiveness divided by cost indexed scoring results by evaluation factor.

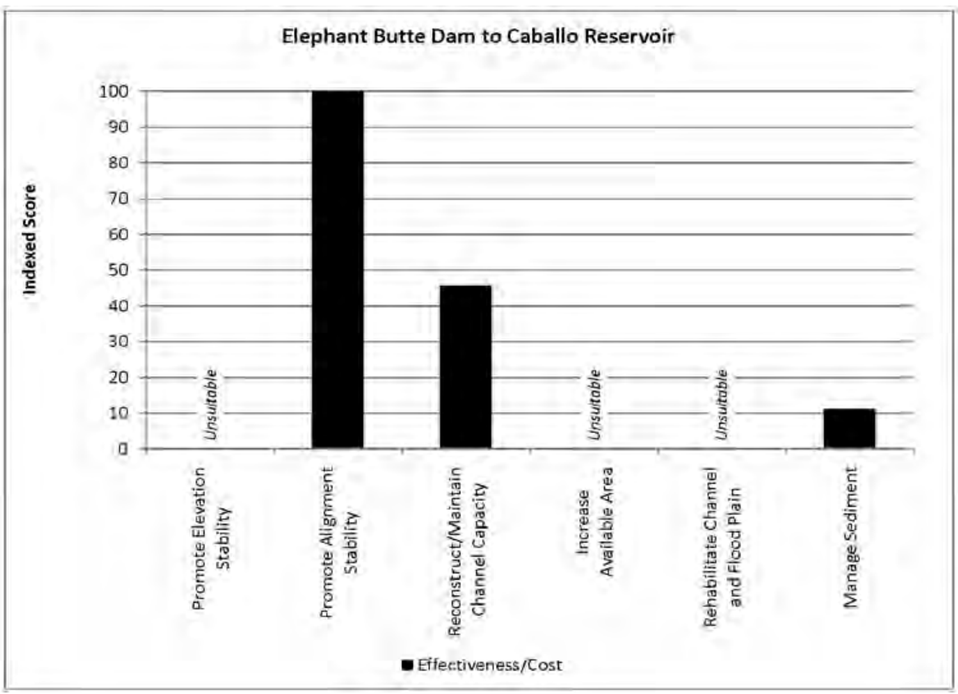

Figure 15.3. Elephant Butte Dam to Caballo Reservoir Reach total effectiveness divided by cost indexed scoring results.

- **Engineering Effectiveness Evaluation Factor**

  The Ability to Implement Attribute is rated high because access and obtaining land instruments are relatively straightforward.

- **Ecosystem Function Evaluation Factor**

  While this strategy would reduce SWFL habitat stability, suitable habitat is already lacking. Habitat is currently poor for native fish species, and this strategy would not change this.

- **Economics Evaluation Factor**

  The Planning and Design Attribute is rated low because landowners have a high interest in bank stability, and Reclamation has extensive experience with the methods used by this strategy.

15.2.3 Reconstruct and Maintain Channel Capacity

- **Geomorphic Effects**

  Several of the tributary arroyos can deposit large amounts of sediment in the channel locally. These sediment deposits have been removed as needed to maintain channel capacity, and this need is expected to continue.

- **Engineering Effectiveness Evaluation Factor**

  The hydraulic capacity can be severely reduced after tributary flow events; however, this strategy effectively maintains channel capacity. Thus, the Hydraulic Capacity Attribute is rated as no change. The Ability to Implement Attribute's high rating is due to landowner and public and resource management agency acceptance of the need for the work. This strategy effectively maintains channel capacity.

- **Ecosystem Function Evaluation Factor**

  The potential for overbank flooding would be reduced, which would be a detriment to any developing or existing SWFL habitat. Habitat is currently poor for native fish species, and this strategy would not change this.

- **Economics Evaluation Factor**

  The Planning and Design Attribute is rated low because the design channel geometry is restored by sediment removal. Sediments can be removed from the channel during periods when there are no flow releases from the reservoir, making environmental compliance relatively straightforward; thus, the Environmental Compliance Attribute is rated low. The Implementation Cost Attribute is rated low because sediment removal is fairly localized.

15.2.4 Increase Available Area to the River – Not Suitable

Urban development makes this strategy not suitable for this reach.

15.2.5 Rehabilitate Channel and Flood Plain – Not Suitable

Urban development makes this strategy not suitable for this reach.

15.2.6 Manage Sediment – Not Recommended

This strategy had a low effectiveness-to-cost ratio; therefore, it is not recommended for further study.

15.3 Recommendations

This reach is strongly influenced by historical channelization work and the presence of multiple ephemeral tributaries with the potential to bring in significant water and sediment in a short timeframe. This has led to the following trends being observed in this reach.

- Bank erosion
- Channel plugging with sediment—as it relates to channel filling from tributary sediment

This reach is rated of low instability for the Channel Instability Reach Characteristic and of low importance for both the SWFL and RGSM Habitat Value and Need Reach Characteristics. The Water Delivery Impact Reach Characteristic is rated medium. The importance of the Infrastructure, Public Health, and Safety Reach Characteristic is rated high due to the close proximity to the riverbank to residential and commercial development.

The effectiveness-to-cost ratio for Manage Sediment is small, and this strategy would not be carried forward for further consideration in future analyses of this reach. Both Promote Alignment Stability and Reconstruct and Maintain Channel Capacity should be investigated further for this reach.

16. Summary and Recommendations

16.1 Plan and Guide Summary

The Plan and Guide is a comprehensive re-evaluation of the River Maintenance Program as a whole and defined a new framework to assess the channel and flood plain on a reach basis through a series of steps.

The Plan and Guide does not select a strategy for implementation, nor does it identify specific locations or methods for future maintenance work. It uses existing data and new analysis results to rate strategies by the Engineering Effectiveness, Ecosystem Function, and Economics Evaluation Factors. The report does not consider water operations as a maintenance strategy because this is outside the scope of the River Maintenance Program authorization. The report uses the most consistent level of data and analysis available across the major divisions of the entire study reach and, thus, may not use the most detailed information in a reach. More detailed information will be used in the next steps of reach prioritization, reach strategy feasibility assessments, project design and implementation, and additional system-wide assessments.

Step 1 included assessing and redefining river maintenance goals[1] to reflect the evolution of practices of river engineering and management and the changing river conditions within the context of the Middle Rio Grande Project authorization (see section 3.2). The updated goals are:

- Support Channel Sustainability
- Protect Riverside Infrastructure and Resources
- Be Ecosystem Compatible
- Provide Effective Water Delivery

Step 2 consisted of two components. The first component examined the available information to define a set of geomorphic trends of importance to river maintenance and analyzed the reaches based on the observed trends (for a further discussion, see appendix C, section C1.2: Current Geomorphic Trends). These trends are:

- Channel narrowing
- Vegetation encroachment
- Incision or channel bed degradation

[1] Please see the inside of the back cover for definitions of unique terms.

- Increased bank height
- Bank erosion
- Coarsening of bed material
- Aggradation
- Channel plugging with sediment
- Perched[1] channel conditions

An imbalance between sediment transport capacity and supply is the fundamental cause of channel and flood plain adjustments that generate these trends. Changes in this balance are caused by changes in the drivers of flow and sediment supply magnitude, duration, and frequency. System controls that influence the effects of the drivers include bank and bed stability, downstream base level, flood plain lateral confinement, and flood plain connectivity. For each trend, the inter-relationship with sediment transport capacity and sediment supply were characterized for each trend in each reach, and the underlying drivers and controls were identified to complete this component.

In step 2's second component, holistic reach scale strategies were formulated to address these trends. These strategies are:

- Promote Elevation Stability (see section 3.3.1)
- Promote Alignment Stability (see section 3.3.2)
- Reconstruct and Maintain Channel Capacity (see section 3.3.3)
- Increase Available Area to the River (see section 3.3.4)
- Rehabilitate Channel and Flood Plain (see section 3.3.5)
- Manage Sediment (see section 3.3.6)

These reach strategies are intended to help integrate more completely the physical processes occurring on the Middle Rio Grande with river maintenance activities. Each of the strategies above has different methods for its implementation, geomorphic responses, effects upon the balance between sediment supply and transport capacity and effectiveness in meeting River Maintenance Program goals. For each reach, multiple constraints that include water delivery, protection of riverside infrastructure, local variations in geology, and endangered species habitat provide additional criteria for strategy considerations.

Step 3 modeled, analyzed, and developed the expected future condition of each reach. Indicators were defined to assess changes in reach conditions due to strategy implementation. Where data were available, several types of analyses

[1] Perched conditions are when the river channel is higher than adjoining riparian areas in the floodway or land outside the levee.

were performed, as documented in appendix B. Sediment modeling to determine long-term reach equilibrium conditions for channel slope adjustment (i.e., vertical or lateral) plus hydraulic modeling and meander belt analysis generated the indicator results that are used in the reach strategy evaluation.

Step 4 defined the reach characteristics identified as critical to Reclamation's Middle Rio Grande Project mission—to help describe existing conditions and to determine the significance of a reach and the suitability of a strategy to address reach trends within Reclamation's mission. These reach characteristics are:

- Channel Instability Reach Characteristic (rated in terms of instability, see section 4.4.1)
- Water Delivery Impact Reach Characteristic (rated in terms of importance, see section 4.4.2)
- Infrastructure, Public Health, and Safety Reach Characteristic (rated in terms of importance, see section 4.4.3)
- Habitat Value and Need Reach Characteristic (rated in terms of importance, see section 4.4.4)

Several types of information were used for each reach characteristic to develop a rating of high, medium, or low. The ratings are comparative between each of the reaches. Thus, a rating of "low" indicates that a reach characteristic may be less of a consideration when addressing maintenance needs in that reach than in other reaches.

Step 5 estimated the geomorphic effects of strategy implementation based on indicator modeling results, implementation method category effects, historical trends, geomorphic outcomes, and professional (scientific and engineering) judgment. Effects are discussed as reach-wide changes from baseline (existing) conditions. See section 4.6 for a discussion of geomorphic effects by strategy and appendix C, section C1.6, for a detailed discussion.

Step 6 developed and scored evaluation factors for the suitable strategies. The three evaluation factors used in this analysis are:

- Engineering Effectiveness Evaluation Factor (see section 4.7.1)
- Ecosystem Function Evaluation Factor (see section 4.7.2)
- Economics Evaluation Factor (in terms of implementation costs only) (see section 4.7.3)

Attributes for the evaluation factors above were defined to focus the assessment on the principal components of each. These attributes were rated using indicator modeling results, historical trends, geomorphic outcomes, and professional (scientific and engineering) judgment. The rated attributes then were combined into a scoring table for each evaluation factor. The Engineering Effectiveness attributes are grouped into two categories: Strategy Performance and River Maintenance Function. The Ecosystem Function Evaluation Factor attributes are grouped by two representative species: SWFL for riparian and RGSM for aquatic considerations. The scoring results from the Engineering Effectiveness and Ecosystem Function Evaluation Factors for each strategy in each reach are termed "effectiveness scores."

The Economics Evaluation Factor involved cost criteria derived from a multiday workshop to develop appraisal level unit costs per river mile to estimate strategy implementation costs. Other attributes of the Economics Evaluation Factor depend on professional judgment for their ratings. The effectiveness scores for Engineering Effectiveness and Ecosystem Function Evaluation Factors were divided by the Economics Evaluation Factor (cost score) to provide information on which strategies should be more economical, provide better maintenance performance and function, reduce negative environmental effects, and/or have increased environmental benefits, resulting in greater overall effectiveness than current practices.

Step 7 used the strategy assessment results and reach characteristics to recommend strategies for further study, which will help guide future maintenance decisions. These decisions will involve selecting the highest priority reaches for future reach feasibility analysis and potential application of reach-wide strategies. These results are discussed by reach in chapters 5–15.

An extensive literature review of methods (including state-of-the-art practices) that can be used to implement strategies was performed and is discussed in appendix A. Appendix A includes descriptions of the general range of application, method objectives and benefits, features, common modes and failures, common countermeasures if needed, advantages, disadvantages, geomorphic response, ecological benefits and effects, requirements, level of reliability, potential construction issues, design criteria, peak flow criteria, durability, and project life.

16.2 Recommended Next Steps

16.2.1 Introduction

In this report, the evaluation has been at the appraisal level, using existing information and limited quantification. Strategies have been recommended to move forward to feasibility-level evaluation for each of the 11 Plan and Guide reaches. The information in the Part 1 Report and this report should be used to prioritize reaches and begin feasibility analysis of the recommended strategies.

Future actions to implement this plan include:

- Information needs assessment
- Reach prioritization
- Reach strategy feasibility assessments
- Start project design and implementation work
- System-wide analyses

These steps are not necessarily sequential, and more work is needed to align and integrate current program activities and the eventual long-term implementation considerations of this plan.

Continued priority site project planning, geomorphic analysis, design, environmental compliance, and implementation work continues as part of daily program accomplishment. The reach feasibility assessments should be conducted and integrated into the River Maintenance Program work as pragmatically as possible with current capabilities and appropriations. Consideration also should be given for future demonstration projects prior to reach scale implementation. These demonstration projects could be applied in more stable reaches before application in more dynamic reaches. Careful work planning will be needed to integrate the reach-based implementation plan approach with the current priority site maintenance work accomplishment.

External stakeholder and resource management agency understanding of this plan is a key ingredient for long-term success. Developing an effective communication plan and conducting workshops to present the Plan and Guide and to receive and discuss comments will aid in developing stakeholder understanding. As much as is practical, comments and feedback from stakeholders should be incorporated into future strategy analysis and river maintenance planning.

16.2.2 Information Needs

The information needs identified in this section will assist Plan and Guide effectiveness over the long term. Satisfying all information needs is not a requirement before beginning other recommended actions.

During the development of the new assessment framework, information needs or gaps were observed in:

- Field data
- Current understanding of drivers/processes/trends
- Response and application of methods
- Management of resources

Identified information gaps are listed below to serve as a guide for future resource management decisions and data collection and analyses efforts. Other AAO divisions and stakeholders may be a source of the additional information developed to meet the identified needs.

16.2.2.1 Field Data

- **Sediment information**
  - Identify and reduce uncertainties associated with field data used in current sediment transport modeling for more accurate results.
  - Analyze differences in sediment volumes calculated from collected U.S. Geological Survey (USGS) gauge sediment load information versus aggradation/degradation volumetric studies.
  - Develop a better understanding of sediment continuity or the balance between transport capacity and load both within a reach and between reaches.
  - Develop a better understanding of sediment contribution from tributaries and other sources.
- **Habitat information**
  - Develop specifics on habitat needs for endangered species including paired data collection of geomorphic and instream/flood plain hydraulic parameters (hydrographic data collection) at the same time as presence and absence surveys.
  - Correlate alluvial ground water well elevation data with surface water and riverbed elevation data (stage levels).
- **Water budget information**
  - Determine the effects on water continuity during plug occurrence relating to the length of the plug and duration in place.
- **Topography information**
  - Develop better topography data in channel and overbank (extent and accuracy); widen the aggradation/degradation data outside the levees.

16.2.2.2 Current Understanding of Drivers/Processes/Trends

- **Geomorphic/river response information**
  - Evaluate further channel evolution modeling in reaches for better quantification of the hydraulic geometry by corresponding stage.

- Develop a better understanding on how sediment contribution from tributaries and other sources affects the geomorphology.

- Provide more detailed two- and three-dimensional modeling within local areas where complex water and sediment flow structure and channel adjustments/responses are not well understood.

- Develop a better understanding of how changes in the watershed (fires and subsequent debris flows, salt cedar mortality resulting from control efforts) affect channel morphology.

- Develop a better understanding of the process linkages related to bank and bed stability; vegetation growth and its senescence; and other influences on geomorphology, hydraulics, sediment continuity, competent channel formation, and delta sedimentation issues below San Antonio. The intricacies of these relationships could be explored through a combination of physical and numerical modeling and field investigations.

- **Hydraulic/hydrologic questions**
  - Determine if sustainable widths can be maintained, given the current sediment and flow regime on the Middle Rio Grande. A sustainable width is a premise that involves sediment and discharge considerations (e.g., effective discharge, dominant, channel forming discharges, and is tied into bank and bed stability).

  - Develop a better understanding of how climate change will affect the watershed contributions of flow and sediment (frequency and amount of precipitation, land cover changes, etc.).

- **Habitat questions**
  - Develop a better understanding of how new habitat is created and habitat succession is supported.

  - Determine how habitat needs (e.g., vegetation succession) interact with the concept of sustainable widths.

  - Develop a better understanding of how changes in the watershed (fires and subsequent debris flows, salt cedar mortality from biologic control practices) affect habitat.

16.2.2.3 Response and Application of Methods

- **Application of methods**
  - Continue work on methods to provide better performance at the design event condition and over the long-term design life in a fluvial system.

This would include physical and numerical modeling and field evaluations to help reduce uncertainties in the design.

- Develop river maintenance and restoration design guidelines for Middle Rio Grande conditions.

- **Response of methods**
    - Document monitoring/performance information on methods.
    - Understand eddy and nursery habitat that may develop from transverse features such as bendway weirs. This could include physical and numerical modeling, in addition to field sampling analyses at installations.
    - Understand the effect of large, woody debris on the channel morphology and habitat.
    - Understand flood plain and main channel interactions in terms of bank erosion and the potential to use overbank lowering in lieu of other bank protection methods.
    - Understand the morphological response to various river maintenance practices (local and longer reach response) and the response variability in different reaches.

16.2.2.4 Management of Resources

- **Data collection/information gathering**
    - Investigate the needed frequency of data collection (aggradation/degradation, hydrographic, aerial photography). Create data collection plans, manuals, and documentation of the data's purpose and need, up-to-date practices, and adequacy for design and modeling work.
    - Assess the various procedures available to measure or estimate sediment load according to the dominant mode of sediment transport and channel characteristics. This would involve maintaining and potentially expanding capabilities with practices for river design and modeling data collection and analysis work (acoustic, optics, physical measurements, time sequence bathymetric surveys, sonar, and total load estimates).
    - Bring all the data together—internal and external—to make it easier to assess what we have and what is still needed.

- **Budgetary tools**
    - Update the River Maintenance Program cost authority (ies) system to be consistent with the work breakdown structure for all phases of the river maintenance work activities (cradle to grave).

- **Hydrologic predictions**
    - Investigate historical water budgets by reaches on a volume basis (annual or 10-year) using Upper Rio Grande Water Operations Model.
    - (URGWOM) modeling, diversion records, inflow/outflow records, etc. Need both a percentage breakdown of the water mass balance and better quantification.
    - Use existing frameworks (URGWOM modeling) to generate a daily basis of inflows and outflows for future projections to use in hydraulic modeling for design and analysis work.

16.2.3 Reach Prioritization

Information developed in the Part 1 Report (Reclamation 2007) and this report can be used to develop and apply a decisionmaking framework to prioritize reaches for feasibility analysis. Such a decision framework will need to be developed to evaluate several factors. Selection considerations would include the Channel Instability, Water Delivery Impact; Infrastructure and Public Health and Safety, and Habitat Value and Need Reach Characteristics.

Reach effectiveness-to-cost ratio, the number and size of priority sites in each reach, channel capacity, risk to riverside infrastructure, endangered species, stakeholder interests, and any AAO management priority interests that may arise in the future also would be consideration factors.

A reach’s geomorphic stage and evolution trajectory of change also should be considered. Some reaches are likely to evolve to a different stage, which could lead to more or different river maintenance activities than the current stage. Further evaluation may show that conducting lower levels river maintenance now would be more economical than maintenance in a succeeding geomorphic stage. This approach could prevent larger implementation costs at a later time (i.e., after a geomorphic threshold is reached).

During the reach prioritization process, a two-fold approach may be identified where feasibility evaluation could begin simultaneously on both more complex and less complex reaches. Evaluating less complex reaches will require less time and resources and provide for quicker implementation. Gaps and improvements in the evaluation process also may be identified more easily. Once the first few reaches are prioritized and selected for additional analysis, feasibility evaluation can begin.

16.2.4 Reach Strategy Feasibility Assessments

Evaluating and selecting a preferred strategy or strategy combination will be conducted as a reach scale feasibility assessment. Feasibility assessment for each strategy includes sufficient information to allow for preliminary layouts and designs of major features from which geomorphic response, environmental benefits and effects, and approximate quantities of work may be obtained. Updated scores for the Engineering Effectiveness, Ecosystem Function, and Economics Evaluation Factors of each strategy would be used to assist in selecting the preferred strategy and its accompanying plan. The preferred strategy may be a combination of the strategies developed in this report. There would be sufficient detail for the evaluated strategies or strategy combinations to be used in ESA, CWA, NEPA, and the land access compliance processes as appropriate.

To prepare the preliminary design and layouts, additional data collection may be needed. Identifying applicable methods for a strategy and their approximate dimensions (hydraulic and/or geomorphic) will be needed to determine geomorphic response. Also necessary are the approximate dimensions, sizing, and total material quantities for feasibility-level cost estimating. The preliminary layout and design may need to be adjusted based upon the geomorphic response and re-evaluated as needed. Depending upon the strategy being evaluated, hydraulic and sediment transport modeling also may be necessary.

With appropriate modifications to reflect this increased level of detail from the Plan and Guide appraisal level of analysis, the existing methodology to generate ratings for Engineering Effectiveness, Ecosystem Function, and Economics Evaluation Factors also can be used to compare strategies at the feasibility level. It is important to note that these feasibility assessments will not be greater than a 30-percent level of analysis for engineering effectiveness, ecosystem function, economics (cost), and geomorphic response. Some attributes used at the appraisal level of analysis may not be needed during the reach strategy feasibility assessment phase. A feasibility evaluation plan flowchart may be helpful to define the appropriate evaluation scope of work for each reach.

Reach strategy feasibility assessments can be used to improve river maintenance planning on a broad spectrum for out years, which likely will enhance maintenance scheduling and potentially streamline environmental compliance and project implementation. The assessments would potentially contain these elements (depending upon reach characteristics and methods used):

- **Assessment of existing information and potential data needs**
    - Evaluate existing data and needs for strategy evaluation at no greater than the feasibility level. It is expected that most data needs can be met with existing information.

  - Collect and analyze data, contingent upon resource availability. Examples of data include aerial photography, LiDAR, cross sections and profiles, bank erodibility testing, and bed material size distributions.

- **Preliminary layout and design of major features**
  - Select strategy methods or combination of methods and features to be used for each strategy (appendix A).
  - Determine preliminary siting and dimensioning of features for each method, based upon reach characteristics, channel dynamics, geomorphic stage, and hydraulic and sediment modeling results from this Plan and Guide analysis and other information as available.

- **Geomorphic and hydraulic evaluation of channel response**
  - Includes upstream and downstream reach response.
  - Hydraulic modeling results.
  - Sediment transport capacity and supply estimates, incipient motion and/or sediment transport modeling results.
  - Meander migration evaluation and bank stability analysis.

- **Update layout and design of major features (if needed)**
  - Revise method and types of features, sites, and dimensions of features and re-evaluate geomorphic response as needed to achieve the optimum channel response while minimizing the cost of method features throughout the reach.

- **Strategy feasibility evaluation**
  - Revise the Plan and Guide evaluation factors (Engineering Effectiveness Evaluation, Ecosystem Function Evaluation, and Economics Evaluation), if needed, and any relevant attributes and indicators to adjust for the level of detail for a feasibility analysis.
  - Develop scores for the Engineering Effectiveness Evaluation Factor by using geomorphic channel response and engineering characteristics of features and methods.
  - Prepare feasibility-level cost estimates for the implementation cost attribute using layout and design information for siting and dimensions of features.

- Develop Ecosystem Function Evaluation Factor scores from the geomorphic response, reach habitat characteristics, presence or absence of listed endangered species, and habitat needs.
- Develop scores for costs (Economics Evaluation Factor) using method and feature characteristics as needed.
- Determine the required levels of compliance under the environmental and lands approval processes. Plan for and begin implementation of these processes to acquire approvals at the appropriate levels.
- Select preferred strategy or combination of strategies

- **Reach scale environmental and lands approval planning for strategy (ies)**
  - The characteristics of each **r**each and each strategy will be used to determine which of the above items will be needed for each reach and strategy feasibility evaluation. The type and amount of analysis work for each of the above items, for each given reach and strategy, also will need to be determined.

16.2.5 Project Development

Eventual project design, implementation, and adaptive management are intended to be the fruition of the appraisal and feasibility strategy evaluations for the Plan and Guide reaches. Project design includes the design of all project details, with documentation incorporated into final drawings. Plan and Guide implementation and adaptive management are the execution of strategies, the ongoing monitoring, and any future changes that may be needed to achieve complete objectives. These steps are briefly described in this section.

- **Initial investigation and assessment**
  - This step is completed in the Reach Strategy Feasibility Assessment (see section 16.2.4).
- **Alternative evaluation**
  - This step is completed in the Reach Strategy Feasibility Assessment (see section 16.2.4).
- **Design data collection**
  - Additional detailed information as needed for design and to support project approval.

- **Project design**
  - A sufficient level of detail for the Socorro Field Division to perform maintenance work in accordance with the project design and technical requirements and the environmental compliance needs is needed. This information includes typical cross sections, typical details, alignments, profiles, and plan view drawings.
  - Design may involve additional hydraulic/sediment transport modeling depending upon the methods and features of the preferred strategy.
  - Design of all dimensions, features, scour protection, elevations, material quantities, engineering properties, etc., depending upon the methods and features of the preferred strategy.
- **Maintenance construction**
  - This likely would be phased in over a few years, depending upon the number and types of features and the quantity of work. Scheduling considerations include other higher priority site or emergency-related work needed during the same scheduling period.
- **Monitoring and adaptive management**
  - Monitor before implementation. Most of this will be the design data used for the final design, but monitoring also may include gathering additional data identified in the adaptive management plan.
  - Monitor after implementation. This may include visual observations, site photos, as-builts, controlled aerial photography, cross sections, profiles, bed material sampling, hydraulic modeling, or sediment transport modeling, etc., depending upon the level of uncertainty of the geomorphic and ecological response as identified in the adaptive management plan.
  - Evaluate monitoring data. Analyze monitoring data to evaluate hypothesis developed as part of the adaptive management plan.
  - Make decisions. Management would make decisions about potential adaptive changes to the project or reach implementation in accordance with criteria in the adaptive management plan.
  - Implement adaptive changes. This could involve changes to the implemented features or the addition of new features.
  - Begin adaptive management cycle again, if necessary, to meet strategy objectives and reduce the level of continued uncertainty.

Final design, implementation, and adaptive management are the realization of this Plan and Guide and subsequent feasibility evaluations for more effective river maintenance.

16.2.6 System-wide Reassessments and Monitoring

Given the dynamic nature of the Middle Rio Grande, the river will continue to evolve and change, which likely will influence long-term future maintenance planning, design, environmental compliance, implementation and monitoring, and adaptive management. A data collection and analysis program plan should be developed as a basis for continued monitoring of river trends and to help predict the effects of changes in sediment supply and discharge upon the river. Data such as aerial photography and LiDAR, cross sections and profiles, bank erodibility, and bed material size distributions are examples of future data needs. Continuing daily suspended sediment measurements together with approximate monthly stream gauging measurements at the USGS measurement stations and bed material size analysis is essential.

There are circumstances where the entire Middle Rio Grande, multiple reaches, or a single reach may need to be reassessed as a whole. The major influences on the geomorphology of the Middle Rio Grande system are water and sediment loading and the basin's natural hydrologic and geologic variability and constraints. Anthropogenic-related influences include various operational actions and the legal, institutional, and public infrastructure constraints. Several sources of potential significant change to these drivers have been identified as triggers for reassessment. These triggers include changes in endangered species habitat conditions, changes in the sediment transport capacity/load relationship due to factors such as large-scale fires, tamarisk die off due to beetles, habitat restoration or other local project implementations, and climate change. The continued monitoring and evaluation of the river trends identified as important to river maintenance will help identify when these triggers cause the need for system-wide scale reassessments. It should be noted that additional trends could be identified in the future as the Rio Grande continues to evolve or new constraints are identified.

16.3 Conclusions

The Plan and Guide has created a new framework for considering the Middle Rio Grande as a whole at the appraisal level; and, in the process, several new assessment tools were developed. It provides a systematic geomorphic, engineering, ecosystem function and economic analysis of all the Middle Rio Grande reaches. Since the Plan and Guide is not an end in itself but rather part of the path towards more effective river management, the following recommendations have been made in regard to using the Plan and Guide:

- **Information Needs** (see section 16.2.2 for more information): It is recommended that plans for data collection and analysis to fill in the gaps identified be formulated and implemented. Information needs are both project-based and system-wide and may overlap. Periodically updating appendix A will help ensure that the AAO is using state-of-the-art methods.

- **Reach Prioritization** (see section 16.2.3 for more information): In addition to other constraints and priorities, it is recommended that AAO decisionmakers and stakeholders should, in defining the priority of the reach-based assessments, consider channel instability, water delivery impact, infrastructure public health and safety, and habitat value and need, along with the effectiveness cost assessment. These elements were developed as part of the Plan and Guide to strike a balance between updated river maintenance goals.

- **Reach Strategy Feasibility Assessment** (see section 16.2.4 for more information): Reach-based strategy feasibility preliminary design and evaluation are recommended to select preferred strategies. Strategies also will need further evaluation to determine the levels of compliance under the environmental and lands approval processes if implemented. The strategy rating system developed in this report can be used in its current form or altered as part of reach strategy feasibility assessment. It is recommended that AAO decisionmakers use the findings in this report to determine which strategies should be advanced in the reach strategy feasibility evaluation. It is envisioned that after reach strategy feasibility is completed, planning, implementation, and adaptive management can occur.

- **System-Wide Assessments** (see section 16.2.6 for more information): The dynamic nature of the Middle Rio Grande causes morphology and ecology changes over time. Significant changes in flow and sediment loads and/or anthropogenic constraints, other large-scale project implementations, and habitat and species conditions could trigger a re-evaluation of the system approach presented herein. It is recommended that any updates should evaluate channel instability, water delivery impact, infrastructure health and safety, and habitat value and need be conducted as warranted. Updates also may be needed to account for endangered species status changes that redefine critical habitat or add additional new endangered species.

The Middle Rio Grande is a complex and changing river system that presents many maintenance challenges. The Plan and Guide (both the Part 1 Report and this report) is a holistic, comprehensive assessment that provides a foundation for more effective Middle Rio Grande River Maintenance Program activities. The Plan and Guide helps guide River Maintenance Program decisions for reach prioritization, future feasibility analyses, data collection, and maintenance practices including environmental compliance needs.

Given the present flow and sediment regime, the geomorphic/ecological process-based approach was developed using the current understanding of the existing and likely future river processes and seeks to strike a balance between the updated River Maintenance Program goals of Support Channel Sustainability, Protect Riverside Infrastructure and Resources, Be Ecosystem Compatible, and Provide Effective Water Delivery. Over time, future reach and strategy feasibility assessments will increase the long-term effectiveness of the River Maintenance Program and help to select more sustainable maintenance strategies for each reach.

17. References

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Unique Terms

The analysis approach is discussed in section 4.1 of the main report, Middle Rio Grande River Maintenance Program Comprehensive Plan and Guide.

Evaluation Factors. For this analysis, we rated strategy implementation effects by the attribute of three evaluation factor for each suitable strategy in each reach:

- Engineering Effectiveness Evaluation Factor (as scored by the Attributes for Strategy Performance and River Maintenance Function)
- Ecosystem Function Evaluation Factor (as scored by the attributes for the SWFL and RGSM)
- Economic Evaluation Factor

Goals. Goals are outcome statements that describe desired conditions on the Middle Rio Grande. The updated goals are:

- Support Channel Sustainability
- Protect Riverside Infrastructure and Resources
- Be Ecosystem Compatible
- Provide Effective Water Delivery

Planform Stages. See appendix C, section C1.4.1.3, for a description of the Middle Rio Grande Planform Evolution Model. For further clarification, please refer to Mesong et al. 2010. The planform stages progress from Stage 1–3 on a common pathway; Stages A4–A6 are aggrading conditions, and Stages M4–M8 are migrating conditions. The planform stages, as listed in the previous described order, are as follows:

- Stage 1 (Mobile sand-bed channel)
- Stage 2 (Vegetating bar channel)
- Stage 3 (Main channel with side channels)
- Stage A4 (Aggrading single channel)
- Stage A5 (Aggrading plugged channel)
- Stage A6 (Aggrading avulsed channel)
- Stage M4 (Narrow single channel)
- Stage M5 (Sinuous thalweg channel)
- Stage M6 (Migrating bend channel)
- Stage M7 (Migrating with cutoff channel)
- Stage M8 (Cutoff is now main channel)

Reach Characteristics. Reach characteristics are overall assessments of the existing conditions of the reach to provide information used in prioritizing reaches and in rating the strategy effects by reach. Reach characteristics are:

- Channel Instability Reach Characteristic
- Water Delivery Impact Reach Characteristic
- Infrastructure, Public Health, and Safety Reach Characteristic
- Habitat Value and Need Reach Characteristic (as reflected by Southwestern willow flycatcher [SWFL] and Rio Grande silvery minnow [RGSM])

Strategies: Strategies are the basic approaches to achieving the goals on a reach-wide basis, and methods are the means to implement those strategies. The variety of river management practices considered for implementation on the Middle Rio Grande is grouped into six basic strategies:

- Promote Elevation Stability
- Promote Alignment Stability
- Reconstruct and Maintain Channel Capacity
- Increase Available Area to the River
- Rehabilitate Channel and Flood Plain
- Manage Sediment