RECLAMATION

Managing Water in the West

Middle Rio Grande River Maintenance Program Comprehensive Plan and Guide

Appendix C: Strategy Assessment

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.

Middle Rio Grande River Maintenance Program Comprehensive Plan and Guide

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Acronyms and Abbreviations

AAO	Albuquerque Area Office
AMAFCA	Albuquerque Metropolitan Arroyo Flood Control Authority
ARRA	American Recovery and Reinvestment Act
AT&SF	Atchison, Topeka and Santa Fe Railway
BASE	baseline
cfs	cubic feet per second
EIS	environmental impact statement
ESA	Endangered Species Act
GIS	Geographic Information System
GRF	Gradient Restoration Facility
HEC-RAS	Hydrologic Engineering Centers River Analysis System Strategy Modeling
LFCC	Low Flow Conveyance Channel
mm	millimeter
MRGCD	Middle Rio Grande Conservancy District
NEPA	National Environmental Policy Act
NMF-H	no maintenance future modeling – horizontal
NMF-V	no maintenance future modeling
O&M	operation and maintenance
Project	Middle Rio Grande Project
Reclamation	Bureau of Reclamation
REHAB	Rehabilitate Channel and Flood Plain Strategy
RGSM	Rio Grande silvery minnow
River Maintenance Plan	The Middle Rio Grande River Maintenance Plan
River Maintenance Program	The Middle Rio Grande River Maintenance Program
RM	river mile
Service	U.S. Fish and Wildlife Service
SSCAFCA	Southern Sandoval County Arroyo Flood Control Authority
SRH-1D	Sedimentation and River Hydraulics One-Dimensional Sediment Transport Dynamics Model
SWFL	southwestern willow flycatcher

URGWOM	Upper Rio Grande Water Operations Model
URGWOPS	Upper Rio Grande Water Operations
USACE	U.S. Army Corps of Engineers
WSE	water surface elevation
~	approximately

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Chapter C1. Strategy Assessment Methodology

This appendix provides further details on the analysis used for the Middle Rio Grande River Maintenance Program Comprehensive Plan and Guide (Plan and Guide). The Plan and Guide provides guidance for the Bureau of Reclamation's (Reclamation) future river maintenance activities within the existing Middle Rio Grande Project (Project) authorization. Please see the main report of the Plan and Guide, for an introduction, maintenance methods, and goals and strategies, and a summary of the assessment approach and analysis results by reach.

C1.1 Strategy Assessment Approach

This strategy assessment reflects an appraisal level of analysis. Analyses are conducted to identify needs and opportunities, formulate and evaluate an array of strategies, and recommend at least one strategy per reach that warrants additional Federal investment in a feasibility study. Existing data are used and quantitative costs and effectiveness estimates are limited to ranges. Final recommendations are based upon limited information. This appraisal-level analysis provides a foundation for additional tiered studies and reach-wide analyses needed to select and implement strategies that could be more economical, reduce negative environmental effects, and/or have increased environmental benefits, resulting in 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 actions.

Section 3.2 of the main report provides information on goals, and section 3.3 of the main report provides information on the six 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. Each strategy's properties and the methods used in their implementation are explained. Chapter 2, Maintenance Methods, of the main report contains a general discussion of the methods; additional information can be found in appendix A.

The strategy assessment is based on the evaluation of site-specific bank and bed stabilization methods using engineering, environmental, and economic

[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.

considerations in Biedenharn et al. (1997). This evaluation was expanded to assess both bank and bed stabilization and nonbank and bed stabilization methods applied as reach scale strategies. Strategy assessment consists of several steps as shown in the flowchart in figure C1.1.

The following summarizes the strategy assessment approach used to describe the reaches and analyze the strategies.[1] More detailed information is available in sections C1.2–C1.9.

C1.1.1 Current Geomorphic Trends

Reach-scale trends currently observed on the Middle Rio Grande that can result in river maintenance actions are identified and described for each reach (see section C1.2 for a description). The trends are:

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

C1.1.2 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 the main report in sections 3.3 and 3.4. Methods are further discussed in appendix A.

Where data to model a reach are available (i.e., from Cochiti Dam to Elephant Butte Reservoir), strategy implementation is modeled. This included sediment modeling to determine reach equilibrium conditions and hydraulic and meander modeling to generate indicators that are used in assessing the suitable reach and strategy combinations (see section C1.3.5 and appendix B chapter 5 for a more detailed discussion of indicators).

[1] Please note that this report uses capitalization to denote specific terms of analysis: Goals, Strategies, Reach Characteristics, Evaluation Factors, Attributes, and Indicators.

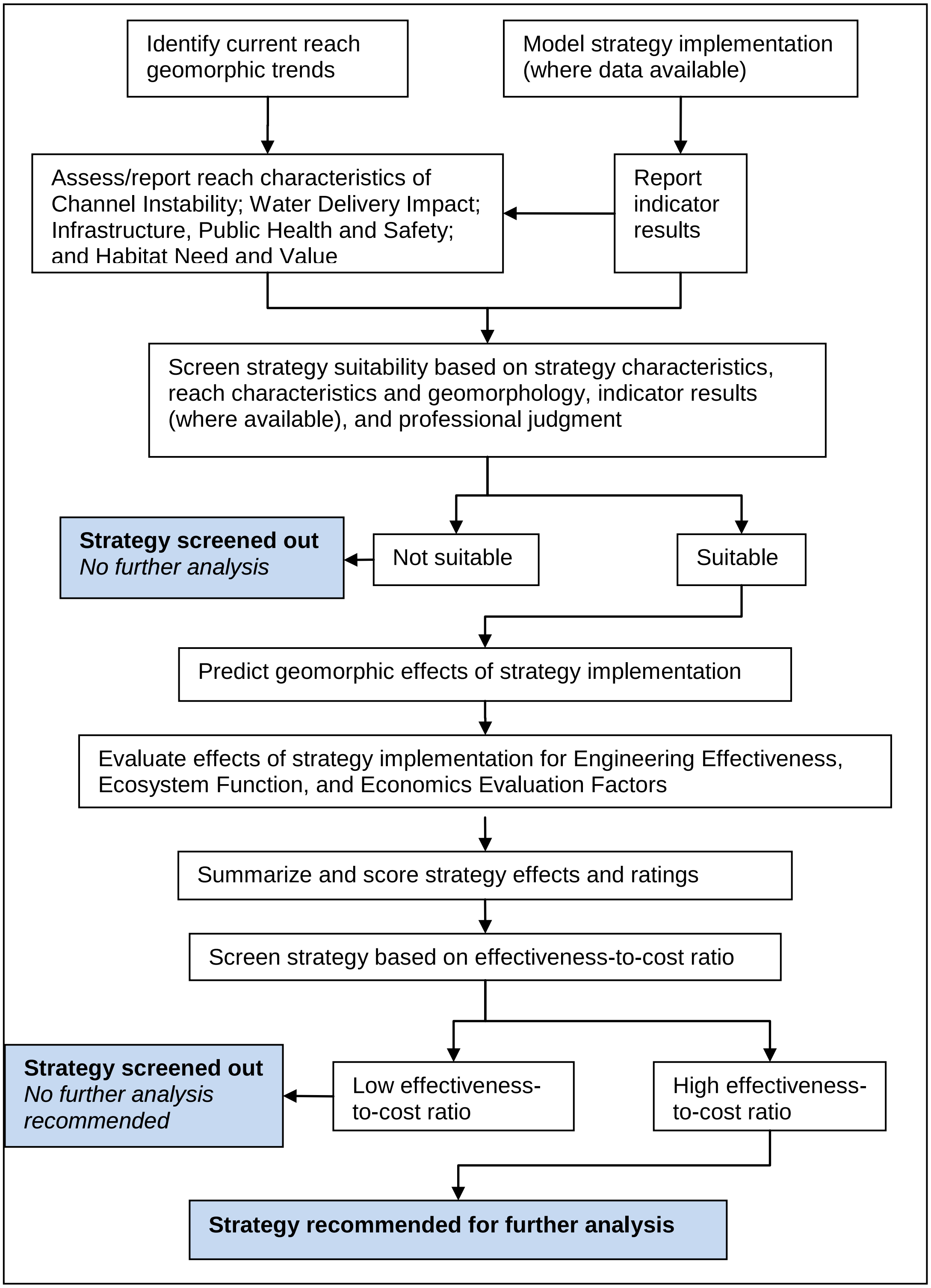

Figure C1.1. Flowchart of strategy assessment process.

C1.1.3 Reach Characteristics

Reach characteristics are used to help determine if a strategy is suitable for that reach, in strategy evaluations, and are described in further detail in section C1.4.

The reach characteristics are rated as high, medium, or low in four areas:

- Channel Instability Reach Characteristic (rated in terms of instability, see section C1.4.1)
- Water Delivery Impact Reach Characteristic (rated in terms of importance, see section C1.4.2)
- Infrastructure, Public Health, and Safety Reach Characteristic (rated in terms of importance, see section C1.4.3)
- Habitat Value and Need Reach Characteristic (rated in terms of importance, see section C1.4.4)

C1.1.4 Strategy Suitability

Indicator results from the modeling, the characteristics of each reach, each strategy's properties and how those properties address trends of change in a reach,, and professional engineering and scientific judgment are used to screen strategies and determine those strategies that do not address the expected future trends of concern in a reach. Where not enough data are available to model a reach, only reach characteristics and professional judgment are used to determine the strategies that are not suitable. Unsuitable strategies are not analyzed further (see section C1.5 for more information).

C1.1.5 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 C1.6 for a detailed discussion of geomorphic effects by strategy.

C1.1.6 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 Evaluation Factor (see C1.7)
- Ecosystem Function Evaluation Factor (see section C1.8)
- Economic Evaluation Factor (in terms of implementation costs only) (see section C1.9)

Strategy assessment consists of several steps as shown in the flowchart in figure C1.1. 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 most of the methods associated with a strategy were essentially the same type and had the same effect upon the attribute being evaluated; the rating was based on this majority of methods.

C1.1.6.1 Evaluation Factor Scoring

The indicators, historical trends (described in section 4.3 in the main report) and professional judgment are used to discuss the geomorphic outcomes of strategy implementation for the remaining strategies as described in section C1.6. The strategies then are rated at a reach-averaged appraisal level on the Engineering Effectiveness, Ecosystem Function, and Economic Evaluation Factors (which are discussed in sections C1.7–C1.9 in this appendix and summarized in section 4.7 in the main report).

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 subevaluation factors: Strategy Performance and River Maintenance. Ecosystem Function Effectiveness attributes are grouped into two subevaluation factors by two representative species: southwestern willow flycatcher, *Empidonax traillii extimus*, (SWFL) and Rio Grande silvery minnow, *Hybognathus amarus*, (RGSM).

C1.1.6.2 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 Economic 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, chapters 2–12.

C1.1.7 Recommended 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 the main report, and in section C9.2 of this report. 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 reach.

C1.2 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 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 flow duration means that more water is available 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 that 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 is now generally degrading, narrowing, and the bed 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 wet 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 dry periods, the reservoir elevations fall, and this base level drop is one of the causes 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. Many changes, both natural and anthropogenic, occurred contemporaneously on the Middle Rio Grande, which greatly complicates the task of interpreting the observed trends of channel and flood plain adjustments and basing predictions on these trends. Figure 4.1 in the main document illustrates the timing of many of these events and dates of significant floods. A more detailed history of events affecting the morphology of the Middle Rio Grande is provided in the report, Channel Conditions and Dynamics of the Middle Rio Grande, by Makar and AuBuchon (2012).

Reach-scale geomorphic trends can create the need for channel maintenance to meet the river maintenance goals described in chapter 4 of the main report. For example, channel incision and narrowing can lead to lateral migration, which can lead to erosion of levees with a possible breach; therefore, actions are taken to meet the Protect Riverside Infrastructure and Resources Goal. The balance between sediment transport capacity and supply or load in a reach strongly influences geomorphic changes and conditions. An imbalance 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 needs include:

- **Channel Narrowing**

  When sediment transport capacity is greater than 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 transport capacity is less than supply, channel narrowing can occur as a result of sediment deposition 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**

  Transport capacity that is greater than 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. Transport capacity greater than supply can result in deposition that becomes vegetated when not remobilized, thereby narrowing the channel. In either case, the increased duration of low flows further facilitates vegetation growth.

- **Incision or Channel Bed Degradation**

  When transport capacity is greater than 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 transport capacity is greater than supply, bank height increases as a result of channel degradation or incision. When transport capacity is less than supply, bank height can increase due to sediment deposition near the bank line.

- **Bank Erosion**

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

- **Aggradation (Riverbed Rising due to Sediment Accumulation)**

  Sediment deposition occurs that raises the bed elevation when transport capacity is less than supply. Bed rising 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 transport capacity is less than supply and sediment deposits in the main channel, flow from the top of the water column can go overbank at lower discharges. Because a higher concentration of sediment is 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 (River Channel Higher than Adjoining Riparian Areas in the Floodway or Land Outside the Levee)**

  When transport capacity is less than supply, with enough aggradation so that sediment-laden waters flow overbank into the riparian zone, flow velocity decreases, causing sediment deposition that raises the riverbank. Continued bed raising and bank line deposition result 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.

C1.3 Strategy Implementation Modeling

Three of the eleven reaches do not have sufficient data to incorporate them into a model. Table C1.1 provides a model reference number for reaches used in the model. More information on modeling can be found in Appendix B.

C1.3.1 SRH-1D Modeling

A one-dimensional mobile bed model, Sedimentation and River Hydraulics One-Dimensional Sediment Transport Dynamics Model (SRH-1D), was developed and implemented to represent approximately 200 miles of the

Middle Rio Grande. The model goal was to estimate an equilibrium slope for the model reaches identified in table C1.1 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 anticipated outcome of the SRH-1D modeling. SRH-1D allows for vertical adjustment of bed elevation via erosion and deposition of material but it 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 as discussed in section C1.3.5. Appendix B explains in more detail the data inputs, modeling assumptions, modeling approach, and sensitivity analyses performed using SRH-1D. The Middle Rio Grande SRH-1D modeling yields the following general conclusions about the eight model reaches:

- The three modeled reaches upstream of the Rio Puerco (**Cochiti Dam to Angostura Diversion Dam, Angostura Diversion Dam to Isleta Diversion Dam, Isleta Diversion Dam to Rio Puerco**)
    - These reaches appear to be in a state of relative equilibrium, as indicated by the relatively low slope change and depositional volumes.
    - Sensitivity analyses show that the results of the three reaches—Cochiti Dam to Angostura Diversion Dam, Angostura Diversion Dam to Isleta Diversion Dam, and Isleta Diversion Dam to Rio Puerco—are insensitive to tributary sediment inputs, model downstream boundary condition, the erosional and depositional limits at the diversion dams, and the hydrologic input at the upstream boundary and at the tributaries.

Table C1.1. Middle Rio Grande Reaches by River Mile (RM)

Reach	Approximate RM	Model Reach Number
Velarde to Rio Chama	285 to 272	Not modeled
Rio Chama to Otowi Bridge	272 to 257.6	Not modeled
Cochiti Dam to Angostura Diversion Dam	232.6 to 209.7	1
Angostura Diversion Dam to Isleta Diversion Dam	209.7 to 169.3	2
Isleta Diversion Dam to Rio Puerco	169.3 to 127	3
Rio Puerco to San Acacia Diversion Dam	127 to 116.2	4
San Acacia Diversion Dam to Arroyo de las Cañas	116.2 to 95	5
Arroyo de las Cañas to San Antonio Bridge	95 to 87.1	6
San Antonio Bridge to River Mile 78	87.1 to 78	7
River Mile 78 to Elephant Butte Reservoir	78 to 46	8
Elephant Butte Dam to Caballo Reservoir	26.6 to 12	Not modeled

- The **Rio Puerco to San Acacia Diversion Dam Reach**
  - This reach encompasses significant geologic and geomorphic transitions—as well as a hydraulic structure—which makes this a transitional reach, separating the upstream reaches from the downstream reaches.
  - This reach is insensitive to downstream boundary conditions and erosional and depositional limits at the diversion dams, is somewhat sensitive to the hydrologic input at the upstream boundary and at the tributaries, and is highly sensitive to the tributary sediment inputs, particularly the Rio Puerco, which constitutes the upstream extent of the model reach.
- The **Rio Puerco to San Acacia Diversion Dam, San Acacia Diversion Dam to Arroyo de las Cañas, Arroyo de las Cañas to San Antonio Bridge, and San Antonio Bridge to River Mile 78 Reaches** have a high, incoming sediment load that leads them to be zones of deposition.
- **San Acacia Diversion Dam to Arroyo de las Cañas, Arroyo de las Cañas to San Antonio Bridge, and San Antonio Bridge to River Mile 78 Reaches** are sensitive to hydrologic input (especially San Antonio to River Mile 78) at the upstream boundary and at the tributaries.
- The results of **San Acacia Diversion Dam to Arroyo de las Cañas, Arroyo de las Cañas to San Antonio Bridge, San Antonio Bridge to River Mile 78, and River Mile 78 to Elephant Butte Reservoir Reaches** are sensitive to tributary sediment inputs and the downstream boundary condition (reservoir pool elevation).
- **River Mile 78 to Elephant Butte Reservoir Reach**—the longest and most downstream reach of the model reaches—is highly sensitive to the downstream boundary condition and may benefit from being split into two subreaches for geomorphic descriptiveness when further analysis is conducted. The design life of any strategy implementation in the River Mile 78 to Elephant Butte Reservoir Reach will be greatly reduced due to the likely fluctuation of water surface elevation in Elephant Butte Reservoir.

C1.3.2 NMF-H Modeling

The equilibrium stable slope was determined from the SRH-1D modeling for the vertical portion of the no maintenance future modeling (NMF-V). The no maintenance future modeling–horizontal (NMF-H) represents the assumption that all changes in the future 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 Reaches to Elephant Butte Reservoir show a reduction in slope (NMF-V modeling) that 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 and an associated decrease in sinuosity. The results of the NMF-H modeling are used in developing the indicators discussed in section C1.3.5. More information on the NMF-H modeling is in appendix B.

C1.3.3 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 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 developing 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 also have been defined (Varyu et al. 2011). The results of the meander modeling are used to develop the indicators H1: Meander Width: Percent Fit of Length and H2: Meander Width: Meander Belt Width Area/Area Between Lateral Constraints, discussed in section C1.4.3. Indicator H1 is the percentage of the total channel length of a reach that fits between the constraints.

C1.3.4 Hydrologic Engineering Centers River Analysis System Strategy (HEC-RAS) Modeling

A hydraulic model was developed for the entire domain from Cochiti Dam to Elephant Butte Reservoir for the Baseline (BASE), 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 being made up of the baseline geometry. For example, assessment of the Rehabilitate

Channel and Flood Plain (REHAB) in the Cochiti Dam to Angostura Diversion Dam Reach would be performed by using the baseline cross-section geometry for model reaches 2 through 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 cubic feet per second (cfs), respectively. The Upper Rio Grande Water Operations (URGWOPS) URGWOPS 2007 environmental impact statement (EIS) (U.S. Army Corps of Engineers [USACE] et al. 2007) recommends 10,000 cfs as the maximum safe channel capacity, and 4,700 cfs represents a common high flow considering all reaches. Each geometry also was 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.

C1.3.5 Indicators

Twenty descriptive indicators were defined to help compare the strategies for each reach. Some of the indicators are grouped together because of similarities, and these general indicators range from Indicator A: Longitudinal Channel Slope Stability to Indicator K: Bed Material (table C1.2). The intent is to have these indicators be as reflective as possible of the physical properties of the strategy implementation that are relevant to the evaluation factors. Unless otherwise stated, the indicators are distance-weighted, reach-averaged values and reported 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 modeling results, while Indicator 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, can be found 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 that are assumed to be representative of the strategy are reported in the results tables. All results tables are in appendix B.

C1.3.6 Differentiation of Indicator Results

To facilitate using the indicators for rating attributes, it was desirable to bin the results for each indicator into categories. Categories vary by indicator and are designed to help score each attribute. Specific information on attribute scoring is found in sections C1.7–C1.9. Only data from the unique scenarios (see

Table C1.2. 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 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 84^{th} percentile of the grain size distribution (strategy/baseline)

section 5.1 in appendix B) were considered: no maintenance future vertical, no maintenance future horizontal, baseline, and rehabilitate channel and flood plain. Furthermore, some of the indicator values were not considered when differentiating indicators. For instance, for indicator A1: Strategy Slope/Stable Slope, the NMF-V and NMF-H values were predetermined to be equal to 1, so only the indicator values 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 values between the 25th and 75th percentile were considered not significantly different than the median, with values below the 25th percentile and values greater than the 75th percentile considered significantly different than the median. These first cut estimates of where to break the values into bins then was further refined using professional judgment. This was done primarily so that two values that were very close but separated based on the quartile definition would not be considered significantly different. In some cases, the values 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, so that was set as the range for the bins. Plots of all indicator values and the differentiation breaks are in appendix B.

C1.4 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 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 Reach Characteristic (rated in terms of instability)
- Water Delivery Impact Reach Characteristic (rated in terms of importance)
- Infrastructure, Public Health, and Safety Reach Characteristic (rated in terms of importance)
- Habitat Value and Need Reach Characteristic (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 C1.3 is a summary table of the four reach characteristics and the types of information used in their ratings.

Table C1.3. 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.

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. They are described and rated for each reach in chapters C2–C12.

C1.4.1 Channel Instability Reach Characteristic

C1.4.1.1 Causes and Effects of Instability

The most important drivers and controls of channel and flood plain adjustments over a decadal timescale are discharge magnitude and frequency, sediment load, system thresholds 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 of 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 frequent drying of the past.

System thresholds have changed through bank stabilization (both vegetation and mechanically based), coarsening of bed material, and decreases in sediment load. 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 (high variability in channel form) and more reflective of regions with higher precipitation (low variability in channel form). 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 active channel seen in much of the 20th century. This shift has resulted in greater uncertainty in predicting responses to both anthropogenic impacts and spatial and temporal variations in hydrology because there is a shorter time period with information that can be used as a basis for predictions.

Several examples follow to illustrate the types of changes occurring on the Middle Rio Grande. When sediment transport capacity is greater than the sediment load in a reach, flow would be expected to erode sediment from the bed and/or banks of the channel to fulfill that need. The reach between San Acacia Diversion Dam and Arroyo de las Cañas has had excess sediment transport capacity. Sediment control measures begun in the 1950s reduced the incoming sediment load. The bed was attacked first and the channel degraded. Preferential removal of finer grained sediments during degradation left a coarser bed that became more stable. The banks also became more vulnerable to erosion as the bank height increased beyond the protective zone of vegetation roots, and significant lateral migration has occurred in the last decade (figure C1.2).

Figure C1.2. RM 114 showing change in bank line over time. The pink arrow points to the same location in the river.

When sediment load is greater than transport capacity, the channel is expected to store sediment through general aggradation or formation of islands and bars. Through much of the Middle Rio Grande, lateral (rather than vertical) accretion occurs through the attachment of those mid-channel bars to the channel banks as sediment accumulation narrows the channel. Pearthree and Baker (1987) provide a discussion of this process in southeastern Arizona. The reach from Isleta Diversion Dam to Rio Puerco has many locations where, in the last decade, vegetation has stabilized islands and bars such that they are resistant to erosion at the current high flows. A narrow single channel is forming there as the bars attach to the banks (figure C1.3). The change in channel shape can result in an increase in sediment transport capacity large enough to become greater than the load, shifting the channel processes to erosion rather than deposition.

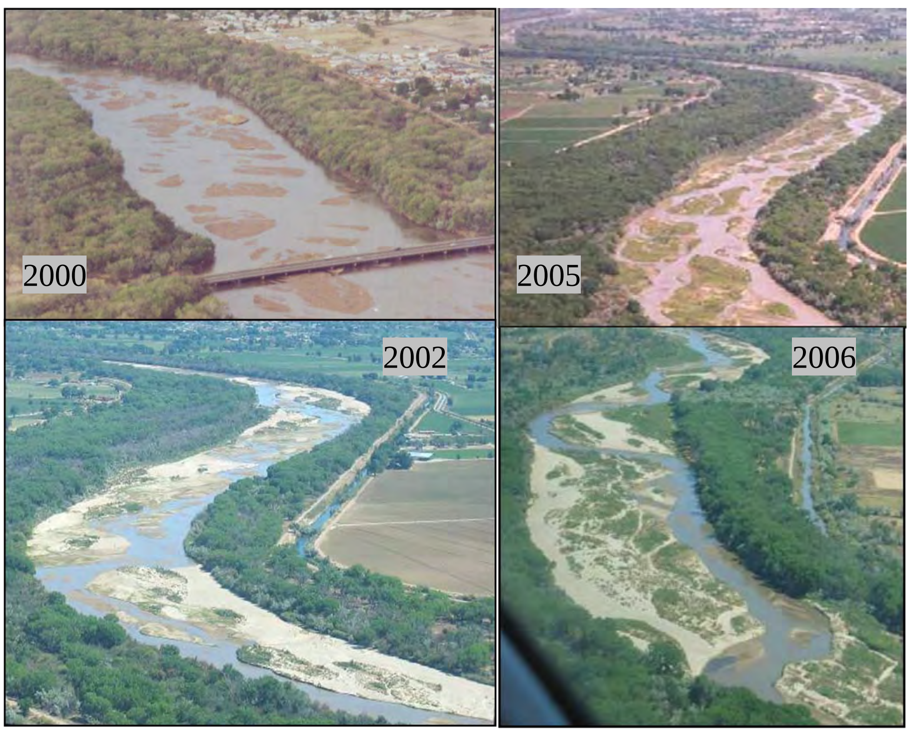

Figure C1.3. Island and bar development near Belen.

An example of general aggradation (as caused by deficient transport capacity) is the reach between San Antonio and River Mile 78. This reach has continued to aggrade over time so that the bed of the channel is higher than the surrounding flood plain as shown in figure C1.4. Natural sand levees along the channel margins rise with the bed and keep low flows in the channel. Historically, the channel would aggrade this reach until it plugged or breached the natural levees and then avulse to the low elevation in the valley. The valley low point in this reach is mostly along the LFCC, and significant efforts are expended to keep the channel in the existing alignment. The base level lowering effect of the low pool elevation of Elephant Butte Reservoir (beginning in 2000) has resulted in an increased channel slope and sediment transport capacity that contributed to the recent degradation in the delta and upstream. The bed at cross section 1670, near RM 71.3, has degraded and, in 2007, was close to the lowest flood plain elevation between the mesa and the Tiffany Levee. It should be noted that it is important to monitor effects both upstream of and downstream from a reach that has an imbalance if projects are implemented to address that imbalance.

There has been an increase in bank height on much of the Middle Rio Grande (Massong et al. 2006) from bed degradation or from deposition along the bank line which decreases flood plain connectivity. The reduction in connectivity can be quite rapid, as shown in figures C1.4 and C1.5. Lateral migration can increase flood plain connectivity through the exchange of tall banks and terraces for inset flood plains along point bars. Channel filling also increases connectivity through a rise in the bed or channel narrowing due to stable bars and islands. This increase may be temporary if the increased sediment transport capacity in the narrowed sections leads to bed degradation.

C1.4.1.2 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. Ratings are derived from indicator modeling results of existing conditions, historical trends, and professional judgment. Ratings for reaches that were not modeled are based on historical trends and professional judgment. Section C1.10 presents the rating results.

Several factors are combined into an overall rating of channel instability:

- **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. Indicator A3 is the baseline or existing reach averaged slope divided by the stable slope for the current reach geometry. The rating is low, meaning little to no change expected, if the ratio is between 1.03 and.97. If outside that range, a moderate amount of change is expected giving a rating of medium. 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. It is also possible that San Antonio to River Mile 78 could be adjusted to a high rating upon further study.

- **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. Indicator H1 is an estimate of how well the meander belt width

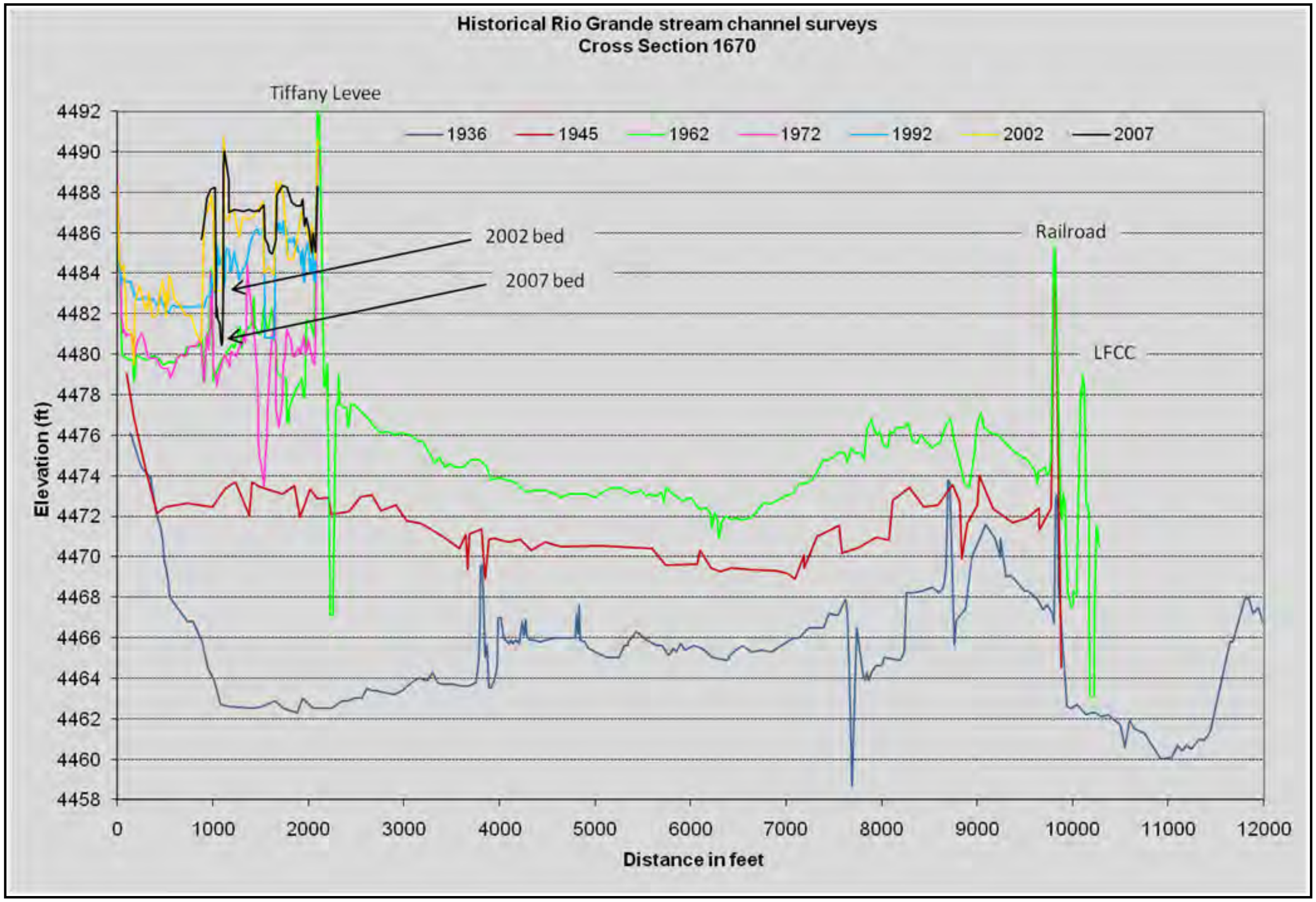

Figure C1.4. Aggradation near the south boundary of the Bosque del Apache National Wildlife Refuge at approximately RM 71.3. Arrows point to the channel degradation between 2002 and 2007 as a result of the base level lowering effect of the drop in the pool of Elephant Butte Reservoir.

Figure C1.5. Bar deposition at Highway 60 near Bernardo (Bauer 2007).

needed for a channel of the current width at the stable slope would fit within the geologic and infrastructure constraints of the reach. If Indicator H1 is below 90 percent, the rating is high because 10 percent or more of the meander belt does not fit. If Indicator H1 is 90 percent or above, 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 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. Indicator H1 is an estimate of how well the meander belt width needed for a channel of the current width at the stable slope would fit within the geologic and infrastructure constraints of the reach. If Indicator H1 is below 90 percent, the rating is high because 10 percent or more of the meander belt does not fit. If Indicator H1 is 90 percent or above, 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. Indicator H2 is a measure of how much area between the constraints is used by the needed meander belt width that helps to assess how much extra area is available for channel adjustment. A rating of high is given to reaches where more than 75 percent of the available area is used and medium where between 25 and 75 percent is used. River Mile 78 to Elephant Butte Reservoir had less than 25 percent of the available area used, but the Atchison, Topeka and Santa Fe Railway (AT&SF) Railroad and Black Mesa both cut through the meander belt near the San Marcial Bridge; therefore, the rating is moved up to medium.

- **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. An initial rating of low is given for reaches with a less than 5,000 cubic yards per mile per year, medium for 5,000–25,000 cubic yards per mile per year, and high for greater than 25,000 cubic yards per mile per year. Final ratings are developed based on professional judgment and 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 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. Reach 7 (San Antonio to River Mile 78) and reach 8 (River Mile 78 to Elephant Butte Reservoir) were rated high due to the perched conditions and the extent of influence of the pool elevation. A channel is perched when its bed is higher in elevation than the surrounding flood plain, which likely will be classed as high, medium, or low.

C1.4.1.3 Middle Rio Grande Planform Evolution

This sequence of planform evolution stages (Massong et al. 2010) has been developed from empirical observations of recent channel planform changes, survey data, valley fill geologic data, historical photography and written descriptions. It is based on the assumption that an inequality between sediment transport capacity and sediment load causes planform change. The planform model is intended to aid in understanding and predicting changes in channel planform on the Middle Rio Grande. Some stages can be very long lasting (i.e., several decades), while others may switch in a single runoff event.

Planform stages are shown in figure C1.6 and are:

- 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)

The model has three types of stages: initial, aggrading, and migrating. In the initial stages, there is an imbalance between sediment transport capacity and sediment load, resulting in movement between the first three stages. After Stage 3 , the channel shifts to either the aggradation or migration path. When sediment load is greater than transport capacity, the channel tends to aggrade and when transport capacity is greater than sediment load, the channel tends to migrate. The last stage of the aggradation path can move to a Stage 1 (Mobile sand-bed channel) channel, and the last stage of migration path can result in a Stage 1 (Mobile sand-bed channel) or a Stage M5 (Sinuous thalweg channel) channel; and the evolution resumes.

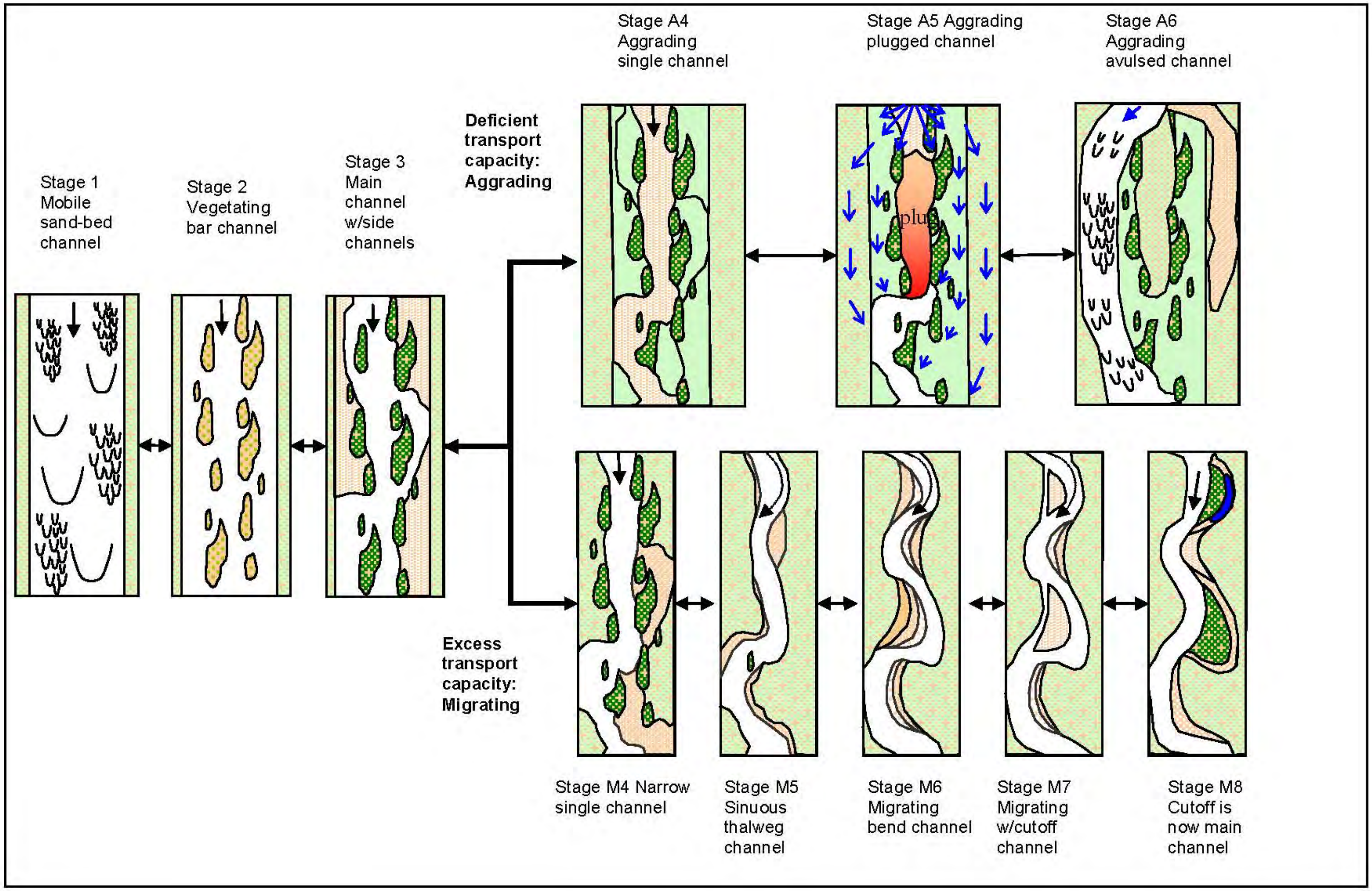

Figure C1.6. Sequence of planforms with path bifurcation beginning after Stage 3 (Massong et al. 2010).

C1.4.1.3.1 Initial Stages

Stage 1 (Mobile sand-bed channel) features large channels that have a sufficiently high sediment load and large floods so that a wide main channel, free of vegetation, is maintained. These channels form a single channel during high flows, usually with a connected flood plain, but become braided during most of the year as the discharge decreases. During the low-flow seasons, the flow is relatively shallow across the channel, without a well-defined thalweg. Bed material is composed mostly of sand with some gravel that is readily transported in the form of dunes and macrodunes. The flood plain is connected, and the channel bed elevation is either stable or slightly aggrading. The bank lines may or may not be stable, but the key factor is that the channel bed, bars, and dunes are active enough to prevent vegetation encroachment. This stage is the traditional description of the Rio Grande.

Stages 2–3 describe the evolution of active sand dunes to islands and bars that act like flood plains. In these two stages, the key change is that the sand dunes from Stage 1 start to stabilize, first through a temporary change in the flood hydrology that evolves into stabilization by vegetation regardless of flow. The transition from Stage 1 (Mobile sand-bed channel) to Stage 2 (Vegetating bar channel) occurred through most of the Middle Rio Grande during the latest drought of 1999–2004. This was 5 years in which virtually no spring or summer floods occurred, and extensive portions of the Rio Grande's channel saw just enough water to grow native vegetation. Vegetation encroachment was rapid. When normal flows returned in 2005, the water found a completely altered channel, with numerous islands blocking significant portions of the active channel. Although the flow was high enough to inundate these islands and erode some of them away, the vast majority of them survived the flood, and the vegetation flourished. With the thick stands of saplings, most islands rapidly aggraded in 2005, which served to only reinforce them in the following year's spring flood. As additional floods occur, the islands become attached to the bank lines as sediment deposits between the islands the bars. Stage 2 (Vegetating bar channel) is specifically the development of the islands, which macrodunes (medial bars) temporarily freeze long enough for vegetation to colonize. The islands force a split in the flow creating an anastomosing network. As the vegetation continues to improve stability of the island surface, they transform into flood plain-like surfaces, Stage 3 (Main channel with side channels); significant vertical accretion of these surfaces may occur during high flows. It appeared that the channel often cycled between these three stages in the 20th century, as dry hydrology allowed vegetation growth and large flows removed vegetation again.

C1.4.1.3.2 Stages of the Aggrading Reach

In reaches of the Middle Rio Grande where the sediment load is close to or exceeds the transport capacity of the river's main channel, the transition from Stage 3 (Main channel with side channels) to Stage A4 (Aggrading single channel) is ongoing and may not even be discrete in time as channel filling may have begun in Stage 3 (Main channel with side channels). In Stage A4 (Aggrading single channel), the flood plain becomes or remains connected at moderate flows as the main channel continues to fill. Although the flood plain and islands also are vertically accreting in this stage, the main channel is accreting faster and becomes super-elevated over its flood plain.

Aggradation rates for channels in Stage A5 (Aggrading plugged channel) are rapid as the channel filling begins to plug the entire channel to the tops of the banks. At this stage, eventually all flow of the river is shed onto the flood plains. Although the downstream conveyance of water is relatively slow on the flood plain, the conveyance of sediment is even slower and readily deposits in the flood plain. As the flood plain fills with coarser sediments, a dominant, new channel forms, Stage A6 (Aggrading avulsed channel). The new channel bypasses the old plugged channel but does not efficiently transport water and sediment until the new channel is well-formed with deep enough banks to convey moderate-sized flows, creating a full avulsion. This is the proposed ancient pattern that gradually aggraded the entire valley.

C1.4.1.3.3 Stages of the Migrating Reach

Although Stages A4 (Aggrading single channel) and M4 (Narrow single channel) might look similar from the air, Stage M4 (Narrow single channel) is distinctly different because the transport capacity in this channel exceeds the incoming sediment. Rather than the channel filling and getting smaller as occurs in Stage A4 (Aggrading single channel), in Stage M4 (Narrow single channel), the channel vertically erodes and increases its channel size. This incision also helps to establish a dominant channel while the other channels convert temporarily into high-flow channels before switching to flood plains. In this stage, vegetation encroaches into these less active side channels as they continue to be abandoned and evolve toward flood plain surfaces. Also, with the increased channel depth, grain sorting begins as the sediment transport processes change from dune migration into a more selective transport process; limited gravel armoring has been observed in this stage as the main channel captures all of the flow.

In Stage M5 (Sinuous thalweg channel), the channel bed continues to scour until either the bed material coarsens sufficiently to protect the bed from erosion or the channel reaches some sort of stable slope where the stream’s available energy to transport sediment is nearly equal to the sediment supply. The general appearance of the channel is a single-threaded, slightly sinuous, main channel. Stage M5 (Sinuous thalweg channel) can be a short-lived stage (a few years) or a final stage, depending on how quickly the armoring occurs or if the stable slope is attained easily and flows continue to be controlled.

Channels that are not trapped in Stage M5 (Sinuous thalweg channel) continue to incise until the unprotected bank material below the riparian root zone begins to erode as well, Stage M6 (Migrating bend channel). These channels efficiently transport sediment and water in a well-formed alternating thalweg. As the migrating pattern forms, prominent point bars develop on the inside of the bends, further enhancing the lateral migration pattern.

In nearly all of the active bends monitored on the Middle Rio Grande, a side channel cuts through the point bar that developed at the bend, Stage M7 (Migrating with cutoff channel). Although this side channel is initially small, it begins to convey increased amounts of water until, eventually, it captures the main flow. This new main channel grows in size until it also can convey all of the water and sediment during the common higher events, which allows the old channel to fully abandon, vegetate, and begin functioning as a flood plain, Stage M8 (Cutoff becomes main channel). Migrating bends can transform quickly from Stage M6 (Migrating bend channel) to Stage M8 (Cutoff becomes main channel).

The channel can change stages rapidly if there are large or sudden imbalances between transport capacity and load. It should be emphasized that this is not a one-way path. Movement to the right is occurring in the existing channel under the current water and sediment loads. Movement to the left generally requires higher energy input to remove vegetation or destabilize banks and terraces, whether through mechanical means or very high flows. Either can reset the channel evolution to a prior stage. Anecdotal evidence shows that, between about 1750 and 1950, very large floods reset the channel to Stage 1 (Mobile sand-bed channel) every few decades or so, sometimes moving it to a different location. Based on the geologic evidence of general valley aggradation with channels in various alignments over time, it is likely this pattern was applicable for several centuries.

C1.4.2 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 Middle Rio Grande Conservancy District (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 (SSPA 2008). In the Cochiti to Angostura and Rio Puerco to San Acacia 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 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 Reservoir reservation boundary. During periods of time 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 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 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 the main report 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 C1.7.

C1.4.3 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) will be 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 river-side 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 of the importance of various riverside infrastructures such as the LFCC, or other large canals and levees that are operated and maintained by MRGCD. Another type of infrastructure to be affected is 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 in 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.

C1.4.4 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, and 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, RGSM 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 RGSM 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 historic 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, age, or other factors?
- How feasible is habitat improvement within a given reach?

C1.5 Strategy Suitability

The first screening of strategies compared the effects of strategy implementation to the 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. Implementation of Promote Elevation Stability 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). These other strategies are Reconstruct/Maintain Channel Capacity, Increase Available Area, and Manage Sediment. This means that the suitability screening included eliminating Promote Elevation in aggrading reaches as not analyzed. Aggradation would be addressed through other complementary strategies (see Table C1.4 for more information). Section C1.10 summarizes the suitability screening results.

C1.6 Geomorphic Effects of Strategy Implementation

The geomorphic effects of strategy implementation provide background information to help in assessing Engineering Effectiveness, Ecosystem Function, and Economic 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 loads
- The balance between sediment transport capacity and sediment load
- Flood plain connectivity
- Planform type or stage[1]

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 there is uncertainty in system responses to the strategies.

C1.6.1 Support for Natural Channel Processes under Current Water and Sediment Loads

A process is “the physical and chemical interactions between the Earth’s surface and the natural forces acting upon it to produce landforms. The processes are determined by such natural environmental variables as geology, climate, vegetation, and base level, as well as human interference. The nature of the process and the rate at which it operates will be influenced by a change in any of these variables” (EIOnet 2011). For example, a process (erosion) is driven by a force (peak flow) and limited or controlled by resistance to change (bank stability) or by another process that modifies the force (attenuation of flood peak velocity when flow goes overbank).

If the strategy supports the natural channel processes, then it should be more sustainable and may be less costly in the long run. The results for this attribute are a function of the methods selected and, as such, will require further assessment and more in-depth analyses of each reach. There is also an

[1] Stages are defined in the planform evolution model from Massong et al. 2010.

assumption of benefit to ecosystem function with natural channel processes. Significant natural channel processes in this system include:

- Water conveyance and sediment transport with water supplied by snow melt, monsoon rainfall, and reservoir releases.
- Channel and flood plain adjustments to achieve dynamic equilibrium (requires enough time and space). A channel's morphology is predominantly shaped by hydrology and sediment load, as limited by geologic or anthropogenic controls. In the Southwest, the channel morphology is related to the length of time since the last large flood and magnitude of common low flows. Adjustments include changes in channel geometry, substrate, vegetation, and alignment (e.g., channel migration and avulsions). These changes can provide variety in depth, velocity, channel substrate, and channel forms (including secondary channels) that result in diverse ecological communities.
- Attenuation of floods peaks through a well-established and connected flood plain.
- Exchanges of water between surface water channels and ground water.
- Episodic sediment transport where the flood plain and channel can be source or sink for sediment. Sediment characteristics of the Middle Rio Grande vary by reach as a result of many factors, such as tributary influences, basin constrictions, bed and bank stability, and location in the watershed.

The effect of the strategies on natural channel processes is assessed through professional judgment based on the characteristics of strategies and associated methods (see section 4.3 in the main report for more information on strategies) and indicators (see section C1.4 for more information on indicators and their development). Ratings are based on:

- **Indicator E.2: 4,700 cfs/Overbank Inundation Discharge.** This indicator is a comparison between 4,700 cfs and the discharge required to cause overbank inundation for half of the reach length. This flow was chosen primarily to assess biological function and as a surrogate for the more frequent channel forming flows. It also is indicative of the degree of incision and gives information on overbank flow potential because it compares the flow needed to overbank to 4,700 cfs. A ratio less than 1 means that there are relatively frequent overbank flows, while a ratio greater than 1 means overbank flows are infrequent.
- **Indicator H1: Percent Fit of Length and Indicator H2: Meander Belt Width Area/Area Between Lateral Constraints.** H1 is an estimate of

how well the meander belt width needed for a channel of the current width at the stable slope would fit within the geologic and infrastructure constraints of the reach. Indicator H2 is a measure of how much area between the constraints is used by the needed meander belt width that helps to assess how much extra area is available for channel adjustment. Together, they provide information on how constrained lateral migration is in a reach.

C1.6.2 Balance Between Sediment Load and Transport Capacity

The extent of any imbalance between sediment supply and transport capacity of a reach gives information on how likely the reach is to change and the direction and degree of change. It is important to monitor effects upstream of and downstream from a reach that has an imbalance. Current unmanaged Middle Rio Grande channel adjustments that affect the balance of load and transport capacity (regardless of whether the initial cause is natural or man-made) are largely restricted to changes in:

- **Channel width**. Vegetation can rapidly colonize sand bars that become less frequently mobilized by flood flows (e.g., due to incision, vertical accretion, reductions in peaks), thus decreasing load by storing sediment and narrowing the channel. This may increase capacity with increased velocity or may decrease hydraulic capacity to contain high flows because of increased resistance. Either way, channel narrowing tends to increase bed erosion if there is an imbalance in sediment load and transport capacity. Rapid narrowing in the last decade began with drought. Riparian vegetation was sustained by irrigation flows routed through and returning to the channel.

  Lateral migration of the channel can increase the channel width. This may be temporary if vegetation colonizes the newly formed point bars.

- **Bank height**. There are at least four different ways bank heights change happens along the Middle Rio Grande.

  - The channel below Cochiti Dam has responded to the reduction in sediment supply with channel-bed erosion and lowering (Lagasse 1980).

  - The channel above Elephant Butte Reservoir responded to the base level lowering of the reservoir pool with degradation, extending upstream to near the south boundary of Bosque del Apache National Wildlife Refuge. The channel slope in the downstream portion of the degradation zone has flattened and, thus, decreased the sediment transport capacity. Degradation may continue upstream until the existing slope is flat enough that incoming sediment load meets sediment transport capacity.

  - During the most recent drought, channel capacity was reduced in many areas by vegetation encroachment. When higher spring flows returned in 2004 and 2005, flow in the channel near Belen went over the bank and deposited sediment along the channel margins a foot or more deep in each event (Bauer 2007).

  - Finally, when the channel migrates, it often exchanges tall banks for lower inset flood plains.

- **Changing bank stability.** This is also often a function of vegetation. Vegetation growth along low to moderately high banks tends to increase the cohesive strength and flow resistance along the bank and reduce the rate of channel migration. If the banks become tall enough through channel incision, they can become undercut, losing stability and thereby increasing channel migration. Bank erosion results in a flatter bank slope and a temporary increase in sediment load.

- **Coarsening bed material.** When the sediment load is less than the transport capacity, the finer sediment particles of the streambed are eroded away and possibly followed by an increased transport of larger grain sizes. The end result is a decreased ability to mobilize the coarser channel bed and possible increase in channel migration. The rate of bank erosion and channel migration depends on the relative resistance of the bed and banks.

- **Channel aggradation or fill.** When sediment load is greater than the transport capacity, sediment deposits along the river channel. Depending on the extent and timing of the imbalance, the channel can become completely plugged and may avulse to a new and lower-elevation alignment. In any case, there may be a reduction in the sediment load downstream.

The effects of strategy implementation on the balance of sediment load and transport capacity are qualitatively assessed through professional judgment based on historical trends, strategy and reach characteristics, and by comparing indicator results for current conditions and after strategy implementation. Indicators used are:

- **Indicator A1: Longitudinal Channel Slope Stability.** A1 is the strategy reach averaged slope divided by the stable slope for the current reach width. If the ratio is between 1.03 and.97, little change is expected from existing conditions. The further the ratio is from 1, the larger the imbalance of sediment load and transport capacity.

- **Indicator C: Bed Elevation Change.** This indicator is the reach average change in channel bed elevation from baseline to strategy conditions and is calculated as Strategy – Baseline. When this value is greater than 0.5 feet, aggradation is occurring in a reach; when it is less than –0.5 feet, degradation is occurring in a reach; otherwise, there is considered to be no change because the values fall within the error of the data

- **Indicator K4: Bed Material: Strategy D50/Baseline D50 and K5: Bed Material: Strategy D84/Baseline D84.** This indicator shows the amount of coarsening or fining due to strategy implementation predicted by the model.

C1.6.3 Flood Plain Connectivity

There has been a recent increase in bank height on much of the Middle Rio Grande, with a corresponding decrease in flood plain connectivity as discussed above in section C1.6.2 on bank height. Historically, the flood plain was well connected and periodically reset through infrequent large magnitude floods. A compound channel resulted from the very large floods, with smaller inset channel formed by more frequent low flows. Based on the change in energy dissipation through overbank flow (from Field and Lichvar 2007), compound channels likely would have the greatest impact from incision because extensive inundation during large floods would be greatly curtailed. Not only would the active channel be confined to a narrower area, but the shape and general form of the channel likely would change. With incision, more permanent vegetation could become established in less active side channels. Also, erosional features along the channel margins would become more prevalent and distinctive compared to a complex patchwork of depositional features. The reduction in the spatial extent and complexity of the channel would be further amplified downstream from dams, because of the added effect of peak flow reductions on inundation area and flood stage (Graf 2006). Through much of the Middle Rio Grande lateral, rather than vertical, accretion occurs through the attachment of midchannel bars to the channel banks as sediment accumulation (Pearthree and Baker 1987) narrows the channel.

Lateral migration can increase flood plain connectivity through exchange of tall banks and terraces for inset flood plains along point bars. Channel filling increases connectivity through the rise in the bed or reduction in sediment transport capacity.

Change in flood plain connectivity due to strategy implementation is qualitatively assessed through professional judgment and Indicator E2: 4,700 cfs/Overbank Inundation Discharge:

- **Indicator E2: 4,700 cfs/Overbank Inundation Discharge.** Connectivity is evaluated at 4,700 cfs and is used to compare baseline conditions to the implemented strategy conditions. This flow was chosen primarily to assess biological function and as a surrogate for the more frequent channel forming flows. It also is indicative of the degree of incision and gives information on overbank flow potential because it compares the flow needed to overbank to 4,700 cfs.

C1.6.4 Planform Change

The possible planform change is estimated using the current planform stage and then applying the three other geomorphic factors to the planform evolution model discussed in section C1.2. The following strategies, Promote Alignment Stability, Increase Available Area to the River, and Rehabilitate the Channel and Flood Plain, allow planform change while Promote Elevation Stability, Reconstruct and Maintain Channel Capacity, and Manage Sediment are designed to keep or re-create the current configuration. The amount of planform change in Promote Alignment Stability is a function of the space available between the lateral constraints.

C1.6.5 Geomorphic Effects of Strategy Implementation

The geomorphic effects of strategy implementation provide information to help assess the Engineering Effectiveness, Ecosystem Function, and Economic 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 loads
- The balance between sediment transport capacity and sediment load
- Flood plain connectivity
- Planform type or stage

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 there is uncertainty in system responses to the strategies.

Reach-specific geomorphic effects of strategy implementation are reported in chapters C2–C12 for strategies that are recommended for further study.

Tables C1.4–C1.9 provide a list, by strategy, of the general reach trends addressed (not in order of importance), the general reach effects of implementing each strategy, additional potential strategies that address the same trends, and general effects of strategy implementation in downstream and upstream reaches. When needed, the strategy effects are separated by the relationship between transport capacity and supply, since they are different if the sediment transport capacity is greater than or less than the sediment supply. If a strategy only lists one condition, such as transport capacity less than supply for Reconstruct and Maintain Channel Capacity, then it can be assumed that this strategy is not applicable to the other condition—that the transport capacity is greater than supply. These are general reach effects; therefore, in the magnitude of physical effect, there may be uncertainty. Where the probable magnitude of physical effect is known, it is so stated.

Table C1.4. Promote Elevation Stability: General Trends Addressed and Strategy Effects

Objective	Reduce the extent and rate of bed elevation changes.
Trends Addressed	Increased bank height. Incision or channel bed degradation. Coarsening bed material. Aggradation (addressed through Reconstruct/Maintain Channel Capacity, Increase Available Area, and/or Manage Sediment).
Reach Effects *Transport Capacity Greater than Supply (erosional)*	General: • Strategy maintains or raises bed elevation • Effects evaluation is based upon cross channel structures approximately (~) 2 feet high or less. • Fixes local lateral channel location and width (to prevent flanking, except deformable; see below). • Reduces the probability of additional future bed material coarsening. • Stabilizes current bed elevation (except deformable; see below). • Could increase bank erosion if bank stability below erosion threshold. This effect could be local when the future potential channel slope change is small. • Downstream degradation is expected to continue and may create possible fish passage issues. This can be addressed through adaptive management. • Can prevent lateral migration by preventing erosion below root zone or beyond geotechnically stable height. This effect could be local when the future potential slope change is small At bed – Maintain upstream water surface elevation (WSE) at same discharge: • No effect on bed elevation downstream – sediment passes through structure; does not halt downstream channel degradation. • Current slope and upstream bed elevation maintained.

Table C1.4. Promote Elevation Stability: General Trends Addressed and Strategy Effects

	Above bed – Raise WSE at same discharge (effects evaluation is based upon low height cross channel structures ~ 2 feet high or less): • Long-term effect is raise bed upstream, ~ height of structure, tapering to the next upstream riffle or high point in the bed. • No long-term effect on bed elevation downstream – sediment passes through structure, but local initial degradation possible that would fill in later. • Previous upstream slope is generally re-created. • Temporary – Aggradation from back water effect. • Can promote increased flood plain connectivity and greater velocity and depth variability depending upon the amount of past channel incision. Deformable – Maintain upstream water surface elevation at same discharge: • Temporary – Structure is mobile at design discharge. • Effects are similar to At bed or Above bed when structure is intact, except that lateral channel location and width may not be fixed. Complementary strategies: • Promote Alignment Stability, Increase Available Area to the River – Allow increased length of channel. • Manage Sediment – Increases sediment supply. • Rehabilitate Channel and Flood Plain – Reduces sediment transport capacity.
Effects on Upstream/ Downstream Reaches *Transport Capacity Greater than Supply (erosional)*	At bed: • Upstream effects: Because future channel bed degradation is reduced or halted, there may be a reduced tendency for degradation in the upstream reach. This would most likely result in the bed material size remaining the same or coarsening at a reduced rate. • Downstream effects: There could be a small reduction in the downstream sediment supply since future degradation is reduced or halted. This is likely to have only a minimal effect upon the downstream reach bed elevation and potential future channel evolution. Bed material size is not likely to be affected in the downstream reach. Above bed: • Upstream effects: The bed would be raised to the nearest riffle or high point in the bed upstream of the structures. Sediment fills the reach upstream at about the previous slope that is determined by channel width, hydrology, sediment load and size, bed and bank material size, and any geologic controls etc. Thus, there would be little, if any additional, effects upon upstream bed elevation, bed material size, or channel slope from those listed for the At bed condition. • Downstream effects: Initially sand sizes or finer gravel sizes could deposit upstream of these structures depending upon the size of the supplied sediment. This could reduce downstream sediment supply for a temporary period of time. During this temporary period of time, there

Table C1.4. Promote Elevation Stability: General Trends Addressed and Strategy Effects

	could be a small amount of downstream channel degradation; however, this effect would be minimal, because the amount of sediment storage upstream of these structures is small. After this temporary period of time, sediment delivery to the downstream reaches would be about the same as pre-implementation. Bed material size is not likely to be affected in the downstream reach. Deformable • Effects are similar to at bed when structure is intact, except that lateral channel location and width may not be fixed.
Reach Effects *Transport Capacity Less than Supply (depositional)*	Addressed through complementary strategies: • Reconstruct and Maintain Channel Capacity – Increases sediment transport capacity. • Manage Sediment – Reduces sediment supply. • Increase Available Area to the River – Increases area for sediment deposition.
Effects on Upstream/ Downstream Reaches *Transport Capacity less than Supply (depositional)*	See Complementary Strategy Effects on Upstream/ Downstream Reaches for the Transport Capacity less than Supply Case.

Table C1.5. Promote Alignment Stability: General Trends Addressed and Strategy Effects

<table>
<tr><td>Objective</td><td>Protect riverside infrastructure while allowing channel to adjust as much as possible horizontally.</td></tr>
<tr><td>Trends Addressed</td><td>Transport Capacity Greater than Supply (stabilizes banks):
Bank erosion.
Transport Capacity Less Than Supply (allows channel relocation nearer to infrastructure):
Channel plugging with sediment.
Perched channel conditions.</td></tr>
<tr><td>Reach Effects

Transport Capacity Greater than Supply (erosional)</td><td>General strategy conditions:
Strategy allows lateral migration until infrastructure is threatened.
Some increase in sinuosity with potential for new deposition.
Longitudinal features: Fixed bank:
Bank line does not move.
No sediment supply from banks.
No new depositional zones.
Increase in local flow velocity and depth.
Longitudinal features: Mobile bank – Degree of mobility varies with methodology:
Moves to a fixed location – Then effects same as above:
Either fixed in advance or when needed.
Temporary sediment supply from banks.
Temporary continuation of lateral migration channel process.
Reduces sediment supply from banks.
Reduces new depositional zones.
Temporary increase in local flow velocity and depth.
Transverse features or Flow deflection techniques:
Fixed bend – Constructed from bank line into channel.
Mobile Bend – Constructed in channel bank:
New location either fixed in advance or as needed.
Moves to a fixed location – Then effects same as above.
Temporary sediment supply from banks.
Reduces sediment supply from banks.
Potential for local bank sediment deposition and/or scalloping between structures.
Reduces new depositional zones on opposite bank.
Creates local eddies, with variable turbulence and velocity shear zones.
Local channel deepening with greater deepening at tip.
Creates local scour pools.
Variable depth and velocity effects are reduced at higher flows.
Local sediment deposition upstream and along scour pool.</td></tr>
</table>

Table C1.5. Promote Alignment Stability: General Trends Addressed and Strategy Effects

	• May help form and maintain side channels. • May form bars and islands. Complementary strategies: • Promote Elevation Stability – Reduces channel incision through cross channel structures that could either increase or reduce bank erosion. • Reconstruct and Maintain Channel Capacity – Keeps the channel in the same location or a selected relocated alignment. • Rehabilitate Channel and Flood Plain – Reduces sediment transport capacity. • Increase Available Area to the River – Moves infrastructure. • Manage Sediment – Increases sediment supply.
Effects on Upstream/ Downstream Reaches *Transport Capacity Greater than Supply (erosional)*	Upstream – As the channel lengthens, sediment transport capacity is reduced, lowering the tendency for channel bed degradation. If the upstream reach is degrading, then this tendency could be reduced. A less degrading upstream bed could result in the bed material sizes remaining about the same or become smaller. Potential changes in flow velocity and channel depth are expected to be minimal. Downstream – To the extent that the sediment supply from bank erosion of the affected reach is reduced, there could be possible impacts to the downstream reach. These impacts could be incision or bed degradation, slope reduction, and increased bed material size depending upon the portion of the sediment load being supplied by lateral migration. Depending upon reach sediment supply from tributaries, this effect could be small.
Reach Effects *Transport Capacity Less than Supply (depositional)*	When the trends of channel plugging with sediment or perched channel conditions are present, channel avulsion or relocation is possible. This strategy reinforces the new bank and has the same effects as listed under Transport Capacity Greater than Supply. Complementary strategies: Reconstruct and Maintain Channel Capacity – Removes sediment, relocates channel, or raises/strengthens levees. Increase Available Area to the River – Moves infrastructure. Manage Sediment – Reduces sediment supply.
Effects on Upstream/Down-stream Reaches *Transport Capacity Less than Supply (depositional)*	Upstream – No change is expected. Downstream – If active bank erosion within the affected reach adds significantly to the sediment load, and this is reduced, than this may bring the sediment supply of the affected reach and the downstream reach more into a dynamic equilibrium with the transport capacity. Downstream, this may help to minimize sedimentation within the channel.

Table C1.6. Reconstruct and Maintain Channel Capacity: General Trends Addressed and Strategy Effects

<table>
<tr><td>Objective</td><td>Ensure safe channel capacity and connectivity.</td></tr>
<tr><td>Trends Addressed</td><td>Channel narrowing.
Vegetation encroachment.
Aggradation.
Channel plugging with sediment.
Perched channel conditions.</td></tr>
<tr><td>Reach Effects

Transport Capacity Less than Supply (depositional)</td><td>General:
Since the implementation reach is experiencing loss of channel capacity, maintenance of this strategy is likely. Maintenance is not expected to incur additional geomorphic effects beyond those listed below. This strategy may help reduce future differential between bed and valley elevation under perched channel conditions.
Excavate sediment:

Complete reconstruction:

Generally more uniform width, depth, and velocity.
Bars can form within excavated channel increasing local depth and velocity variation. Adaptive management can allow more variation.
Reduces braiding and split delta channels.
Reduces water surface area.
Lowers ground water table.

Partial reconstruction (e.g., pilot cuts):

Temporary increase in velocity and bed lowering,
Temporary increase in sediment load delivered downstream,
Generally less uniform width, depth, and velocity than complete reconstruction,
Extent of sediment removal is flow peak and duration dependent:

Channel width may be narrower than existed before sediment plugging with increase in depth and velocity,
Spoil piles may disconnect flood plain, but adaptive management could reduce this effect.

Effects which occur at a slower rate:

Reduces braiding and split delta channels.
Reduces water surface area and evapotranspiration losses.
Lowers ground water table.

Confine overbank flow:

Can create zone of increased main channel flow velocity and depth.
Created at high flows and may remain for low flows.
Can increase uniformity of channel dimensions.
Created at high flows and may remain for low flows.
Decreases surface area of overbank flow.
Adaptive management can reduce this effect.
</td></tr>
</table>

Table C1.6. Reconstruct and Maintain Channel Capacity: General Trends Addressed and Strategy Effects

Reach Effects *Transport Capacity Less than Supply (depositional)*	• Can cause local bed lowering. Levee raising or strengthening: • Increased high flow capacity. May allow channel relocation closer to levee. Complementary strategies: • Increase available area to the river – Moves infrastructure. • Manage sediment – Decreases sediment supply.
Effects on Upstream/ Downstream Reaches *Transport Capacity Less than Supply (depositional)*	Upstream – Bed degradation could occur, which would increase channel capacity. Higher flows would be required to go overbank, and lowered ground water tables may accompany degradation. Sediment transport rates could increase temporarily during the degradational process. Bed material size may coarsen. Since the implementation reach is experiencing aggradation, maintenance of this strategy is likely. As the channel fills between maintenance events, the upstream reach could begin to aggrade and then degrade after maintenance, with this cycle potentially being repeated. Downstream – Increased sediment supply, because the sediment transport capacity is restored to its previous condition. This could steepen the channel slope in the downstream reach due to sediment deposition and channel aggradation. The bed material could become finer. It is likely that maintenance of this strategy will be needed since the channel is aggrading in the implementation reach. As the channel fills between maintenance events, there could be a decrease in sediment supply to the downstream reach causing channel bed degradation. There then would be an increase in the sediment supply in the downstream reach after maintenance in the implementation reach. This cycle potentially could be repeated with each maintenance action.

Table C1.7. Increase Available Area to the River: General Trends Addressed and Strategy Effects

Objective	Provide area for the river to evolve in response to changing conditions and minimize the need for future river maintenance actions.
Trends Addressed	*Transport Capacity Greater than Supply* (allows lateral migration and/or increased length): Channel narrowing. Increased bank height. Incision or channel bed degradation. Bank erosion. Coarsening bed material. *Transport Capacity Less Than Supply (*allows channel relocation): Aggradation. Channel plugging with sediment. Perched channel conditions.

Table C1.7. Increase Available Area to the River: General Trends Addressed and Strategy Effects

Reach Effects *Transport Capacity Less than or Greater than Supply (depositional or erosional)*	Wider area for natural channel processes: • Encourages new flood plain areas and side channels. • Provides opportunity to reconnect historical flood plain and side channels. • Encourages variability in channel dimensions and velocity. • Provides opportunity to increase bank erosion and new deposition. • Preserves flood plain connectivity. • Possible temporary change in sediment load. For reaches with transport capacity less than supply, this likely would be a reduction through deposition. For reaches with transport capacity greater than supply, this likely would be an increase through bank/bed erosion. • Reduces future maintenance. Extent of reduction depends upon the area needed versus the area acquired. Complementary strategies (Transport Capacity Greater than Supply): • Reconstruct and Maintain Channel Capacity – Strengthens/raises levee to allow channel migration closer to levee and reduce area needed. Complementary strategies (Transport Capacity Less than Supply): • Manage Sediment – Sediment removal.
Effects on Upstream/ Downstream Reaches *Transport Capacity Greater than Supply (erosional)*	Upstream –The channel slope in the implementation reach likely would decrease as the channel lengthens. If the upstream reach is degrading, then this tendency could be reduced, resulting in bed material sizes to remain about the same or become smaller than the current size. This also may cause a slight reduction in the sediment supply. Downstream – There may be a short-term effect of increased sediment load from bank erosion, but the long-term effect downstream likely would be reduced sediment load as the channel lengthening lowers sediment transport capacity. In addition, there likely would be new depositional features such as bars, or an inset flood plain, which would form and/or grow in size during lateral migration. These sediment storage areas also could lower downstream sediment supply. Reduced sediment supply could initiate channel incision or bed degradation, coarsening of the bed material, increasing channel capacity, and increasing the flows necessary to go overbank.
Effects on Upstream/ Downstream Reaches *Transport Capacity Less than Supply (depositional)*	Upstream –The upstream reach effect depends upon whether or not there is a change in the water surface elevation in the area where the river migrates or avulses to. For the case where the water surface elevation in the implementation reach decreases, then the upstream bed will degrade, increasing the channel capacity and the discharge needed to go overbank. Bed material size would likely increase but remain sand sized in sand dominated reaches. Upstream degradation will continue until such time as the relocated channel bed fills with sediment. Then the upstream bed elevation could increase to the previous or higher level. For the case where the water surface elevation does not change, the upstream effect would be minimal. Downstream – Sediment deposition could occur in the area where the river migrates or avulses to, which would decrease downstream sediment supply. This could cause bed degradation, bed coarsening, increased channel capacity, and increase the flow necessary to go overbank. Over time, the area available for sediment deposition may fill, during which time downstream sediment supply would increase, potentially leading to channel aggradation and finer bed material sizes.

Table C1.8. Rehabilitate Channel and Flood Plain: General Strategy Trends Addressed and Effects

Objective	Help stabilize the channel by reconnecting abandoned flood plains, which reduces the sediment transport capacity of higher flows to more closely match the existing sediment supply.
Trends Addressed	Channel narrowing. Vegetation encroachment. Increased bank height. Incision or channel bed degradation. Bank erosion. Coarsening bed material.
Reach Effects *Transport Capacity Greater than Supply (erosional)*	General • Applies to reaches with degradation or incision that may be a result of narrowing • Reduces erosion and/or encourages deposition by increasing floodplain connectivity • Maintenance may be needed but is not expected to incur additional geomorphic effects beyond those listed below. • Conservation easements could increase area for river relocation and side channels Complete construction – Longitudinal bank lowering and channel reconstruction: • Flow goes overbank at lower discharge – greater flood plain connectivity. • Can increase high flow capacity. • Wider surface area at high flows. • More depth and velocity variation at high flows. • Decrease high-flow velocity and depth because reduces energy of higher flows, which could reduce future incision, bank erosion, or induce overbank deposition. • Could increase braiding. • Promotes increased connectivity with backwaters and side channels. • Preserves ground water table. Partial construction – Clearing, destabilizing, encouraging sediment movement: • Takes longer; only applicable where there already is some flood plain connection. • May induce temporary bank erosion until transport/load balanced. • Same effects as complete construction above but lesser degree. Partial channel realignment – clearing, pilot cut, encourage channel widening along new alignment: • May re-establish meanders and change channel length • May reduce high flow energy, which reduces incision and/or migration. • Promotes increased connectivity with backwaters and other side channels (if close enough to bank line). • Temporary decrease velocity and depth variability. • Temporary increase in sediment supply downstream. Side channel construction: • May raise ground water table. • Promotes increased connectivity with backwaters and other side channels (if close enough to bank line). • May reduce high-flow energy, which reduces incision and/or migration.

Table C1.8. Rehabilitate Channel and Flood Plain: General Strategy Trends Addressed and Effects

	• Increase velocity and depth variability. • May reduce high-flow water surface elevations. • Increase high-flow water surface area. Complementary strategies: • Promote Elevation Stability – Reduces channel incision. • Manage Sediment – Increases sediment supply. • Increase Available Area – Allows space for river to readjust
Effects on Upstream/ Downstream Reaches *Transport Capacity Greater than Supply (erosional)*	Upstream: This strategy may allow the reach of implementation to experience sediment deposition. This may cause a slope reduction on upstream reaches, which in turn may cause the sediment load to decrease and the bed material to become finer. This sediment deposition also could result in lower discharges to go overbank. Downstream: There may be a short-term effect of increased sediment load depending upon the method and where the excavated material is placed. But the long-term effect downstream likely would be reduced sediment supply, channel degradation, and coarsening bed material. The slope of the channel could decrease. Channel degradation likely would result in a higher discharge being needed to go overbank, and increased channel capacity.

Table C1.9. Manage Sediment: General Trends Addressed and Effects

Objective	Aid in balancing sediment transport capacity and sediment supply.
Trends Addressed	*Transport Capacity Greater than Supply:* • Incision or channel bed degradation. • Increased bank height. • Coarsening bed material. *Transport Capacity Less than Supply:* • Aggradation. • Channel plugging with sediment. • Perched channel conditions.
Reach Effects *Transport Capacity Greater than Supply (erosional)*	General • Sediment addition would need to continue for long term benefits Direct augmentation (move sediment into channel): • Effects are volume of sediment dependent, and volume of augmentation depends upon high flow discharge amount and duration. • Flow goes overbank at lower discharge. • May have wider surface area at high flows. • May increase depth and velocity variation at high flows. • May decrease high-flow velocity and depth. • Could induce overbank deposition. • Could increase braiding. • Promotes increased connectivity with backwaters and side channels. • Help preserve ground water table. • Likely to require adaptive management (continuing adjustment of augmentation volume and location). • Could reduce bed material size (dependent on size supplied). • May fill in pools and/or create bars. • May increase width-depth ratio. Indirect augmentation (clearing, destabilization, encouraging sediment movement): • Effects are similar to direct augmentation. • Slower rate of additional sediment supply. Complementary strategies: • Increase Available Area to the River – Potential area to increase channel length, thus decreasing sediment transport capacity. • Rehabilitate Channel and Flood Plain – Reduces sediment transport capacity.
Effects on Upstream/ Downstream Reaches *Transport Capacity Greater than Supply (erosional)*	Upstream – If the augmentation results in the riverbed elevation increasing, then the downstream portion of the upstream reach bed elevation could increase potentially resulting in a reduced channel slope. It is expected that the augmentation rate and location can be planned and adaptively managed in the implementation reach so that the upstream bed elevation remains at about the current elevation. Downstream – The effects downstream are dependent on the amount of sediment augmentation, but an increase in the sediment supply may be possible. This would have the effect of increasing the channel slope through deposition/aggradation of the bed elevation as the implementation reach increases. Deposition in local subreaches of the downstream reach could result in a local flatter slope. The bed material size could reduce depending upon the size of augmentation sediments. The downstream channel bed elevation could increase resulting in lower discharge to go overbank. The effects can be adaptively managed.

Table C1.9. Manage Sediment: General Trends Addressed and Effects

Reach Effects *Transport Capacity less than Supply (depositional)*	General • Sediment removal would need to continue for long term benefits Constructed basins: • Slows or reverses aggradational trends. • Could increase discharge necessary to go overbank. • Could cause downstream bed size coarsening. • Reduce braiding potential. • Provide new areas of deposition. • In-Channel – Dredging low area in the channel bed, then allowing deposition to occur and re-dredge. o Widening and subsequent dredging or movement to new area. o Provides new areas of deposition. • Flood plain (berm-enclosed basin with inlet and outlet channel): o Similar to in-channel. o More likely to relocate when full than tributary. o More vegetation clearing than tributary or channel. • Tributary – More likely to dredge than flood plain. Natural topography basins: • Similar effects to constructed basins. • Becomes the new channel alignment. • In-Channel - May relocate when full and provides new areas of deposition. • Flood plain similar effects to in-channel but more vegetation clearing than channel. Complementary strategies: Increase Available Area to the River – Potential area for sediment deposition.
Effects on Upstream/ Downstream Reaches *Transport Capacity less than Supply (depositional)*	Upstream • Constructed Basins- Depending upon the method used, the subsequent maintenance, and the sediment deposition area volume relative to the incoming sediment supply, upstream aggradation or channel bed raising could occur. This could result in lower discharges being needed to go overbank, decreased bed sediment size, and increased tendency for braiding. • Natural topography basins – Effects would be similar to upstream effects for Increase Available Area to the River for the transport capacity less than supply case. Downstream • Constructed Basins - No change expected unless amount of sediment reduced is significant. If the sediment load reduction is significant, there may be channel degradation or bed lowering, which would cause a higher discharge to go overbank, less velocity and depth variability, and bed material coarsening. The amount of bed lowering is not expected to increase bank erosion rates or lead to significant lateral migration. • Natural topography basins – Effects would be similar to downstream effects for Increase Available Area to the River for the transport capacity less than supply case.

C1.7 Engineering Effectiveness Evaluation Factor

Engineering effectiveness assessment is used to evaluate strategy durability and design life, level of confidence in being able to perform its intended functions, ability to deliver water, hydraulic 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, the majority of methods were used in the rating. If two or more methods are different than the majority, and it has an impact upon an attribute rating, this is noted in this section. Attributes used in this assessment are summarized in table C1.10 and discussed in sections C1.7.2–1.7.8. Attributes are assigned into two subevaluation factors. The first is strategy performance that helps to describe the qualities of a strategy that determine implementability and how well a strategy will work. The second is river maintenance function that helps to describe 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. The general Engineering Effectiveness Evaluation Factor effects of strategy implementation are discussed in section C1.7.9.

C1.7.1 Construction Location

Construction can be on the terraces, flood plain, the bank line, or in the channel. Each location has different construction effects which will be evaluated as part of the ecosystem effectiveness strategy assessment. When construction takes place on the flood plain, there may need to be measures to avoid or minimize potential impacts to RGMS and SWFL. Construction on the bank line and river terraces may need to have measures to avoid or minimize potential impacts to SWFL habitat. Construction along the bank line and in the channel could potentially affect RGSM, and measures would need to be taken to avoid or minimize impacts to the species. For cross channel structures, cofferdams, or river diversion berms/dikes, the construction is in the channel. Measures to protect RGSM might include seining the site to relocate fish or other actions as deemed appropriate. In some instances, an incidental take permit could be obtained from the U.S. Fish and Wildlife Service (Service) for regulatory compliance if there is incidental fish mortality. This information is recorded in the assessment tables for general information but is not used in the Engineering Effectiveness Evaluation Factor rating.

Table C1.10. Engineering Effectiveness Evaluation Factor Attributes

Construction Location	Identifies the construction location: terraces, 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	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	Assesses the level or amount of information and documentation on design criteria, performance, case studies, and local geomorphic response.
Duration and Design Life Attribute	Qualitatively evaluates how long a strategy will meet its intended purposes (see main report, 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	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 a strategy meets the purpose of the Middle Rio Grande River Maintenance Program (River Maintenance Program) with respect to water delivery, hydraulic capacity, and public health and safety.
Water Delivery Attribute	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 values for Indicators B: Wetted Area at 4,700 cfs , F: Sinuosity, G: Width-to-Depth Ratio, and 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 decrease.
Hydraulic Capacity Attribute	Describes whether or not modeled 10,000-cfs flow is contained without overtopping the levees or going to, 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 the Velarde to Rio Chama Reach, 7,500 cfs for the Rio Chama to Otowi Bridge Reach, and 4,500 cfs for the Elephant Butte Dam to Caballo Reservoir Reach.
Public Health and Safety Attribute	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. The degree of public health and safety that exists in a given reach is not addressed.

C1.7.2 Ability to Implement Attribute

This attribute describes 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). Size also includes the number and types of features. Scope of the environmental effects includes the degree of disturbance defined by acres of potential clearing, and work quantities.

- **High:** The qualities of strategies with a high ability to implement are listed below:
  - Have low numbers, sizes, and types of features. Are constructed in reaches where access and acquisition of land instruments are relatively straightforward to obtain, based upon land use and ownership.
  - Are constructed on the terraces, flood plain, or in the channel along the bank line.
  - Use methods or tools with limited impacts to the environment in terms of minimal clearing, shorter length/smaller quantities for implementation, etc., and fewer numbers and types of features.

Promote Alignment Stability is an example of a strategy that is easier to implement because there are low numbers and types of features, minimal clearing, and land instruments are relatively straightforward to obtain.

- **Medium:** Strategies that have two of the four items in the high rating description but also could have two or less of the low strategy items.
- **Low**: Strategies that are harder to implement:
  - Have a high number, size of features.
  - Have more complex features.
  - Are constructed in reaches where access and acquisition of land instruments can be difficult based upon land use and ownership.
  - Are constructed mostly in or across the channel.
  - Have high impacts to the environment in terms of having large areas of clearing, longer lengths. and larger quantities for implementation, etc.

Promote Elevation Stability, Increase the Available Area to the River, and Rehabilitate Channel and Flood Plain are examples of strategies that have a low rating for the Ability to Implement Attribute.

C1.7.3 Level of Confidence Attribute

This attribute describes the level or amount of information and documentation on design criteria, performance, case studies, and local geomorphic response. For each strategy, there are multiple methods as described in section 4.3 of the main report. The strategy rating is based upon the majority of methods having the same level of confidence as discussed in section 3.4 of the main report and in appendix A. Appendix A describes the level of confidence for these methods in detail, using the following ranking system, based on whether the local response is well known, has limited information, or has little information using the following definition of levels:

- **Level 3.** Well established, widely used, well documented performance; reliable design criteria; numerous case studies; and 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 characterize Level 1; little or no long-term monitoring; limited design criteria; limited knowledge about the local geomorphic response; and limited documentation.
- **Level 1.** Emerging promising technique does not have a track record, field or lab data, or design or test data; few literature citations; little is known about local geomorphic response; and little documentation.

Strategies are rated high, medium, or low overall for the Level of Confidence Attribute as defined below:

- **High.** Most methods meet the Level 3 definition for the level of confidence. Promote Alignment Stability is an example of a strategy with a high rating for the Level of Confidence Attribute.
- **Medium**. Most methods meet the Level 2 definition for the level of confidence. Reconstruct Maintain Channel Capacity, Increase Available Area to the River, and Reconstruct Channel and Flood Plain are examples of strategies with a medium rating for the Level of Confidence Attribute.
- **Low.** Most methods meet the Level 1 definition for the level of confidence. Manage Sediment is medium or low, depending upon reach characteristics.

C1.7.4 Water Delivery Attribute

For this attribute, a qualitative evaluation is made of whether a strategy has the potential to increase or decrease water delivery or whether there would be no change. The evaluation is based upon potential changes in Indicators B: Wetted Area at 4,700 cfs, F: Sinuosity, G: Width-to-Depth Ratio, and J: Wetted Width at 4,700 cfs from the SRH1-D model indicator results (appendix B). For the reaches that were not modeled, the Water Delivery Attribute is qualitatively evaluated.

- **Increase**. Corresponds to a potential increase in water delivery due to strategy implementation. For this analysis, water delivery is rated as increasing when the wetted width, width-to-depth ratio, wetted area, and sinuosity decrease.

- **Decrease**. Corresponds to a potential decrease in water delivery due to strategy implementation. Water delivery is rated as decreasing when the wetted width, width-to-depth ratio, wetted area, and sinuosity increase. A larger width-to-depth ratio would result in a wider, shallower channel with lower hydraulic efficiency. Greater wetter perimeter would increase potential channel seepage losses. Increased sinuosity would increase the channel length with potential for increased water surface area and wetted perimeter.

- **No Change**. Means no significant change in the water delivery potential for a reach. Determinations of no change are based on professional judgment and are a function of the error inherent in data collection and modeling.

Results from the SRH-1D model are used in this analysis because a one-dimensional model does consider that more sinuous channels often have lower wetted width and lower width-to-depth ratio than relatively straight channels; so there can be offsetting water loss effects. Modeling results show no or relatively low change in sinuosity. Thus, SRH1-D indicator results are used without any attempt to model changes in channel width that may occur when there are changes in channel slope or length at this level of analysis.

C1.7.5 Hydraulic Capacity Attribute

This attribute describes whether or not the current high-flow capacity of a reach is contained. Indicator D: Containment of 10,000 cfs is used for reaches between Cochiti Dam and Elephant Butte Reservoir. The two possible values for this indicator are “contained” and “not contained” and are determined by comparing the water surface elevation for a discharge of 10,000 cfs to the lowest (left or right) lateral constraint elevation. See appendix A for additional information on “contained” or “not contained.” Levees are used to determine flow capacity. Where there is no levee, the elevation of other important infrastructure is used to determine containment. The locations of these other infrastructures were determined by the Albuquerque Area Office. Other infrastructures include the current residential areas in Bosquecito and Bosque Encantada. More information on Indicator D: Containment of 10,000 cfs is in appendix B, section 5.1.

For the other reaches that were not modeled, hydraulic capacity is qualitatively evaluated. The discharge used to qualitatively determine if the flow is contained is 5,000 cfs for the Velarde to Rio Chama Reach, 7,500 cfs for the Rio Chama to Otowi Bridge Reach, and 4,500 cfs for the Elephant Butte Dam to Caballo Reservoir Reach.

This attribute is rated as only "increase" or "no change" in the Engineering Effectiveness Evaluation Factor rating tables. The rating of "increase" occurs when a reach was rated not contained for existing conditions and containment is achieved by strategy implementation. Reaches that are rated contained under existing conditions will always be rated as "No Change." If strategy implementation increased capacity, the required flow would still be contained. A strategy would not be implemented that creates an outcome of not contained in a reach that met the criteria of contained. Thus, Rehabilitate Channel and Flood Plain could be rated as no change even though a higher discharge can flow in the enlarged cross section without raising the water surface elevation.

C1.7.6 Duration and Design Life Attribute

This attribute describes the effective service life duration and length of the design life of a strategy. This is a qualitative evaluation of the probability of failure for more structural strategies and the ability of a strategy to promote dynamic equilibrium.

- **High.** Strategies that use methods or tools with fixed features and low probability of failure, such as Promote Alignment Stability, are ranked high. Strategies that promote or have the potential to achieve dynamic equilibrium and/or are compatible with natural processes and natural variability within the lateral constraints also are ranked high.

- **Medium.** Strategies with features that are mobile at higher flows where mobility would potentially lead to lateral migration, which could undermine riverside infrastructure and facilities, are ranked medium. Strategies promoting dynamic equilibrium but are unable to achieve this result or will fill in with sediment over an extended period of years (beyond a few years) are included. Example strategies are Reconstruct and Maintain Channel Capacity, Increase Available Area to the River, and Rehabilitate Channel and Flood Plain (except where the model results show a steeper slope).

- **Low.** Low-ranking strategies are those that use mobile features that may not promote dynamic equilibrium and will likely fill in (at least in part) with sediment within a few years (approximately 1–3 years). Strategies that are affected by base level changes at Elephant Butte Reservoir also would be ranked low.

C1.7.7 Adaptability Attribute

Adaptability looks at both modification and addition at a later time (modularity). While all strategies can be modified or added to at a later time, some are more difficult than others.

- **High.** Strategies that can easily be modified and added to at a later time are ranked high. Examples are strategies with mobile features such as Rehabilitate Channel and Flood Plain or Reconstruct and Maintain Channel Capacity.

- **Medium.** Strategies implemented along the bank line, such as the Promote Alignment Stability Strategy, are easier to modify than strategies that span the channel, such as Promote Elevation Stability; but they are more difficult than strategies with mobile features. These strategies are rated medium.

- **Low.** Strategies that are difficult to modify or to be added to at a later time are ranked low. These are strategies that have fixed features that cross the channel, such as Promote Elevation Stability.

C1.7.8 Public Health and Safety Attribute

This attribute denotes whether a strategy results in the same or an increased level of public health and safety. Strategies that would negatively impact public health and safety would not be considered further. This indicator does not address the degree of public health and safety needs that may or may not exist in a given reach. Strategies rated as an increase are those that have fixed features, increase/maintain flow capacity, or promote dynamic equilibrium within lateral constraints (such as Promote Elevation Stability, Promote Alignment Stability, Increase Available Area to the River, and Rehabilitate Channel and Flood Plain). This attribute only relates an "increase" or a "no change" because a strategy that would reduce public health and safety would not be implemented. When channel hydraulic geometry and channel capacity remain the same, the public health and safety attribute receives a "no change" rating, such as Reconstruct and Maintain Channel Capacity and Manage Sediment.

C1.7.9 General Strategy Effects

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

- **Promote Elevation Stability.** Cross channel features have a low ability 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 complexity. Thus, the Ability to Implement Attribute would be rated lower.

In general, the Level of Confidence Attribute is rated high due to fixed features such as riprap and sheet pile (when the Gradient Restoration Facilities [GRF] 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. There is a high duration and design life—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.

No change in the Water Delivery Attribute is anticipated 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, 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 remain the same or increase, depending upon reach characteristics. Increased public health and safety would be expected for reaches where stabilizing the bed prevents degradation below the vegetation root zone, thus reducing the potential for future lateral migration.

- **Promote Alignment Stability.** This strategy generally can 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. Thus, this strategy is considered highly implementable. 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 methods have high ratings for the Level of Confidence and Duration and Design Life Attributes as discussed in appendix A.

  Transverse methods have medium ratings for the Level of Confidence Attribute. Transverse methods generally require more future maintenance than longitudinal 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 bank line access (Adaptability Attribute would be rated medium). Model results show, in general, that wetted perimeter, width-to-depth ratio, wetted width, and sinuosity remain about the same—resulting in no change in values 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 formed 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, which could be eroded away unless the bank line is stabilized. For reaches where the sinuosity increases, the ratings for the Water Delivery Attribute could decrease. Because of the low amount of 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 depositional. This sediment imbalance can be caused in part by base level changes as a result of variations in 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 (no change), and the Public Health and Safety Attribute is rated as no change.

- **Increase Available Area to the River.** Construction can be accomplished on the flood plain or terraces. This strategy requires land instruments to move infrastructure located outside the levee. In many reaches, land use would need to change for infrastructure to be relocated, resulting in a low rating for the attribute ability to implement. This strategy promotes dynamic equilibrium; however, there are limited postproject 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. Point bars may form during future lateral migration, resulting in a greater wetted width and hydraulic capacity. 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, only when sinuosity increases would a decrease in water delivery potentially occur (Water Delivery Attribute). In addition, model results show that hydraulic capacity would remain the same as the baseline. A potentially wider flood plain or inset flood plain for incised reaches creates additional flood storage—potentially increasing the rating for the Public Health and Safety attribute.

- **Rehabilitate Channel and Flood Plain.** The channel bank and flood plain are the construction location for this strategy. The Ability to Implement Attribute generally has low ratings due to the large, riparian forest area that would 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 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 adaptability. The wetted area, width-to-depth ratio, and wetted width will all increase, while the water surface elevation will decrease. Sinuosity would remain about the same as baseline. Thus, water delivery would potentially decrease (Water Delivery Attribute). Hydraulic capacity will increase (Hydraulic Capacity Attribute). However, if 10,000 cfs (or other discharges for the nonmodeled reaches) are contained for the baseline condition (Indicator D: Containment of 10,000 cfs), then the rating is no change. The Public Health and Safety Attribute will increase due to 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 medium due to 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, owing 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 or design or postproject 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 a river channel. Thus, the ratings for the Level of Confidence Attribute for most reaches are low.

  Ratings for the Duration and Design Life Attribute would be 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.

Ratings for the Adaptability Attribute are 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 rating for the Hydraulic Capacity Attribute would not change.

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

C1.8 Ecosystem Function Evaluation Factor

Two federally endangered species are used to assess the habitat value and needs—southwestern willow flycatcher, *Empidonax traillii extimus*, and Rio Grande silvery minnow, *Hybognathus amarus*, (RGSM). 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) have evolved in the Rio Grande system and require a properly functioning river and flood plain to thrive.

The discussion of effects in this report are general in nature, as this analysis attempts to broadly define effects to SWFL and RGSM and their habitat from river maintenance and related activities on a reach basis. Individual projects will be fully evaluated through specific Endangered Species Act, section 7 consultations. Where the probable magnitude of an effect is known, it is analyzed.

If management strategies are used to promote habitat for both species, it is assumed (at this appraisal level of analysis) that all other aspects of the river system will be functioning properly and will support the other species that depend upon it. The following sections explain how selected habitat attributes will be used to predict impacts to each species and, in turn, to the ecosystem as a whole from various river management strategies. Table C1.11 lists the attributes used in the ecosystem function assessment. Attributes are scored as a “3” when the implemented strategy is judged likely to increase the attribute or result in a low construction impact, a “2” when little change is expected in the attribute or result in a medium construction impact, and a “1” when there is may be a decrease in the attribute or result in a high construction impact.

Table C1.11. Ecosystem Function Effectiveness Evaluation Factor Attributes

Subevaluation Factor: SWFL	
Opportunity for a Variety of Successional Stages Attribute[1]	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 K: Bed Material.
Water Table Elevation Attribute	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]	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	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: 4,700 cfs/Overbank Inundation Discharge, and Indicator J: Wetted Width at 4,700 cfs.
Construction Impacts Attribute[1]	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	
Opportunity for Complexity Attribute	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	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 Flooding (High Flow Inundated Area/Channel Area), Indicator E2: High Flow Inundated Area/Channel Area, and Indicator J: Wetted Width at 4,700 cfs
Sinuosity Attribute	Indicator F2: Sinuosity: Strategy Sinuosity/Baseline Sinuosity represents the amount of sinuosity within each reach compared to the current conditions. Under the existing water and sediment loads, 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 Attribute)[1]	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 evaluated with habitat requirements to provide an overall rating.

C1.8.1 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 due to constraints that have limited high flows. The duration, frequency, magnitude, recession rate, and timing of high flows are all critical to establishing and developing SWFL habitat. All five of these elements must be in sync for vegetation to develop into suitable habitat:

- Duration of overbank flooding must be for a period necessary to deposit new sediments, flush salts, and raise ground water levels.

- 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.

- 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.

- Recession rates following a flood must be at a rate 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).

- Timing of overbank events is critical for establishing 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 as a result of such a breech, resulting in potential long-term benefits.

Analysis of strategy impacts to SWFL habitat via computer models is difficult at best and requires a significant amount of professional judgment. The attributes in table C1.11 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 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.

C1.8.1.1 Opportunity for a Variety of Successional Stages Attribute

Breeding habitat for the SWFL typically consists of early successional stage riparian habitat. Given proper hydrologic conditions, SWFL habitat can develop rapidly. The highest quality native SWFL habitat in the Middle Rio Grande is composed of Goodding's willow (*Salix gooddingii*) between the ages of 4–8 years. Habitat (particularly willows) that matures past this age tends to decrease in quality and will eventually reach a point of unsuitability. Maintenance strategies that promote overbank flooding, scouring, and deposition of sediment generally benefit SWFL habitat by creating areas that can be colonized by regenerating willow habitat. This also will promote rejuvenation and recolonization of understory vegetation within existing habitat, effectively increasing the vertical vegetative stratification and diversity that is essential to breeding SWFLs. Three indicators help predict impacts to this attribute:

- **Indicator A1: Longitudinal Channel Slope Stability.** A reduction in slope, depending on its relationship to sediment supply and other slope features, would either promote sediment deposition both within the river channel and, during overbanks events, within the adjacent flood plain or degrade the channel resulting in slope reduction if sediment is in short supply at the upper end of a reach. Sediment deposition would promote aggradation of the river channel and increase the likelihood of overbank events, which would promote SWFL habitat development. Sediment removal would be detrimental to SWFL habitat. Conversely, an increasing slope also has the potential to "reset" succession by scouring and deposition of bed material, which can then be colonized by native vegetation, also effectively increasing the diversity of riparian habitat available.

- **Indicator F2: Sinuosity: Strategy Sinuosity/Baseline.** The more sinuous the river channel, the more potential for habitat creation and destruction as well as a greater variety of successional stages.

- **Indicator K: Bed Material.** This indicator will determine a reach's potential for bed movement, river bar formation, and sediment deposition—which all pertain to lateral habitat recycling and establishing young successional stages of vegetation. Indicators K1: Percent Fines, K2: Percent Sand, and K3: Percent Gravel were used to determine how a strategy would make the bed material more coarse or fine.

C1.8.1.2 Water Table Elevation Attribute

The single biggest threat to the SWFL is habitat loss and degradation. High water demands during the past several decades have contributed to reduced or heavily modified river flows, which, in turn, reduce the amount of water available to flood plain riparian vegetation—either directly through a reduction in overbank flooding or via a lowering water table. River channel degradation, which can essentially drain the surrounding riparian area, is also a factor in water table lowering. The ultimate result is a decrease in habitat quality either through reduction in vigor or density of native vegetation or a replacement of native vegetation with more drought-tolerant, exotic vegetation like salt cedar (*Tamarix* sp.). River maintenance strategies that promote flood plain connectivity are beneficial to SWFL habitat. One indicator is used to predict strategy impacts to this attribute.

- **Indicator C: Bed Elevation Change.** Bed elevation changes indicate river channel aggradation or degradation and will determine if the river is increasing the adjacent water table elevation or acting as a drain.

C1.8.1.3 Flood Plain Width/Patch Availability Attribute

Another factor contributing to SWFL habitat loss throughout the Southwestern United States is the historic narrowing of the active flood plain through using berms, levees, and other flood plain development. A wider flood plain, either within or without historic bounds, allows floodwaters to spread out over a larger area, promoting sediment scouring and deposition and allowing native riparian plant species to colonize and revegetate. This promotes the habitat diversity and edges that are important to high-quality SWFL habitat. Maintenance strategies that broaden the active flood plain and increase the available area for habitat establishment are beneficial to breeding SWFLs. Three indicators were used to predict impacts to this SWFL habitat attribute:

- **Indicator E1: Overbank Inundation: High Flow Inundated Area/Channel Area.** This indicator determines the amount of overbank flow at typical high flows. Greater overbank flow area would increase the potential for habitat development and, thus, patch availability.

- **Indicator F2: Sinuosity: Strategy Sinuosity/Baseline Sinuosity.** This indicator represents the amount of sinuosity within each reach compared to the current conditions. It is assumed that greater sinuosity increases the opportunity for patches of habitat to develop into quality SWFL habitat due to bank line movement, erosion, and deposition.

- **Indicator I: Wetted Width at 4,700 cfs/Width Between Lateral Constraints.** This indicator determines what proportion of the flood plain is wetted at 4,700 cfs. Values closer to one are better for SWFL habitat.

C1.8.1.4 Attribute: Flood Plain Elevation Attribute

This attribute is similar to the previous attribute in its impact to SWFL habitat. A reduction in flood plain elevation would increase the opportunity for overbank flood events and the potential for scouring and deposition of sediment and regeneration of habitat. Strategies that reduce the flood plain elevation would be beneficial to SWFL habitat. While it is difficult to model potential strategy impacts to this attribute, three indicators were chosen that help in predicting impacts:

- **Indicator C: Bed Elevation Change.** An increase from baseline bed elevation shows a potential for aggradation within the reach that promotes flow access to flood plain. Conversely, a decrease shows a potential for degradation that would reduce flow access to flood plain.

- **Indicator E2: Overbank Inundation: 4,700 cfs/Overbank Inundation Discharge**. This indicator is a ratio between a common storm discharge and the discharge at which the flood plain becomes accessible to the flow. The larger the number, the greater the frequency of flooding.

- **Indicator J: Wetted Width at 4,700 cfs.** This indicator is useful because change from baseline wetted width shows the impact of a given strategy.

C1.8.1.5 Construction Impacts Attribute

Construction effects to SWFL and SWFL habitat would occur for most types of river maintenance projects. To minimize negative impacts to SWFLs, best management practices have been and will continue to be used. These practices include, but may not be limited to, avoiding construction from April 15–August 15, conducting annual surveys to ensure SWFL territories are identified, and ensuring at least a one-quarter mile 'buffer' between construction activities and known historic SWFL territories.

Some projects occur at locations where there are no other viable options and impacts are unavoidable. Impacts to the riparian area and SWFL habitat occur from clearing vegetation for access, staging areas, and the project area along the bank line, islands, and point bars. The amount of impact is variable. Overall, all vegetation removal is a detriment to the riparian area. The lack of vegetation opens up lanes for predators, increases erosion, and allows access to recreational activities; this lack of vegetation also means a loss of riparian plant density and variability. Re-vegetation is a constant aspect to all projects, and it takes 3–6 years for riparian habitat for SWFL and other nesting birds to grow—assuming that all hydrologic and environmental conditions are functioning properly.

Since all construction impacts are on a case-by-case basis, indicators are not used for assessment, and professional judgment is used for high, medium, and low rankings.

- **High.** High ratings are from projects that occur at or near suitable and/or occupied habitat, affect a wider riparian bank line, modify overbank flows, or affect potential habitat in islands and point bars; 50–70 percent of projects are of this type.

- **Medium.** Medium ratings are projects that have little access impacts, the project area is restricted to a very narrow bank line, impacts to point bars and islands are minimal, and the work is done from within the river; 30–50 percent of projects are of this type.

- **Low.** Low ratings are projects that have no need for new access and are totally within the river channel or outside of the riparian area. There are very few projects that fit this concept.

C1.8.1.6 General Strategy Effects

- **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 flood plain. 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 flood plain 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, which 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 flood plain 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 flood plain 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.

C1.8.2 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 historic range for RGSM, and RGSM has not been collected between Angostura and Cochiti Dams since 1995. RGSM was 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 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 that often are 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 most often are collected in shallow, low velocity areas. Turbidity is believed to provide a level of cover for the RGSM. 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 that 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-channel work may cause harassment or take of RGSM in the construction area due to equipment, increased sedimentation, and other water quality issues due to equipment fluid leakage. Best management practices will be used to minimize these effects. Effects to RGSM critical habitat are project specific. Indirect effects may include entrapment into constructed features during inundation, increased turbidity due to degradation of recently constructed areas, and some potential disturbance from equipment noise and vibration.

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

Attributes used in this assessment are briefly described in table C1.11 and in more detail in the following subsections.

C1.8.2.1 Habitat Complexity Attribute

RGSM require a variable mix of river habitats to survive. The needs of different life stages of the fish vary but are sometimes closely linked to habitats. For example, low velocity habitats provide nursery area for larval fish and resting cover for adult fish; deep pools provide thermal cover during extreme temperature seasons; and riffle and run areas provide feeding areas.

Good nursery habitat is a low velocity area that is highly productive (i.e., with high densities of plankton, diatoms, and small aquatic invertebrates, where young fish do not have to expend much energy—thus, allowing them to increase in size and swimming ability). Food availability is linked to habitats and tied to depth and substrate as well as riparian and aquatic vegetation.

High opportunity for complexity exists for strategies such as channel rehabilitation. This strategy is used in some locations to rehabilitate a less complex stretch of river to a more complex situation (e.g., more backwaters, side channels, braiding). Areas without high incision usually present greater opportunities to provide complexity. High rankings would be applicable for projects that provide complex habitats in a variety of discharge levels. Medium opportunities exist within areas that are intermediate in their confinement and incision. Projects may only provide seasonal complexity. Low opportunities for habitat complexity usually exist in a confined, highly incised channel with relatively straight, deep flows. Reconstructing the channel on a regular basis to maintain channel capacity likely will limit habitat complexity by removing bars and other in-channel features. Habitat complexity factors will be modeled later in more detailed reach specific analyses. Professional judgment is applied at this time.

C1.8.2.2 Flood Plain Connectivity and Frequency of Flooding Attribute

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. Overbank flooding creates abundant low velocity areas for egg entrainment, RGSM nursery habitat, and potential spawning habitat. Duration of overbank flooding is as important as frequency but is difficult to assess from the indicators. It is assumed that a lower flood plain elevation likely is to be wetted longer and more often. Correspondence of overbank flooding and RGSM spawning is critical to enable RGSM to benefit from of the out-of-channel habitats.

Gradual recession from the flood plain is important during inundation to reduce stranding potential and allow larvae enough time to develop into free swimming RGSM. Overbank pockets or near-bank backwaters probably will have the greatest potential of stranding young RGSM when in-river flows decline dramatically. Low velocity side-channels that maintain flow at all times are desirable.

High connectivity occurs when there is a minimum elevation difference with the river channel and flood plain areas. Backwaters and side-channels are inundated at various discharge levels. Medium flood plain connectivity occurs when only moderate discharge levels are needed to inundate off channel habitat areas. Low flood plain connectivity occurs in an incised, high-bank situation where the river cannot access flood plain or side channels without large magnitude floods to connect the off channel habitats.

Three indicators describe features of the Flood Plain Connectivity and Frequency of Flooding Attribute to provide data input to ratings that indicate whether RGSM or native fish habitat will be benefitted, degraded, or not changed by a particular strategy.

- **Indicator C: Bed Elevation Change.** Calculated by subtracting the baseline elevation from the strategy bed elevation. Positive values would be better for the ecosystem by increasing the potential for flood plain connectivity.

- **Indicator E2: Overbank Inundation: 4,700 cfs/Overbank Inundation Discharge.** This indicator is a ratio between a common storm discharge and the discharge at which the flood plain becomes accessible to the flow. The larger the number, the greater the frequency of flooding.

- **Indicator J: Wetted Width at 4,700 cfs.** Indicator values greater than 1 indicate greater potential for overbank flows and inundation of off channel habitat for fish.

C1.8.2.3 Sinuosity Attribute

RGSM require different habitat types during various portions of their life cycle. When the Rio Grande is more sinuous, it can provide juxtapositioned habitat types. Faster velocity, deeper water can flow next to slower velocity, shoreline water. Also, oxbows and islands can form that provide habitat complexity to the fish. Vegetative material on the shore with roots into the river seems to be a desirable habitat for juveniles and adults and also may be a seasonal location with more fish located in debris in the fall and winter. A meandering river with gradual bank lines has higher value than a steep-banked, straight section of river. The meander provided the greatest amount of bank line per distance of river and opportunities for complex multiuse habitat.

High sinuosity is a relative term on the Middle Rio Grande because the river is generally classified as straight in most classification systems. A single indicator was used to rate sinuosity:

- **Indicator F2: Sinuosity: Strategy Sinuosity/Baseline Sinuosity.** This indicator 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.

C1.8.2.4 Construction Impacts Attribute

Construction impacts to suitable habitat are kept to a minimum, if possible, during project planning. Work in the wet occurs mostly during September–April, when the river is at low levels. River maintenance projects are determined by specific locations along the river where infrastructure or houses will be impacted. Other types of river maintenance work occur along existing drains and canals. All projects along the river have possible impacts to fish during construction in the wet. Impacts to the riverine area occur from work along the bank line, clearing/lowering/removing islands and point bars, and accessing and crossing the river channel. The amount of impact is variable; but, overall, all work in the wet has a direct and indirect impact to the riverine area. Work along the bank line, islands, and bars in the wet may affect fish and water quality. Using silt fences and berms may help reduce impacts. Construction equipment crossing the river may impact fish. Habitat for fish can be restored or created in very short timeframes. Thus, if fish are only harassed away from a work area, reoccupation will occur almost immediately.

Since construction impacts are on a case-by-case basis, indicators are not used for assessment; and professional judgment is used with rankings of high, medium, or low:

- **High.** High impacts are from projects that occur along large wetted areas, involve multiple river crossings per day, require removing islands and bars, and involve heavy work with amphibious excavators in the wet. Projects that impact habitats for long durations will have greater effect on RGSM. Any water quality degradation could have a high impact potential as well.

- **Medium.** Medium impacts are from projects that have moderate bank line work, use riprap and coir fabric to stabilize the bank line, use silt fences, have minimal impacts to islands and bars, have few river crossings, and perform most of the work in the wet.

- **Low.** Low impacts are projects that are small in size, with few river crossings, and only impact the bank line outside of the wetted channel.

C1.8.2.5 General Strategy Effects

The effects on RGSM vary by reach, but general strategy effects are:

- **Promote Elevation Stability**

  In reaches with a degrading or stable bed elevation, this strategy essentially either will 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/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 flood plain 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 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**

  Overall, this strategy would increase the width-to-depth ratio and encourage overbank flooding that, ultimately, should benefit RGSM habitat by creating high productivity larval fish habitats, which are inundated more often than unrehabilitated areas. The possibility exists 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.

C1.9 Economic Evaluation Factor

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 cost of methods that most likely would be used to implement a strategy was the basis for the cost rating 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 C1.12 and in further detail in sections C1.9.1–1.9.8. General strategy effects on economics are discussed in section C1.9.9. 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.

[1] Because this report is not a National Environmental Policy Act (NEPA) environmental compliance document nor a Reclamation planning analysis, the ability to pay, unemployment in the region, and environmental justice aspects are not included in the economic analysis.

Table C1.12. Economic Evaluation Factor Attributes

Planning and Design Attribute	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	The degree of effort, analysis, and documentation required for a particular strategy to achieve environmental compliance.
Implementation Cost Attribute	Implementation costs of a strategy (including construction and annual sediment augmentation or removal costs).
Monitoring and Evaluation Attribute	The amount of monitoring and evaluation necessary to make effective decisions to perform effective maintenance and adaptations.
Frequency of Maintenance Attribute	How often maintenance work is anticipated. Frequencies will vary between strategies.
Amount of Maintenance Attribute	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	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	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.

C1.9.1 Planning and Design Attribute

Factors influencing the cost of planning and design include the spatial and temporal range of potential channel responses, uncertainty in channel response, and the types and sizes, etc. of features. Also included are land ownership, number and type of government agencies involved, potential impacts to diversion dams, proximity of infrastructure (horizontal and vertical), and biological significance of the reach for the SWFL and RGSM.

- **High.** High cost strategies include those that may have variable or potentially significant channel responses that require more detailed analysis (may include numerical modeling of channel response and processes). These strategies have more complex features requiring large design staff time, and the channel response is uncertain. Situations like the following could involve higher planning and design costs:

- Multiple private landowners, pueblos, wildlife refuges, and/or government agencies are involved.
- There are potential impacts to diversion dams.
- Infrastructure is in close proximity (vertical and horizontal) to planned project.
- A large amount infrastructure would be relocated.
- There are high uncertainties in channel response.
- There are significant features in the reach.
- The reach is biologically significant for the SWFL or RGSM.
- There are sufficient complexities that a numerical model such as SRH-1D or SRH-2D is needed

Costs for planning and designing methods under Sediment Management would be considered high since a sediment model study would need to be completed to estimate the channel response. Likewise, methods under Promote Elevation Stability also would be higher because the number, spatial distance between, and the height of structures can have different effects upon the channel. Rehabilitate Channel and Flood Plain is another example of high cost planning and design because a numerical model is needed to determine the dimensions of flood plain lowering to promote dynamic equilibrium.

- **Medium.** Medium cost strategies use methods that would be constructed in the channel with less certain channel response. Using multiple transverse features in a bend requires more design time and is an example of a medium rating. Strategies are rated medium for planning and design when both:
  - Two or three landowners' would be involved.
  - The reach is biologically less significant for the SWFL and RGSM.
- **Low.** Low cost strategies are those with easy-to-identify channel responses, simpler features, and more routine planning and design.

C1.9.2 Environmental Compliance Attribute

This attribute rates the degree of effort, analysis, and documentation required for a particular strategy to achieve environmental compliance. This includes obtaining Endangered Species Act (ESA), Clean Water Act (401 and 404), NEPA, and National Historic Preservation Act compliance. The amount of mitigation is included in this attribute. Since the 1993 Operation and Maintenance (O&M) Supplement to the Environmental Impact Statement was completed prior to the listing of the SWFL and RGSM on the endangered species list, additional NEPA compliance is accomplished on a case-by-case basis. ESA compliance with the current Biological Opinion (Service 2003) or the upcoming new Biological Opinion (when approved) is considered to be the relevant compliance document on a programmatic basis. Either document also contains the criteria and suite of methods that are considered to be bioengineering and habitat restoration. Note that, for the economic attributes, “high” ratings mean more cost and, thus, are not desirable.

The level of environmental compliance effort can be influenced by:

- The amount of potential short-term environmental impacts during construction.
- The amount and duration of potential long-term environmental effects.
- Whether environmental effects are significant or a finding of no significant impact can be made.
- The degree the strategy works with or initiates beneficial channel processes.
- The amount of mitigation required.
- The level of biological significance for the endangered SWFL and/or RGSM.

The effect of short-term construction impacts is reflected in the Ecosystem Function Evaluation Factor.

- **High.** Strategies that use methods with fixed features (e.g., Promote Elevation Stability and Promote Alignment Stability) would, in general, have higher mitigation and compliance costs because they reduce the potential for future channel bank line migration and habitat regeneration. In general, there are lower environmental compliance and mitigation costs associated with strategies that work with or encourage natural channel fluvial processes (e.g., Increase Available Area to the River and Rehabilitate Channel and Flood Plain). It should be recognized that there are specific instances where the work itself has relatively simple features with low construction impacts, but local site conditions cause compliance costs to increase. An example is excavating a pilot channel through sediment plugs. This maintenance action has low construction impacts; however, if there are adjacent suitable SWFL habitat and wetlands, then the cost of compliance would increase. The cost of compliance can increase even more if the suitable SWFL habitat is occupied. While these situations are acknowledged, it is not possible for these factors to be included in an appraisal-level analysis to compare alternatives.

High cost environmental compliance strategies include those with fixed channel features that reduce future opportunities for natural habitat development and sustainability and would be implemented across the channel. Promoting Elevation Stability (with cross channel features) is an example of a strategy that would have higher costs and potentially longer upstream and downstream effects than other features. Strategies with high environmental compliance costs also would include those involving large areas of riparian zone clearing and large earthwork quantities such as Rehabilitate Channel and Flood Plain and Reconstruct and Maintain Channel Capacity. Due to the high level of uncertainty in channel response and biological effects, environmental compliance costs for Sediment Management also are considered high. A strategy will have high environmental compliance costs if the reach is biologically significant for the SWFL and/or RGSM and if the implementation work will be conducted below the mean high water mark, such as in Promote Alignment Stability.

- **Medium.** Medium cost environmental compliance strategies would be those that either would be constructed below the mean high water mark or in biologically significant reaches for the SWFL and/or RGSM—but not both. When a strategy is constructed below the mean high water mark and is in a biologically significant reach, then the rating would be high. Promote Alignment Stability, when implemented in a reach that is not biologically significant for the RGSM and/or SWFL, is an example of a strategy with medium costs. Implementation is along the bank line and in the channel along the bank line.

- **Low.** Low cost environmental compliance strategies would be those that re-establish flood plain processes without using fixed features such as those used in Increase Available Area to the River. Costs would be low if there were no known presence or locations of biological significance for the RGSM and/or SWFL in a given reach. In this case, the amount of mitigation is expected to be low.

C1.9.3 Implementation Cost Attribute

This attribute provides information on the implementation (including construction and maintenance) costs of a strategy. A workshop was held on August 12–14, 2009, in Albuquerque, New Mexico, to determine appraisal level cost estimates for each method. For each strategy, the costs for the most applicable methods, as shown in appendix A, were used to estimate costs for each reach and strategy.

Since each reach has a different length, all costs were normalized by distance for better comparison between reaches.

Some strategy cost estimates use results from the SRH-1D model results (see appendix B). The estimated amount of sediment deposited or removed by the river per mile, the percentage of the meander belt width that does not fit between current infrastructure constraints, and the amount of anticipated change in channel slope were used in the cost estimates. In reaches where the future slope was calculated to decrease in the model, the number of structures was estimated by using two steps:

1. Calculating the vertical elevation change between the baseline and future estimated slope change at the downstream of each reach.

2. Dividing the downstream vertical change by the estimated grade control structure height of 1 foot and rounding up.

The potential number of sites for Promote Alignment Stability and Increase Available Area to the River was calculated by using two steps:

1. Estimating the reach average river channel bend arc and chord lengths (Moffitt and Bouchard 1975) using Geographic Information System (GIS) data

2. Multiplying the reach length by the percent of length that does not fit within the lateral constraints and the ratio of the reach average arc length divided by the chord length

For Increase Available Area to the River, the cost associated with any potential land acquisition was not included in the implementation estimate, because land values are highly variable, depending upon the location. There are areas that are project lands where this strategy could be applied without incurring land acquisition costs. In addition, evaluation of land costs is outside the scope of this report. These quantity estimates also are considered to be appraisal level (qualitative) and only for the purpose of comparing strategies by reach. The estimated costs are internal to the Albuquerque Area Office (AAO) and are not of suitable quality for distribution. Their only purpose is to compare strategies by reach, and the estimates are determined to be of suitable quality for this exclusive purpose.

Using the strategy cost results per mile, cost classes were determined as follows:

- **High.** High cost rating is reserved for any strategy with a cost greater than $1,500,000 per mile.

- **Medium.** The medium cost rating ranged from $500,000–$1,500,000 per mile.

- **Low.** The low rating is less than $500,000 per mile.

C1.9.4 Monitoring and Evaluation Attribute

This attribute evaluates the amount of monitoring and evaluation necessary to provide information about uncertainty and new knowledge needed to make effective decisions to perform effective adaptations. The amount of monitoring can be influenced by how close the reach is to dynamic equilibrium, how much variability exists in the strategy, the level of uncertainty in channel response, proximity of infrastructure, and the biological significance of the reach for the SWFL and RGSM. In general, strategies with fixed features have low variability, and strategies with erodible features have greater variability.

- **High.** High level monitoring and evaluation strategies have a high level of uncertainty in channel response and a large amount of anticipated maintenance and/or adaptive management. For these strategies, a large amount of monitoring is needed to determine channel response, effectiveness, and sustainability. High level of monitoring includes collection of cross sections, thalweg profiles, bed material, modeling, geomorphic assessment, and could include discharge measurements, etc., as well. Examples include Reconstruct and Maintain Channel Capacity and Manage Sediment. Strategies for reaches that have been determined to be biologically significant and have a medium amount of expected maintenance and/or adaptive management also would be included as high level of monitoring.

- **Medium.** Medium levels of monitoring and evaluation strategies have some uncertainty in channel response and effectiveness. Medium level includes collecting cross-section surveys, results from visual inspections, and sequential photographs over a period of time from fixed photograph points. Evaluation could include time comparison of cross sections, visual assessment using photographs to compare conditions through time, and careful observations of visual change. Examples include Rehabilitate Channel and Flood Plain and Promote Elevation Stability.

  Medium levels also would include strategies in reaches that have been determined to be biologically significant for the SWFL and/or RGSM and do not have a high level of uncertainty or anticipated future adaptive management, such as Promote Alignment Stability Strategy. Increase Available Area to the River allows current channel processes to continue uninterrupted, so this strategy would not be rated as medium even when located in a biologically significant reach. For reaches where both vertical and horizontal channel processes occur, the rating for Increase Available Area to the River would be medium. Should river conditions change for medium level monitoring and evaluation strategies, then high level monitoring may be necessary at a later time.

- **Low.** Low levels of monitoring would be strategies with low variability associated with fixed features, or when the infrastructure is relocated, for which little or no monitoring is needed to determine channel response, effectiveness, and sustainability. Low level monitoring includes visual inspection and sequential photographs over a period of time from fixed photograph points. Examples where this type of monitoring is useful are Promote Alignment Stability and Increase Available Area to the River. Should river conditions change for strategies with low level monitoring and evaluation ratings, then medium or high level monitoring may be necessary.

C1.9.5 Frequency of Maintenance Attribute

This attribute is used to rate how often maintenance work is anticipated. Types of periods and frequencies will vary between strategies. If the design life is longer than when maintenance and/or adaptive management are needed, the strategy would be rated high.

- **High.** High frequency of maintenance will be strategies that require sediment removal, can be affected by base level changes, or have high potential for erosion or deposition (e.g., Reconstruct and Maintain Channel Capacity and Manage Sediment).

- **Medium.** Medium frequency of maintenance strategies may need some maintenance but do not have fixed features (e.g., Rehabilitate Channel and Flood Plain).

- **Low.** Low frequency of maintenance strategies either have fixed, non-erodible features, are deformable, or work with natural channel processes to bring sediment load and sediment transport capacity closer. Promote Elevation Stability, Promote Alignment Stability, and Increase Available Area to the River are examples of strategies with a low rating. The frequency of maintenance for Manage Sediment is considered low since the annual cost of adding sediment is included in the implementation cost.

C1.9.6 Amount of Maintenance Attribute

This attribute focuses on maintenance that is known to be necessary on a recurring basis. This attribute describes the relative maintenance cost magnitudes necessary for the estimated frequencies described in the previous attribute. The amount, frequency, and type of maintenance is generally known and reconstructs or restores strategy features to about the implemented condition. The amount of maintenance can be influenced by the how close the reach is to equilibrium, how much effect base level changes of Elephant Butte Reservoir have on the reach, and the expected sustainability of the strategy.

- **High.** Strategies with a high level of maintenance are those with more mobile features such as Reconstruct and Maintain Channel Capacity. Sediment deposition occurs on a recurring basis in the reach upstream of the reservoir pool, which needs to be removed to maintain channel capacity and water delivery to the reservoir.

- **Medium.** A medium rating is for strategies that have a low amount of maintenance used in a reach with characteristics that may increase the amount of maintenance, such as Promote Alignment Stability in the River Mile 78 to Elephant Butte Reservoir Reach. When the bed elevation lowers as a result of changes in water surface elevation of Elephant Butte Reservoir, the toe of riprap fixed features may need to be augmented with additional sediment.

- **Low.** Strategies with a low level of maintenance have more fixed features or work with natural channel processes. Strategies such as Promote Elevation and Alignment Stability, Increase Available Area to the River, and Rehabilitate Channel and Flood Plain generally have a low amount of potential maintenance. The amount of maintenance for managing sediment is considered low since the annual cost of adding sediment is included in the implementation cost.

C1.9.7 Frequency of Adaptive Management Attribute

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 project/strategy implementation and river dynamics become better understood. It is a stepwise process of stakeholder involvement, alternative identification, prediction of channel response (using state-of-the-art design and analysis methods), selection of a management alternative, development of monitoring plans, implementation, monitoring the effects of implementation, evaluation of monitoring results, and execution of adjustments to the constructed project/strategy (adapted from Williams et al. 2007). The intent is to adjust the implementation (which may be staged to respond to uncertain conditions) in a timely manner to address any concerns that may arise, meet project/strategy objectives, and provide lessons learned to projects in the future. Adaptive management can change implemented channel conditions and features. The frequency and type of adaptive management are not known prior to implementation.

This attribute describes the relative frequency of potential adaptive adjustments that may be needed to realize strategy objectives.

- **High.** High frequency of adaptive management would be strategies or reaches with more dynamic characteristics and variability. Also included are strategies where there is more opportunity for the river to accomplish some of the goals, and adaptively managing later to minimize strategy costs. Reconstruct and Maintain Channel Capacity would have a high frequency of adaptive management due to the frequent need and spatial extent of sediment removal. A high frequency of adaptive management may be needed for strategies implemented in reaches that are biologically significant for the SWFL and RGSM. Strategies within reaches that are highly dynamic and are significant for the SWFL and RGSM are rated high. A high rating also is given for strategies that use uncertain technologies and high potential variability. Strategies within a reach that has high dynamics is significant for the listed species; either technology uncertainty or high variability also is rated high.

- **Medium.** Medium frequency is for strategies that usually have a low need for adaptive management but are implemented in a reach that is biologically significant for the SWFL and RGSM. Reaches that are either highly dynamic or are significant for the SWFL and RGSM, but not both, are rated medium. A medium rating also is given for strategies that have either technology uncertainty or high potential variability, but not both. Strategies with a reach that has high dynamics and has either technology uncertainty or high variability are also rated medium. A strategy that has either uncertain technology or is highly variable and is in a reach that is significant for the SWFL and RGSM but with low reach dynamics also is rated as medium.

- **Low.** Low frequency of adaptive management would be strategies with fixed features that have little variability and uncertainty and for which the channel dynamics are expected to be low. Strategies that work with natural channel processes also are rated low. Reaches with low dynamics, relatively certain technology, and low biological significance for the SWFL and RGSM are rated low. Promote Elevation and Alignment Stability and Increase Available Area to the River are examples of a low rating when implemented in reaches that are not biologically significant for the SWFL and RGSM.

C1.9.8 Amount of Adaptive Management Attribute

This attribute describes the relative magnitude of potential adaptive adjustments after strategy implementation. Some methods under some strategies may be implemented with a lower level of effort as the river can do some of the work, and additional implementation can be performed later to complete the work (e.g., plug removal in Reconstruct and Maintain Channel Capacity). In this case, it is anticipated that this effort would be smaller than if there was full mechanical implementation. Another approach would be to design for variability and uncertainty, rather than to assume the worst case, and perform monitoring, evaluation, and adaptive management later to realize the planned benefits. The cost of augmenting sediment each year is considered part of the implementation cost. Adaptive management can change the implemented project feature and conditions.

- **High.** High levels of adaptive management would be needed for strategies or reaches with more dynamic characteristics and variability as well as with more opportunities for the river to accomplish some of the strategy goals and adaptively managing later to minimize strategy costs. For example, Reconstruct and Maintain Channel Capacity would have a high level of adaptive management because of the frequent need and spatial extent of potential sediment removal. High levels of adaptive management also may be needed for strategies implemented in reaches that are biologically significant for the SWFL and RGSM. Reaches that are highly dynamic have uncertain technology or more variability in the strategy; reaches that are biologically significant for both the SWFL and RGSM are rated high.

- **Medium.** Medium levels would be needed for strategies that usually would have a low need for adaptive management but are implemented in a reach that is biologically significant for the SWFL and RGSM. Rehabilitate channel and flood plain would be rated as medium since it is difficult to accurately estimate the elevation of the lowered terraces using fixed bed models and sediment transport models during peak flows. The river can scour during peak flows and fill during the recession of the hydrograph, making estimating this elevation difficult. Once a suitable elevation is determined or altered after implementation, future adaptive management would be low. Sediment will deposit in the newly established flood plain diminishing channel capacity over time. Removal of these sediments would disturb the newly established riparian zone. If a reach is highly dynamic and there is uncertain strategy technology or variability, the rating is also medium.

- **Low.** Low level of adaptive management would be strategies with fixed features that have little variability or uncertainty, low amounts of channel dynamics, or which work with natural channel processes. Reaches that are not biologically significant for the SWFL and RGSM are rated low. Examples are Promote Elevation Stability, Promote Alignment Stability, and Increase Available Area to the River when implemented in reaches that are not biologically significant for the SWFL and RGSM.

C1.9.9 General Strategy Effects on Economics

The general effects on economics are described by strategy below. For this analysis, economics are based on costs that depend on a variety of factors, including the biological significance of and methods appropriate to a reach.

- **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 high planning and design cost rating. Cross channel, fixed structures reduce opportunity for natural habitat development and sustainability requiring a high amount of environmental compliance.

- The range of implementation costs depend on the amount of slope change between the stable slope and base line. With some uncertainty in channel response, ratings for the Monitoring and Evaluation Attribute are medium. For fixed non-erodible features, there is low frequency and amount of maintenance unless reach characteristics increase the ratings of the Frequency of Adaptive Management and Amount of Adaptive Management Attributes to medium. There may need to be future structures added to a given reach after the channel response is known to adaptively manage this strategy. These attributes are rated low for fixed features, except in reaches that are biologically significant for the RGSM and SWFL.

- **Promote Alignment Stability.** Reclamation has extensive experience with planning and design of longitudinal methods and less experience with transverse features. Planning and design costs are 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 RGSM or SWFL. Work also is conducted below the mean high water mark adding to environmental compliance costs. 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 RGSM or SWFL (see appendix A for more detail). Fixed features require low amounts of both frequency and amount of future maintenance. 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 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 implementation of other strategies.

- **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.

  To improve the estimation of future channel response, conducting a numerical sediment model is advisable. The Planning and Design Attribute is rated high for costs due to the need to conduct numerical modeling to improve the certainty in estimating channel response and to maximize strategy benefits.

  As implementation includes excavation of the main channel and there is uncertainty in the channel response, this strategy is rated as high for environmental compliance costs.

  The Monitoring and Evaluation Attribute is rated high for this strategy as it has mobile features and a higher likelihood of maintenance and/or adaptive management. The frequency of maintenance can be high, especially in the River Mile 78 to Elephant Butte 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. 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, ratings for the Frequency of Adaptive Management and Amount of Adaptive Management Attributes are high.

- **Increase Available Area to the River.** Infrastructure relocation generally requires a high amount of planning and design, especially if there are multiple landowners or government agencies involved. 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. Implementation ranges from low to high depending upon the value of Indicator: H1: Percent Fit of Length. Frequency and amount of maintenance and of adaptive management are all low with the infrastructure being relocated. However, because it is unlikely that enough space can be acquired to permanently ensure that relocated levees will not be impacted, future migration monitoring is necessary, and additional strategies may need to be implemented.

- **Rehabilitate Channel and Flood Plain.** A numerical model is needed to determine the dimensions and elevations of flood plain lowering, resulting a high planning and design costs. The large amount of vegetation clearing in the riparian zone, coupled with the large earthwork quantities, means that environmental compliance and implementation costs are high.

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, and a low frequency and amount of maintenance is expected. Sediment deposition will occur over time in the newly created flood plain area during inundation events; however, the presence of a new riparian zone would prevent excavation of these deposits to maintain the post implementation flow capacity.

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 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. Due to the level of uncertainty in channel response and biological affects, the Environmental Compliance Attribute would be rated high. Implementation costs 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 amount of monitoring and evaluation is associated with uncertain channel response. 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 is 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.

C1.10 Summary of Strategy Assessment

In each reach chapter (C2–C12), there are discussions on the reach characteristics, specific evaluation results, and recommendations of strategies to be studied further. The results of the reach characteristics evaluations on Channel Instability and importance of Water Delivery Impact; Infrastructure, Public Health and Safety; and Habitat Value and Need reach characteristics are presented first. A summary of all ratings is in section C1.10.1.

Next, the scores for the Engineering Effectiveness, Ecosystem Function, and Economic Evaluation Factors are presented by strategy. Comparison tables of attribute ratings by evaluation factor follow. Index scores are developed for the ratios of subevaluation factors to cost, overall evaluation factors to cost, and total effectiveness to cost and presented graphically for each reach.

This is followed by the recommendations. Within a reach, those strategies with low effectiveness-to-cost ratios are eliminated from more detailed study. The remaining strategies are recommended for feasibility evaluation and possible site design. A summary of all recommendations is in section C1.10.2.

Note that general effects of strategy implementation are discussed in sections C1.6–C1.9. These general effects are not repeated in the discussions for each reach.

C1.10.1 Summary of Reach Characteristics Ratings

Table C1.13 presents a summary of the reach characteristics ratings. Table C1.14 gives more detail on the Channel Instability rating.

C1.10.2 Summary of Assessment Results

Please note that reach prioritization for further study should include consideration of reach characteristics. Table C1.15 shows a summary of the strategy assessment results and identifies which strategies are recommended for further study or why a strategy was unsuitable or not analyzed.

Strategies are screened out as not suitable when they do not address the reach characteristics of concern, if the modeled indicator results do not show the need for a strategy, or if the implementation of a strategy is simply not feasible within a reach. Promote Elevation Stability is not analyzed in aggrading reaches because aggradation is addressed through other complementary strategies (see table C1.4 for more information). The remaining strategies are scored for the Engineering Effectiveness, Ecosystem Function, and Economic Evaluation Factors.

Table C1.13. Reach Characteristics Ratings

Reach	Channel Instability	Water Delivery Impact	Infrastructure, Public Health, and Safety	Habitat Value and Need	
				SWFL	RGSM
Velarde to Rio Chama	Medium	Low	Medium	High	Low
Rio Chama to Otowi Bridge	Low	Low	High	Low	Low
Cochiti Dam to Angostura Diversion Dam	Low	High	Medium	Low	Low
Angostura Diversion Dam to Isleta Diversion Dam	Medium	High	High	Low	High
Isleta Diversion Dam to Rio Puerco	Medium	Medium	High	High	Medium
Rio Puerco to San Acacia Diversion Dam	Medium	High	Low	High	Medium
San Acacia Diversion Dam to Arroyo de las Cañas	Medium	High	Medium	Low	High
Arroyo de las Cañas to San Antonio Bridge	Medium	High	Medium	Low	High
San Antonio Bridge to River Mile 78	High	High	Medium	High	High
River Mile 78 to Elephant Butte Reservoir	High	High	Low	High	Medium
Elephant Butte Dam to Caballo Reservoir	Medium	Medium	High	Low	Low

Table C1.14. Channel Instability Factor Ratings

Reach	Slope Change	Length of Meander Belt Outside Constraints[1]	Available Area Used by Meander Belt[2]	Sediment Volume Change	Planform Change	Bed Level Change
Velarde to Rio Chama	Low	Medium	Medium	Low	Medium	Low
Rio Chama to Otowi Bridge	Low	Medium	Medium	Low	Low	Low
Cochiti Dam to Angostura Diversion Dam	Low	Medium	High	Low	Low	Low
Angostura Diversion Dam to Isleta Diversion Dam	Low	High	High	Low	Low	Low
Isleta Diversion Dam to Rio Puerco	Low	Medium	Medium	Low	Medium	Low
Rio Puerco to San Acacia Diversion Dam	Medium	Medium	Medium	Low	Medium	High
San Acacia Diversion Dam to Arroyo de las Cañas	Medium	Low	Medium	Low	Medium	High
Arroyo de las Cañas to San Antonio Bridge	Medium	Medium	Medium	High	Medium	High
San Antonio Bridge to River Mile 78	Medium	Medium	Medium	High	High	High
River Mile 78 to Elephant Butte Reservoir	High	Medium	Medium	Low now, but high historically	High	High
Elephant Butte Dam to Caballo Reservoir	Low	Medium	Medium	Medium	Low	Medium

[1] Rating is based on the percentage of reach length where the calculated meander belt does ***not*** fit within lateral constraints of infrastructure or geology.

[2] Rating compares area of meander belt to available area between lateral constraints.

Table C1.16 gives more detail on the Water Delivery Attribute ratings as used in the Engineering Effectiveness Evaluation Factor. The scores for Engineering Effectiveness and Economic Evaluation Factors are weighted by attribute. The Ecosystem Function scores were based on attributes of equal weight at this appraisal level of analysis. Index scores are developed for the ratios of subevaluation factors to cost, evaluation factors to cost, and total effectiveness to cost. The largest score for each is assigned 100, and the smallest score is assigned a value of zero. All scores in between are linearly indexed to allow comparison of the ratios between reaches. These indexed results are summarized graphically for each reach. Within a reach, those strategies with low effectives to cost ratios are eliminated. The remaining strategies are recommended for more detailed analysis. Results are presented by strategy and summarized for each reach by evaluation factor.

It should be noted that site-specific application of any of the methods of a strategy is not precluded by the screening out of reach-wide implementation. Further information on strategy assessment can be found in the reach chapters that follow.

Table C1.15. 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 C1.15. 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.

Table C1.16. Indicator Ratings for Water Delivery Attribute

Reach	Indicator	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to River	Rehabilitate Channel and Flood Plain	Manage Sediment*
Velarde to Rio Chama	Findings	Not suitable	Further study	Not suitable	Further study	Not recommended	Not suitable
	B: Wetted Area at 4,700 cfs		No Change		No Change	Decrease	
	F1: Strategy Sinuosity		No Change		No Change	No Change	
	G: Width-to-Depth Ratio at 4,700 cfs		No Change		No Change	Decrease	
	J: Wetted Width at 4,700 cfs		No Change		No Change	Decrease	
Rio Chama to Otowi	Findings	Not recommended	Further study	Not suitable	Further study	Not recommended	Not suitable
	B: Wetted Area at 4,700 cfs	No Change	No Change		Decrease	Decrease	
	F1: Strategy Sinuosity	No Change	No Change		Decrease	No Change	
	G: Width-to-Depth Ratio at 4,700 cfs	No Change	No Change		No Change	Decrease	
	J: Wetted Width at 4,700 cfs	No Change	No Change		No Change	Decrease	
Cochiti Dam to Angostura Diversion Dam	Findings	Further study	Further study	Not suitable	Further study	Not recommended	Not suitable
	B: Wetted Area at 4,700 cfs	No Change	No Change		No Change	Decrease	
	F1: Strategy Sinuosity	No Change	Decrease		Decrease	No Change	
	G: Width-to-Depth Ratio at 4,700 cfs	No Change	No Change		No Change	Decrease	
	J: Wetted Width at 4,700 cfs	No Change	No Change		No Change	Decrease	
Angostura Diversion Dam to Isleta Dam	Findings	Further study	Further study	Not suitable	Not suitable	Further study	Further study
	B: Wetted Area at 4,700 cfs	No Change	No Change			Decrease	No Change
	F1: Strategy Sinuosity	No Change	No Change			No Change	No Change
	G: Width-to-Depth Ratio at 4,700 cfs	No Change	No Change			Decrease	No Change
	J: Wetted Width at 4,700 cfs	No Change	No Change			Decrease	No Change
Isleta Dam to Rio Puerco	Findings	Further study	Not suitable	Not recommended	Further study	Further study	Not recommended
	B: Wetted Area at 4,700 cfs	No Change		No Change	No Change	Decrease	No Change
	F1: Strategy Sinuosity	No Change		No Change	No Change	No Change	No Change
	G: Width-to-Depth Ratio at 4,700 cfs	No Change		No Change	No Change	Decrease	No Change
	J: Wetted Width at 4,700 cfs	No Change		No Change	No Change	Decrease	No Change
Rio Puerco to San Acacia Diversion Dam	Findings	Not suitable	Further study	Not suitable	Further study	Not suitable	Not suitable
	B: Wetted Area at 4,700 cfs		No Change		No Change		
	F1: Strategy Sinuosity		Increase		Increase		
	G: Width-to-Depth Ratio at 4,700 cfs		No Change		No Change		
	J: Wetted Width at 4,700 cfs		No Change		No Change		

Table C1.16. Indicator Ratings for Water Delivery Attribute (continued)

Reach	Indicator	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to River	Rehabilitate Channel and Flood Plain	Manage Sediment*
San Acacia Diversion Dam to Arroyo de las Cañas	Findings	Further study	Further study	Not suitable	Further study	Further study	Not recommended
	B: Wetted Area at 4,700 cfs	No Change	No Change		No Change	Decrease	No Change
	F1: Strategy Sinuosity	No Change	Decrease		Decrease	No Change	No Change
	G: Width-to-Depth Ratio at 4,700 cfs	No Change	No Change		No Change	Decrease	No Change
	J: Wetted Width at 4,700 cfs	No Change	No Change		No Change	Decrease	No Change
Arroyo de las Cañas to San Antonio Bridge	Findings	Not suitable	Not suitable	Further study	Not suitable	Not suitable	Further study
	B: Wetted Area at 4,700 cfs			No Change			No Change
	F1: Strategy Sinuosity			No Change			No Change
	G: Width-to-Depth Ratio at 4,700 cfs			No Change			No Change
	J: Wetted Width at 4,700 cfs			No Change			No Change
San Antonio Bridge to River Mile 78	Findings	Not suitable	Not suitable	Further study	Further study	Not suitable	Further study
	B: Wetted Area at 4,700 cfs			No Change	Decrease		No Change
	F1: Strategy Sinuosity			No Change	Increase		No Change
	G: Width-to-Depth Ratio at 4,700 cfs			No Change	No Change		No Change
	J: Wetted Width at 4,700 cfs			No Change	No Change		No Change
River Mile 78 to Elephant Butte Reservoir	Findings	Not suitable	Not suitable	Further study	Further study	Not suitable	Further study
	B: Wetted Area at 4,700 cfs			No Change	No Change		No Change
	F1: Strategy Sinuosity			No Change	Decrease		No Change
	G: Width-to-Depth Ratio at 4,700 cfs			No Change	No Change		No Change
	J: Wetted Width at 4,700 cfs			No Change	No Change		No Change
Elephant Butte Dam to Caballo Reservoir	Findings	Not suitable	Further study	Further study	Not suitable	Not suitable	Not recommended
	B: Wetted Area at 4,700 cfs		No Change	No Change			No Change
	F1: Strategy Sinuosity		No Change	No Change			No Change
	G: Width-to-Depth Ratio at 4,700 cfs		No Change	No Change			No Change
	J: Wetted Width at 4,700 cfs		No Change	No Change			No Change

Chapter C2. Velarde to Rio Chama (RM 285 to RM 272)

C2.1 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, an 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 in this reach, particularly in the downstream three-fourths 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 the 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

C2.1.1 Channel Instability Reach Characteristic – Medium Instability

This reach was not modeled, therefore, the rating for Channel Instability is assessed through historical data and professional judgment. The Channel Instability is rated medium because it appears that the meander belt width needed (based on active channel locations from photography after 1971) fits between the infrastructure in most areas and there is space available for additional channel migration. There are several locations where the channel bank is near infrastructure; it is actively eroding near the San Ildefonso fishing ponds. Recent historical reach-wide trends show a low potential for change in slope, volume of sediment, and bed elevation.

Without further data and analysis, the rate and extent of channel change (migration) is uncertain, but it appears that lateral migration could increase, and the planform stage evolve to the right in the planform evolution model.[1] The upstream section of the reach is predominately in Stage M5 (Sinuous thalweg channel), and the downstream part in Stage M6 (Migrating bend channel) with some point bars that are vegetating. There are also isolated instances of split channels in the downstream portion (Stage M7 [Migrating with cutoff channel]). It appears that continued channel evolution to Stages M7 (Migrating with cutoff channel)/M8 (Cutoff is now main channel) is possible.

C2.1.2 Water Delivery Impact Reach Characteristic – Low Importance

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

C2.1.3 Infrastructure, Public Health, and Safety Reach Characteristic – Medium Importance

This reach has a medium rating since it 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. Part of Ohkay Owingeh Pueblo is along the southern portion of this reach.

C2.1.4 Habitat Value and Need Reach Characteristic

C2.1.4.1 Southwestern Willow Flycatcher – High Importance

Although not included in the critical habitat designation (Service 2005 [SWFL]), several patches of moderately to highly suitable SWFL habitat exist within this reach both inside and outside Ohkay Owingeh Pueblo. The best of these patches outside the pueblo were surveyed annually by Reclamation between 1995–2009. Several breeding territories were documented during surveys between 1995–2000. However, these pairs rarely produced a successful nest because habitat in this reach is narrow, predation, and brown-headed cowbird parasitism rates are high. Since 2000, only one unpaired territorial male has been documented. This population has not been able to sustain itself

[1] See section C1.4.1.3 in this appendix for a description of the Middle Rio Grande Planform evolution model.

and could be considered a sink (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). As stated above, berms and levees within this reach maintain a narrow active flood plain, which prevents habitat development in most areas.

A small population of SWFL has persisted within suitable habitat on the Ohkay Owingeh for the past several years. Exact numbers are unclear, but this population is typically between 10–15 territories and could serve as a source population for nearby suitable habitat. 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.

C2.1.4.2 Rio Grande Silvery Minnow – Low Importance

Though there are historic records of RGSM from the lower portions of this reach, it was likely never abundant and perhaps only seasonally occupied (Bestgen and Platania 1991). RGSM have not been documented in this reach for over 30 years. There are several large diversions in the river that create barriers to upstream movement of fish, minimizing the ability of fish to migrate. There is no “critical habitat” associated in this reach of the river. Ecosystem assessment for this reach is based on to the potential to support RGSM if they were repatriated as well as on the current native fish fauna. River sections with intact native fish assemblages are often closer to their historic condition, and this does not appear to be the case in this reach. The current fish fauna is comprised mainly of nonnative fishes, including white sucker (*Catostomus commersoni*) and common carp (*Carpiodes carpio*). Native fishes such as Rio Grande chub (*Gila pandora*) and Rio Grande sucker (*Catostomus [Pantosteus] plebeius*) are collected occasionally. There are small numbers of sport fish in the area; the closest stocking of rainbow trout occurs upstream near Pilar. There is little information on recreational fishing demand in the area.

Currently, this reach would be considered a low priority for management of RGSM and other native fishes. Any action that would provide greater habitat diversity and connectivity would improve function for native fish species.

C2.2 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 data were not available, but an agreement to share data acquired by the USACE is in progress.

This section highlights considerations for suitable strategies that should be studied further. Ratings for suitable strategies that are not recommended for further study are provided as an analytic aid.[1] Recommendations based on this analysis are in section C2.3.

C2.2.1 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.

C2.2.2 Promote Alignment Stability

Table C2.1 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

C2.2.2.1 Geomorphic Effects for Promote Alignment Stability

Minimizing lateral migration in this reach could start local bed degradation, resulting in increasing bank height. It appears that, in certain sections, transport capacity may be greater than the sediment load. Visual observation suggests that much of this reach is near dynamic equilibrium. The bed is fairly coarse, which reduces the likelihood of degradation, but the stability of the bed material should be assessed in this reach before implementing this strategy. There would be no improvement in attenuation of flooding in incised sections, and a decrease in episodic sediment transport is expected with the loss of local bank interaction. There is little space available for planform adjustment before stabilizing banks, so

[1] Ratings that are the same for a particular strategy and not affected by reach characteristics are discussed in the sections C1.7: Engineering Effectiveness Evaluation Factor, C1.8: Ecosystem Function Evaluation Factor and C1.9: Economic Evaluation Factor.

Table C2.1. Effectiveness and Cost Scores for Velarde to Rio Chama Reach, Promote Alignment Stability

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	Attribute	Raw Score	Weight	Weighted Score
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	3	20%	0.60
	Level of Confidence	3	10%	0.30
	Duration and Design Life	3	13%	0.39
	Adaptability	2	7%	0.14
	Strategy Performance Score		*50%*	*1.43*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.22*
	Engineering Effectiveness Score		**100%**	**2.65**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	1	10%	0.10
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*0.90*
	RGSM			
	Habitat Complexity	1	13%	0.13
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	2	13%	0.25
	RGSM Score		50%	0.88
	Ecosystem Function Effectiveness Score		**100%**	**1.78**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	Attribute	Raw Score	Weight	Weighted Score
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	2	11%	0.22
	Implementation Cost	1	25%	0.25
	Monitoring and Evaluation	1	9%	0.09
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	1	9%	0.09
	Economics Score		**100%**	**1.41**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem

little change in planform is anticipated. There should be a tendency to reduce connectivity because the banks are more stable, and few new areas of inset flood plain are anticipated.

C2.2.2.2 Engineering Effectiveness Evaluation Factor for Promote Alignment Stability

Agricultural/sparse development exists nearly to the riverbank, with only a small riparian zone. Landowners are usually interested in bank protection to preserve their property. The small riparian zone and sport fishery reduce environmental compliance needs. As a result, this strategy has high rating for the Ability to Implement Attribute in this reach. The likelihood of implementing other strategies in this reach at a later time is low. Longitudinal features most likely will be used as the channel is narrow (average width is 190 feet), especially when the river is laterally confined and has low sinuosity.[1] The low likelihood of future bed degradation increases the duration and design life.

C2.2.2.3 Ecosystem Function Evaluation Factor for Promote Alignment Stability

C2.2.2.3.1 Southwestern Willow Flycatcher

SWFL habitat depends on a dynamic, meandering river system that alternately scours and deposits new sediments where regenerating habitat can colonize. Promoting alignment stability decreases the ability of the river to do this and would, in turn, decrease the opportunity for a variety of successional stages; thus, the Variety of Successional Stages Attribute is rated as decreased. The Construction Impacts Attribute rating is medium because some work would occur both within the riparian area and within the river channel itself.

C2.2.2.3.2 Rio Grande Silvery Minnow

Since RGSM are not currently present, ecosystem assessment for this reach is based on to the potential to support RGSM if they were repatriated as well as on the current native fish fauna. Many of the areas have been altered from their historic condition, especially in 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. Generally, more confined river sections have less habitat diversity in the channel; thus, the Habitat Complexity Attribute is rated as decreased.

Construction could occur on the bank. Construction Impacts Attribute is rated medium because work in Rio Grande establishing stability would be primarily shore-based, and minimal construction would be in the active river channel.

C2.2.2.4 Economic Evaluation Factor for Promote Alignment Stability

Multiple landowner involvement would raise the Planning and Design Attribute rating to high, 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. With the relatively low sinuosity and confined land use, lower maintenance or adaptive management would be expected even for fixed features; thus, ratings for the Frequency of Adaptive Management and the Amount of Adaptive Management Attributes are low.

[1] Note that sinuosity in the Engineering Effectiveness Evaluation Factor section and discussion is a description, not an attribute.

C2.2.3 Reconstruct Main 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.

C2.2.4 Increase Available Area to the River

Table C2.2 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

Table C2.2. Effectiveness and Cost Scores for Velarde to Rio Chama Reach, Increase Available Area to the River

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	1	7%	0.07
	Strategy Performance Score		*50%*	*0.73*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.22*
	Engineering Effectiveness Score		**100%**	**1.95**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	3	10%	0.30
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	3	10%	0.30
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*1.20*
	RGSM			
	Habitat Complexity	3	13%	0.38
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	3	13%	0.38
	RGSM Score		*50%*	*1.25*
	Ecosystem Function Effectiveness Score		**100%**	**2.45**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	1	11%	0.11
	Implementation Cost	1	25%	0.25
	Monitoring and Evaluation	1	9%	0.09
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	1	9%	0.09
	Economics Score		**100%**	**1.30**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C2.2.4.1 Geomorphic Effects for Increase Available Area to the River

This strategy allows space for the channel to adjust its morphology as needed, which tends to increase the renewal of habitat, attenuate of extreme events, increase the chance of channel and flood plain adjustments, increase flood plain connectivity, sediment balance, and episodic sediment transport. In this reach, historical trends show mainly local adjustments that should give low to moderate increases using the processes listed above. Continued channel evolution to M7 (Migrating with cutoff channel)/M8 (Cutoff is now main channel) is possible as well as a possible short-term decrease of effective transport of water and sediment as the channel evolves.

C2.2.4.2 Engineering Effectiveness Evaluation Factor for Increase Available Area to the River

Because most of the land in this reach is privately owned and agricultural production extends nearly to the riverbanks, land instruments may be difficult to obtain for this strategy, without land purchase. It is unlikely that the land area will be available to allow lateral migration through the estimated meander belt width. Some irrigation canals, roads, and miscellaneous structures are adjacent to the river. This infrastructure would need to be relocated, but they are sparsely distributed. The riparian zone is small, so environmental impacts would be small. This strategy seeks to promote dynamic equilibrium. 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. Visual observations indicate that it is fairly close to dynamic equilibrium, with lateral migration possible.

C2.2.4.3 Ecosystem Function Evaluation Factor for Increase Available Area to the River

C2.2.4.3.1 Southwestern Willow Flycatcher

Impacts to SWFL habitat from this strategy should be positive by allowing the river to meander over a greater flood plain, potentially creating new and younger age classes of vegetation through scouring and deposition of sediments.

The Construction Impacts Attribute was rated medium, as most of the work could be conducted within the flood plain but outside of the riparian area.

C2.2.4.3.2 Rio Grande Silvery Minnow

Habitat availability in this reach would increase with this strategy. This reach is rated low for the Construction Impacts Attribute, because most of the equipment work could be done from the flood plain and terraces.

C2.2.4.4 Economic Evaluation Factor for Increase Available Area to the River

Each parcel of agricultural or sparsely developed land is relatively small and could be only a few acres. The potential involvement of numerous landowners would increase the planning and design costs even with a lower amount of infrastructure relocation designs, thus raising the Planning and Design Attribute rating to high. The riparian zone is narrow, reducing the difficulty in obtaining environmental compliance. The Implementation Cost Attribute was qualitatively evaluated, and the low rating is based upon smaller structures to relocate.

C2.2.5 Rehabilitate Channel and Flood Plain – Not Recommended

This strategy is not recommended for further study due to the low effectiveness-to-cost ratio. Table C2.3 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

Table C2.3. Effectiveness and Cost Scores for Velarde to Rio Chama Reach, Rehabilitate Channel and Flood Plain

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	2	7%	0.14
	Strategy Performance Score		*50%*	*0.80*
	River Maintenance Function			
	Water Delivery	1	13%	0.13
	Hydraulic Capacity	3	15%	0.45
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.24*
	Engineering Effectiveness Score		**100%**	**2.04**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	3	10%	0.30
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	3	10%	0.30
	Flood Plain Elevation	3	10%	0.30
	Construction Impacts[1]	1	10%	0.10
	SWFL Score		*50%*	*1.20*
	RGSM			
	Habitat Complexity	3	13%	0.38
	Flood Plain Connectivity and Flood Frequency	3	13%	0.38
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	3	13%	0.38
	RGSM Score		50%	1.38
	Ecosystem Function Effectiveness Score		**100%**	**2.58**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	2	11%	0.22
	Implementation Cost	3	25%	0.75
	Monitoring and Evaluation	2	9%	0.18
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	2	9%	0.18
	Economics Score		**100%**	**2.09**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C2.2.6 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.

C2.2.7 Strategy Assessment Result Comparison Tables

The ratings for each attribute for each of the evaluation factors for each strategy are shown in table C2.4 (Engineering Effectiveness Evaluation Factor), table C2.5 (Ecosystem Function Evaluation Factor), and table C2.6 (Economic Evaluation Factor).

Tables C2.7 and C2.8 summarize the effectiveness and economic scores for all suitable strategies for the reach.

For ease of comparison, figures C2.1–C2.3 graphically present the indexed scores for effectiveness divided by cost for each subevaluation factor, factor, and strategy total, respectively.

C2.3 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.

Table C2.4. Engineering Effectiveness Evaluation Factor Attribute Ratings for Velarde to Rio Chama Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
Construction location		Bank		Flood Plain and Terraces	Channel, Bank, Terraces, and Flood Plain	
Strategy Performance						
Ability to Implement		High		Low	Low	
Level of Confidence		High		Medium	Medium	
Duration and Design Life		High		Medium	Medium	
Adaptability		Medium		Low	Medium	
River Maintenance Function						
Water Delivery		No Change		No Change	Decrease	
Hydraulic Capacity		No Change		No Change	Increase	
Public Health and Safety		Increase		Increase	Increase	

Table C2.5. Ecosystem Function Evaluation Factor Attribute Ratings for the Velarde to Rio Chama Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability*	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
SWFL						
Variety of Successional Stages		Decrease		Increase	Increase	
Water Table Elevation		No Change		No Change	No Change	
Flood Plain Width/Patch Availability		No Change		Increase	Increase	
Flood Plain Elevation		No Change		No Change	Increase	
Construction Impacts		Medium		Medium	High	
RGSM[1]						
Habitat Complexity		Decrease		Increase	Increase	
Flood Plain Connectivity and Frequency of Flooding		No Change		No Change	Increase	
Sinuosity		No Change		No Change	No Change	
Construction Impacts		Medium		Low	Low	

No endangered species present. Assessment is an indication of aquatic health for general fish and wildlife benefit; species were present historically, but have since been extirpated.

Table C2.6. Economic Evaluation Factor Attribute Ratings for the Velarde to Rio Chama Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
Planning and Design		High		High	High	
Environmental Compliance		Medium		Low	Medium	
Implementation		Low		Low	High	
Monitoring and Evaluation		Low		Low	Medium	
Frequency of Maintenance		Low		Low	Low	
Amount of Maintenance		Low		Low	Low	
Frequency of Adaptive Management		Low		Low	Low	
Amount of Adaptive Management		Low		Low	Medium	

Table C2.7. Summary of Economics and Effectiveness Scores by Subevaluation Factor for Velarde to Rio Chama Reach

	Economics Score	Effectiveness Score			
Strategy	Cost	Strategy Performance	River Maintenance Function	SWFL	RGSM
Promote Elevation Stability					
Promote Alignment Stability	1.41	1.43	1.22	0.90	0.88
Reconstruct/ Maintain Channel Capacity					
Increase Available Area	1.30	0.73	1.22	1.20	1.25
Rehabilitate Channel and Flood Plain	2.09	0.80	1.24	1.20	1.38
Manage Sediment					

Table C2.8. Summary of Economics and Effectiveness Scores for Velarde to Rio Chama Reach

Strategy	Cost	Engineering Effectiveness	Ecosytem Function Effectiveness		Total Effectiveness
Promote Elevation Stability					
Promote Alignment Stability	1.41	2.65	1.78		4.43
Reconstruct/ Maintain Channel Capacity					
Increase Available Area	1.30	1.95	2.45		4.40
Rehabilitate Channel and Flood Plain	2.09	2.04	2.58		4.62
Manage Sediment					

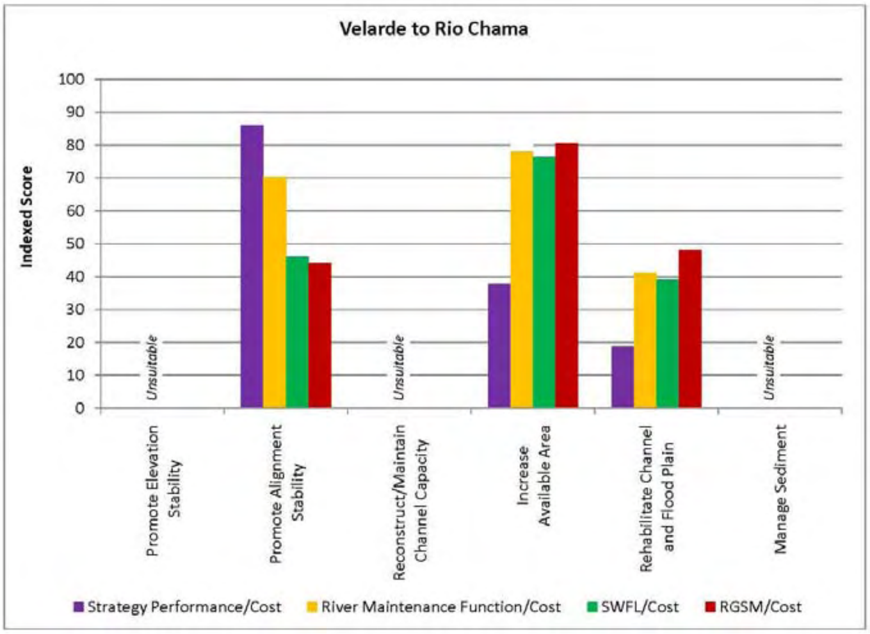

Figure C2.1. Velarde to Rio Chama Reach indexed effectiveness divided by cost scoring results by subevaluation factor.

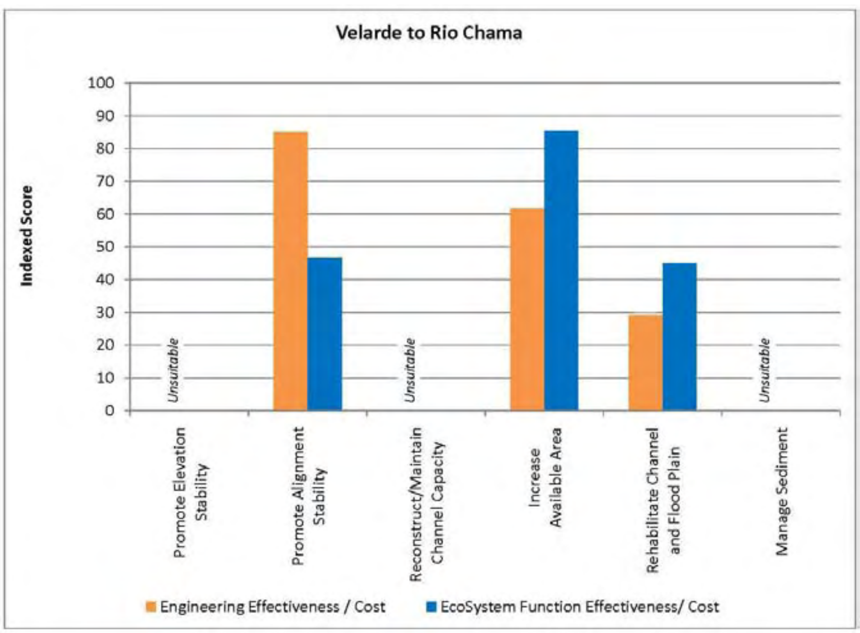

Figure C2.2. Velarde to Rio Chama Reach indexed effectiveness divided by cost scoring results by evaluation factor.

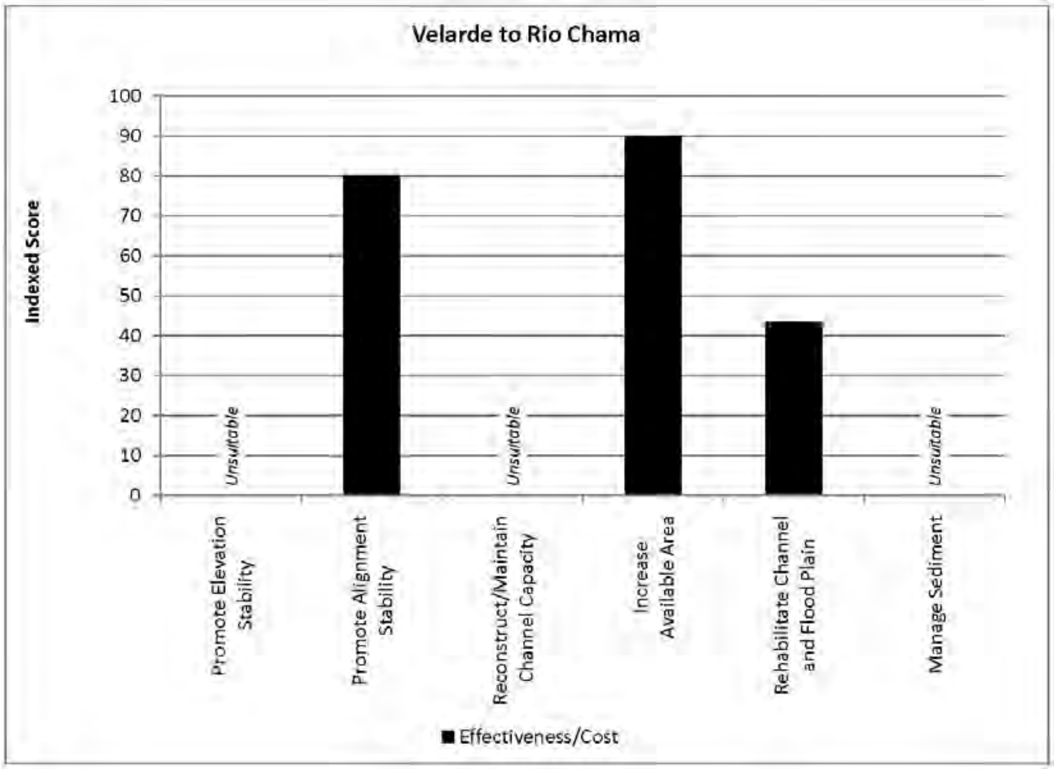

Figure C2.3. Velarde to Rio Chama Reach total effectiveness divided by cost indexed scoring results.

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.

Chapter C3. Rio Chama to Otowi Bridge (RM 272 to RM 257.6)

C3.1 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 about 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 historically has not been prone to widespread lateral erosion. Extensive gravel mining in the 1980s resulted in the bed of the river being lowered; degradation has progressed upstream since the conclusion of gravel mining operations. Continued bed lowering could initiate more channel migration. The channel is slightly sinuous and generally single-thread with sections of migrating bends and split channels. Continued bed lowering could initiate more channel migration.

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 San Ildefonso Pueblo.

C3.1.1 Channel Instability Reach Characteristic – Low Instability

As in the Velarde to Rio Chama Reach, modeling was not performed in this reach because current modeling data are not available. An agreement to share data acquired by USACE is in progress. The likelihood of reach-wide changes in channel slope, bed elevation, and bed elevation change are low. Several bends have been active since 1992. One bend near the San Ildefonso fishing pond has potential to impact infrastructure in the short term, but this appears to be a local phenomenon. In general, the meander belt mostly fits between the infrastructure (since 1971), and there is some space for adjustment; therefore, these two factors are rated as medium. The low rating for the Channel Instability Reach Characteristic in this reach is based on historical trends and professional judgment.

Without further data and analysis, it is uncertain just how much (and how fast) channel change to expect, but it appears that the planform could advance stages if stable slope analysis indicates a flatter slope than at present. The reach is predominately in Stages M5 (Sinuous thalweg channel) through M7 (Migrating with cutoff channel), with more large, well-established islands and generally less channel narrowing than upstream. It appears that continued channel evolution to Stages M7 (Migrating with cutoff channel)/M8 (Cutoff is now main channel) is possible but less likely than upstream.

C3.1.2 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 exists for diverting a small amount of irrigation water.

C3.1.3 Infrastructure, Public Health, and Safety Reach Characteristic – High Importance

The city of Española and associated infrastructure lie within this reach, which leads to a high rating for land use. A sewer lift station, levees, and several bridges are located through the town of Espanola. Ohkay Owingeh is along the northern portion of this reach. Santa Clara and San Ildefonso Pueblos are also in this reach.

C3.1.4 Habitat Value and Need Reach Characteristic

C3.1.4.1 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.

C3.1.4.2 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 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 incising all have 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 would still block fish passage upstream into this reach.

Reclamation has assisted Santa Clara Pueblo with fish surveys annually since 2001. The current fish fauna is comprised mainly of nonnative fishes including white sucker (*Catostomus commersoni*) and common carp (*Carpiodes carpio*). The most collected native fishes include longnose dace (*Rhinichthys cataractae*) and flathead chub (*Platygobio gracillis*). There are small numbers of sport fish (brown trout [*Salmo trutta]* and smallmouth bass [*Micropterus dolomeiui]*) in the area. Strategies to improve fisheries should focus on improving habitat complexity for all native fishes.

C3.2 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 would require outside agencies to accomplish. Current modeling data are not available for this reach, but an agreement to share data acquired by the USACE is in progress.

This section highlights considerations for suitable strategies that should be studied further. Ratings for suitable strategies that are not recommended for further study are provided as an analytic aid. Recommendations based on this analysis are in section C3.3.

C3.2.1 Promote Elevation Stability – Not Recommended

Promote Elevation Stability did not rate highly in this reach, so further study is not recommended unless new data shows significant bed elevation changes on a reach-wide basis. Table C3.1 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

Table C3.1. Effectiveness and Cost Scores for Rio Chama to Otowi Bridge Reach, Promote Elevation Stability

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	3	13%	0.39
	Adaptability	1	7%	0.07
	Strategy Performance Score		*50%*	*0.86*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.22*
	Engineering Effectiveness Score		**100%**	**2.08**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	3	10%	0.30
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	3	10%	0.30
	SWFL Score		*50%*	*1.20*
	RGSM			
	Habitat Complexity	2	13%	0.25
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	2	13%	0.25
	RGSM Score		50%	1.00
	Ecosystem Function Effectiveness Score		**100%**	**2.20**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	2	25%	0.50
	Monitoring and Evaluation	2	9%	0.18
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	1	9%	0.09
	Economics Score		**100%**	**1.86**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C3.2.2 Promote Alignment Stability

Table C3.2 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

Table C3.2. Effectiveness and Cost Scores for Rio Chama to Otowi Bridge Reach, Promote Alignment Stability

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	3	20%	0.60
	Level of Confidence	3	10%	0.30
	Duration and Design Life	3	13%	0.39
	Adaptability	2	7%	0.14
	Strategy Performance Score		*50%*	*1.43*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.22*
	Engineering Effectiveness Score		**100%**	**2.65**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	1	10%	0.10
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*0.90*
	RGSM			
	Habitat Complexity	1	13%	0.13
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	2	13%	0.25
	RGSM Score		50%	0.88
	Ecosystem Function Effectiveness Score		**100%**	**1.78**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	2	15%	0.30
	Environmental Compliance	2	11%	0.22
	Implementation Cost	1	25%	0.25
	Monitoring and Evaluation	1	9%	0.09
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	1	9%	0.09
	Economics Score		**100%**	**1.26**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C3.2.2.1 Geomorphic Effects for Promote Alignment Stability

It appears that channel migration and bed degradation have recently slowed in this reach. Measurements and analysis of how much the bank height has increased and whether the river has narrowed enough to boost reach-wide meandering should be performed to determine the need for this strategy before implementation. If the channel incision continues, thus increasing bank height, then the potential for lateral migration may be high enough to warrant implementation, and local areas may require bank protection.

C3.2.2.2 Engineering Effectiveness Evaluation Factor for Promote Alignment Stability

Landowners are most often interested in preventing lateral migration, so obtaining land instruments is relatively straightforward. However, the three pueblos identified above are in this reach. The limited size of the riparian zone through much of this reach, together with an absence of endangered species, makes environmental compliance[1] relatively straightforward. Thus, the Ability to Implement Attribute is rated high. Bank stabilization features have a high confidence level; and since lateral migration has not been a dominate process in this reach, flanking is not expected to occur. The low sinuosity and a low likelihood for incision increase the confidence in this strategy; thus, the Level of Confidence Attribute is rated high. The likelihood of the slope changing in the future is low, increasing the duration and design life.

C3.2.2.3 Ecosystem Function Evaluation Factor for Promote Alignment Stability

C3.2.2.3.1 Southwestern Willow Flycatcher

SWFL habitat depends on a dynamic, meandering river system that alternately scours and deposits new sediments that regenerating habitat can colonize. Promoting alignment stability decreases the ability of the river to do this and would, in turn, decrease the opportunity for a variety of successional stages; therefore, the Variety of Successional Stages Attribute is rated as decreased. The Construction Impacts Attribute is rated medium because some work would occur both within the riparian area and within the river channel itself.

C3.2.2.3.2 Rio Grande Silvery Minnow

RGSM are not currently found in this reach. Habitat complexity for native fishes would be decreased; and, thus, the Habitat Complexity Attribute is rated as decreased. Construction work occurs on the bank.

C3.2.2.4 Economic Evaluation Factor for Promote Alignment Stability

The Planning and Design Attribute is rated medium because of multiple landowners, the city of Española, and the three pueblos. The number of sites, qualitatively determined to be five, resulted in a low rating for the Implementation Cost Attribute. In a reach with relatively low sinuosity and without lateral migration as a dominant channel process, maintenance and adaptive management needs would be even lower than for fixed bank stabilization features. Thus, both the Frequency of Adaptive Management and the Amount of Adaptive Management Attributes were rated low.

[1] Note that while environmental compliance is not an engineering attribute, it is a consideration in the Ability to Implement Attribute. See section C1.7.2.

C3.2.3 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.

C3.2.4 Increase Available Area to the River

Table C3.3 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

Table C3.3. Effectiveness and Cost Scores for Rio Chama to Otowi Bridge Reach, Increase Available Area to the River

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	1	7%	0.07
	Strategy Performance Score		*50%*	*0.73*
	River Maintenance Function			
	Water Delivery	1	13%	0.13
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.09*
	Engineering Effectiveness Score		**100%**	**1.82**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	3	10%	0.30
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	3	10%	0.30
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*1.20*
	RGSM			
	Habitat Complexity	3	13%	0.38
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	3	13%	0.38
	RGSM Score		50%	1.25
	Ecosystem Function Effectiveness Score		**100%**	**2.45**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	1	11%	0.11
	Implementation Cost	1	25%	0.25
	Monitoring and Evaluation	1	9%	0.09
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	1	9%	0.09
	Economics Score		**100%**	**1.30**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C3.2.4.1 Geomorphic Effects for Increase Available Area to the River

There is a similar potential for channel migration as in Promote Alignment Stability, but it is unknown how much space may be needed. The effects should be larger than in Promote Alignment because the amount of migration would not be limited by infrastructure, and sediment stored in the banks would not be protected. The rate of change may be slow enough or the area provided limited, so any increase in support for natural channel processes might not extend through the majority of the reach in the next decade, thereby creating local impacts.

C3.2.4.2 Engineering Effectiveness Evaluation Factor for Increase Available Area to the River

The land along the river in this reach is either pueblo or privately owned. Since the land area needed for this strategy is likely large, land instruments will be difficult to obtain. This strategy seeks to promote dynamic equilibrium; however, how close this reach is to dynamic equilibrium is an unknown. There may be increases in sinuosity and wetted area, causing a small potential for water delivery to decline (thus, the Water Delivery Attribute is rated low). Due to close to decline (thus, the Water Delivery Attribute is rated low). Due to close proximity of infrastructure in portions of this reach, there may not be lands available for this strategy without land use changes. However, there are undeveloped areas in the pueblos where this strategy could be applied.

C3.2.4.3 Ecosystem Function Evaluation Factor for Increase Available Area to the River

C3.2.4.3.1 Southwestern Willow Flycatcher

Impacts to SWFL habitat from this strategy should be positive by allowing the river to meander over a greater flood plain, potentially creating new and younger age classes of vegetation through scouring and deposition of sediments. The Construction Impacts Attribute is rated medium because most of the work could be conducted within the flood plain but outside of the riparian area.

C3.2.4.3.2 Rio Grande Silvery Minnow

Meandering rivers tend to provide a variety of habitats for native fishes, including low-velocity pools, riffles, and runs. The Construction Impacts Attribute is rated low because work occurs on the flood plain and terraces.

C3.2.4.4 Economic Evaluation Factor for Increase Available Area to the River

Since multiple landowners, pueblos, and government agencies are involved in this strategy, the Planning and Design Attribute is rated high, even though the potential infrastructure to be relocated is sparsely distributed except through the town of Espanola. In some subreaches, a relatively small or highly disturbed riparian zone exists, reducing the level of impact. Thus, the Environmental Cost Attribute is rated low. A sparse distribution of infrastructure also results in a low rating for the Implementation Cost Attribute. The Amount of Maintenance, Frequency of Adaptive Management and the Amount of Adaptive Management Attributes are rated low because infrastructure could be relocated away from the current active channel.

C3.2.5 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. This strategy is not recommended for further study; however, local alternatives to improve habitat should be explored.

Table C3.4 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

C3.2.6 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.

C3.2.7 Strategy Assessment Result Comparison Tables

The ratings for each attribute for each of the evaluation factors for each strategy are in table C3.5 (Engineering Effectiveness Evaluation Factor), table C3.6 (Ecosystem Function Evaluation Factor), and table C3.7 (Economic Evaluation Factor).

Table C3.8 and table C3.9 summarize the effectiveness and economic scores for all suitable strategies for the reach.

For ease of comparison, figures C3.1–C3.3 graphically present the indexed scores for effectiveness divided by cost for each subevaluation factor, factor, and strategy total, respectively.

C3.3 Recommendations

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

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

Table C3.4. Effectiveness and Cost Scores for the Rio Chama to Otowi Bridge Reach, Rehabilitate Channel and Flood Plain

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	3	7%	0.21
	Strategy Performance Score		*50%*	*0.87*
	River Maintenance Function			
	Water Delivery	1	13%	0.13
	Hydraulic Capacity	3	15%	0.45
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.24*
	Engineering Effectiveness Score		**100%**	**2.11**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	3	10%	0.30
	Water Table Elevation	3	10%	0.30
	Flood Plain Width/Patch Availability	3	10%	0.30
	Flood Plain Elevation	3	10%	0.30
	Construction Impacts[1]	1	10%	0.10
	SWFL Score		*50%*	*1.30*
	RGSM			
	Habitat Complexity	3	13%	0.38
	Flood Plain Connectivity and Flood Frequency	3	13%	0.38
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	3	13%	0.38
	RGSM Score		50%	1.38
	Ecosystem Function Effectiveness Score		**100%**	**2.68**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	2	11%	0.22
	Implementation Cost	3	25%	0.75
	Monitoring and Evaluation	2	9%	0.18
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	2	9%	0.18
	Economics Score		**100%**	**2.09**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

Table C3.5. Engineering Effectiveness Evaluation Factor Attribute Ratings for the Rio Chama to Otowi Bridge Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
Construction Location	Channel and Bank	Bank		Flood Plain and Terraces	Channel, Bank, Terraces, and Flood Plain	
Strategy Performance						
Ability to Implement	Low	High		Low	Low	
Level of Confidence	Medium	High		Medium	Medium	
Duration and Design Life	High	High		Medium	Medium	
Adaptability	Low	Medium		Low	High	
River Maintenance Function						
Water Delivery	No Change	No Change		Decrease	Decrease	
Hydraulic Capacity	No Change	No Change		No Change	Increase	
Public Health and Safety	Increase	Increase		Increase	Increase	

Table C3.6. Ecosystem Function Evaluation Factor Attribute Ratings for the Rio Chama to Otowi Bridge Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
SWFL						
Variety of Successional Stages	Increase	Decrease		Increase	Increase	
Water Table Elevation	No Change	No Change		No Change	Increase	
Flood Plain Width/Patch Availability	No Change	No Change		Increase	Increase	
Flood Plain Elevation	No Change	No Change		No Change	Increase	
Construction Impacts	Low	Medium		Medium	High	
RGSM[1]						
Habitat Complexity	No Change	Decrease		Increase	Increase	
Flood Plain Connectivity and Frequency of Flooding	No Change	No Change		No Change	Increase	
Sinuosity	No Change	No Change		No Change	No Change	
Construction Impacts	Medium	Medium		Low	Low	

[1]No endangered species present; species were present historically but have since been extirpated. Assessment is an indication of aquatic health for general fish and wildlife benefit.

Table C3.7. Economic Evaluation Factor Attribute Ratings for the Rio Chama to Otowi Bridge Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
Planning and Design	High	Medium		High	High	
Environmental Compliance	High	Medium		Low	Medium	
Implementation	Medium	Low		Low	High	
Monitoring and Evaluation	Medium	Low		Low	Medium	
Frequency of Maintenance	Low	Low		Low	Low	
Amount of Maintenance	Low	Low		Low	Low	
Frequency of Adaptive Management	Low	Low		Low	Low	
Amount of Adaptive Management	Low	Low		Low	Medium	

Table C3.8. Summary of Economics and Effectiveness Scores by Subevaluation Factor for Rio Chama to Otowi Bridge Reach

	Economics Score	Effectiveness Score			
Strategy	Cost	Strategy Performance	River Maintenance Function	SWFL	RGSM
Promote Elevation Stability	1.86	0.86	1.22	1.20	1.00
Promote Alignment Stability	1.26	1.43	1.22	0.90	0.88
Reconstruct/ Maintain Channel Capacity					
Increase Available Area	1.30	0.73	1.09	1.20	1.25
Rehabilitate Channel and Flood Plain	2.09	0.87	1.24	1.30	1.38
Manage Sediment					

Table C3.9. Summary of Economics and Effectiveness Scores for Rio Chama to Otowi Bridge Reach

Strategy	Cost	Engineering Effectiveness	Ecosytem Function Effectiveness	Total Effectiveness
Promote Elevation Stability	1.86	2.08	2.20	4.28
Promote Alignment Stability	1.26	2.65	1.78	4.43
Reconstruct/ Maintain Channel Capacity				
Increase Available Area	1.30	1.82	2.45	4.27
Rehabilitate Channel and Flood Plain	2.09	2.11	2.68	4.79
Manage Sediment				

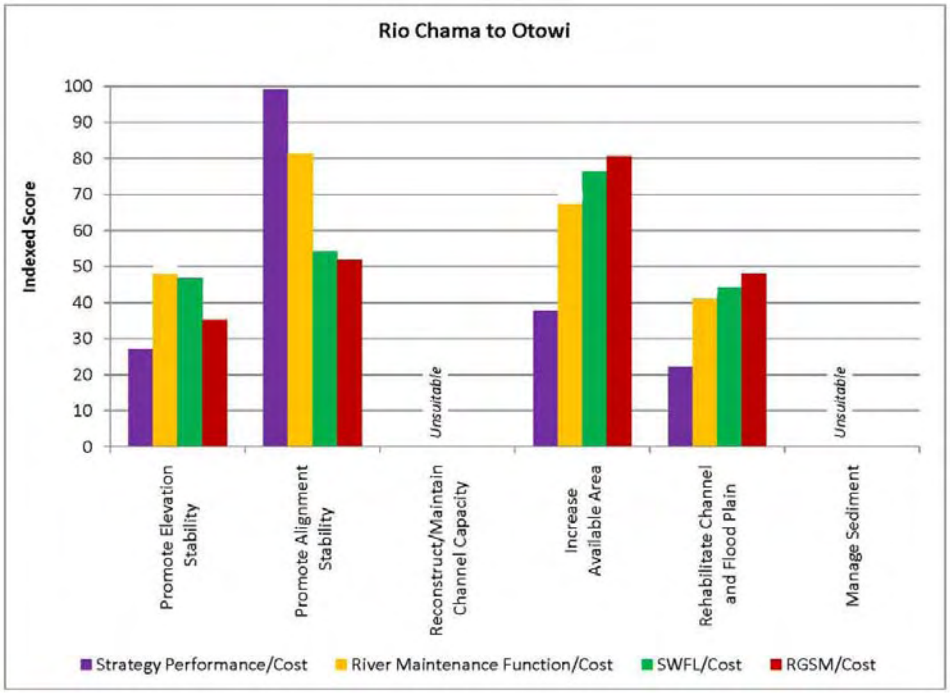

Figure C3.1. Rio Chama to Otowi Bridge Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

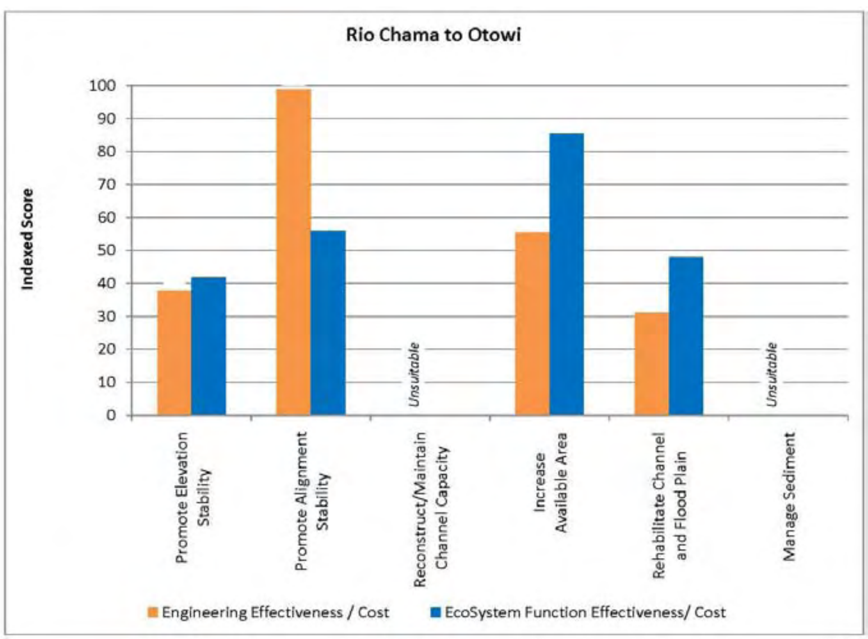

Figure C3.2. Rio Chama to Otowi Bridge Reach effectiveness divided by cost indexed scoring results by evaluation factor.

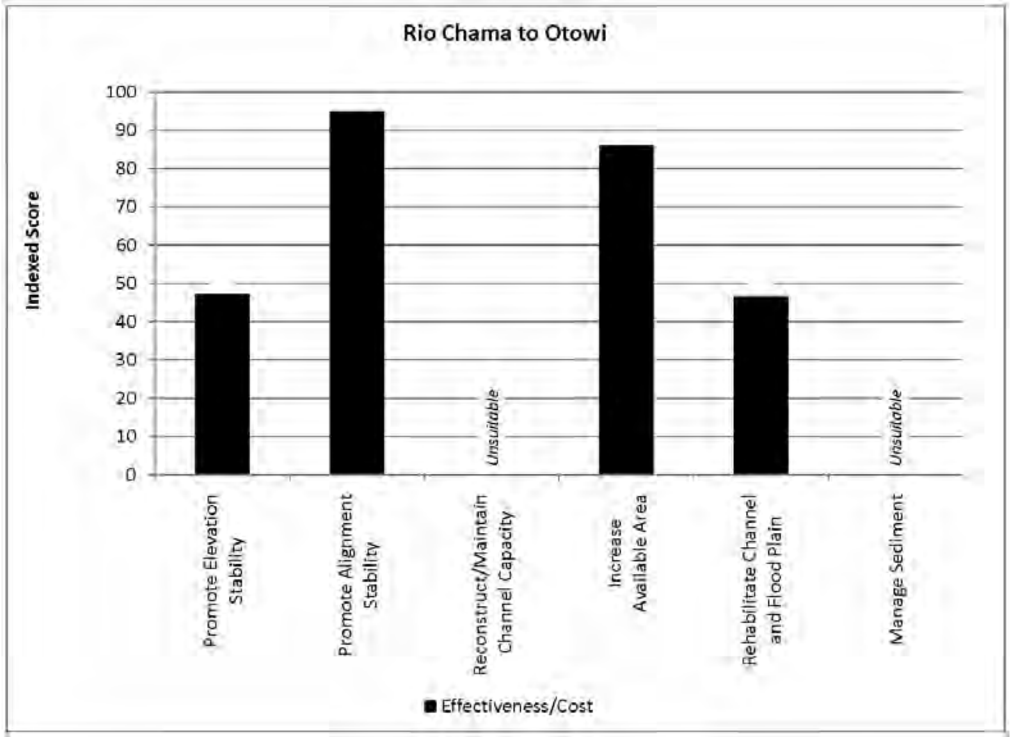

Figure C3.3. Rio Chama to Otowi Bridge Reach total effectiveness divided by cost indexed scoring results.

C3.4 Recommendations

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

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

This reach appears to be a bit more stable than the Velarde to Rio Chama Reach; so the 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 Strategy 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.

Chapter C4. Cochiti Dam to Angostura Diversion Dam (RM 232.6 to RM 209.7)

C4.1 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. Galisteo Dam, also a flood and sediment control dam, was constructed on Galisteo Creek in 1970. Major tributaries, Galisteo Creek and Tonque Arroyo, are ephemeral streams. 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 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, and the reach is probably the most sinuous portion of the Middle Rio Grande. 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]–M8 [Cutoff is now main channel]).

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

C4.1.1 Channel Instability Reach Characteristic – Medium Instability

Model results show that the stable slope in this reach is flatter than existing with little expected bed elevation change, so most factors were rated low. Baseline conditions show that less than three-fourths of the modeled channel meander belt fits within the infrastructure and geologic constraints at the current slope, and nearly three-fourths of the constrained area is used—therefore, these rating factors were rated high for the Channel Instability Reach Characteristic. There are a few locations where there is some room for the river to migrate, but it should be noted that these do not necessarily coincide with active bend locations. 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 modeling shows the area of most potential impact to infrastructure to be near San Felipe, approximately RM 212–217. The most overbank flows occurred at RM 225–216. The channel planform is expected to remain in Stage M5 (Sinuous thalweg channel)–Stage M8 (Cutoff is now main channel), but there is a real potential for continued local bend migration.

C4.1.2 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.

C4.1.3 Infrastructure, Public Health, and Safety Reach Characteristic – Medium Importance

Lands along the river are mostly pueblo with some private ownership that are agricultural. 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. The agricultural land rating factor is medium.

C4.1.4 Habitat Value and Need Reach Characteristic

C4.1.4.1 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 without significant modification. Also, colonization of any developing habitat by breeding SWFL would be unlikely due to the abundance of habitat in other reaches of the river (e.g., San Marcial) and lack of a nearby source population. Lastly, this reach is outside of the critical habitat designation.

C4.1.4.2 Rio Grande Silvery Minnow – Low importance

This reach is a historical habitat for RGSM, though the RGSM has not been documented in this reach since 1999 (Service 2008). The Service has listed the habitat in this reach as "critical habitat" for the RGSM. This reach is incised with no channel meandering or braiding and few opportunities for overbank flows. It also has cooler, swifter, and more clear-flowing waters and coarser bed materials than are generally found in downstream occupied RGSM habitat. Further downstream, inputs from arroyos and tributaries begin to provide finer sediments, which help scour the channel and build side channel flows, side and backwater habitats, and develop more suitable RGSM habitat characteristics.

Although a variety of management actions could improve the viability of Cochiti Reach as RGSM habitat, this reach currently would be considered a low priority for management for the RGSM due to diversion dams which act as a barrier to fish passage. Low-temperature water from the dam may be the greatest limiting factor. The lack of upstream migration over Angostura Diversion Dam limits natural colonization of RGSM.

Regardless of any management decision, it must be taken into account that the land base encompassing the Cochiti 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).

C4.2 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.

This section highlights considerations for suitable strategies that should be studied further. Ratings for suitable strategies that are not recommended for further study are provided to aid analysis. Recommendations based on this analysis are in section C4.3.

C4.2.1 Promote Elevation Stability

Table C4.1 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

Table C4.1. Effectiveness and Cost Scores for Cochiti Dam to Angostura Diversion Dam Reach, Promote Elevation Stability

Evaluation Factor	Attribute	Raw Score	Weight	Weighted Score
Effectiveness: 3 is the most effective, and 1 is the least effective.				
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	1	7%	0.07
	Strategy Performance Score		*50%*	*0.73*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.22*
	Engineering Effectiveness Score		**100%**	**1.95**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	3	10%	0.30
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	3	10%	0.30
	SWFL Score		*50%*	*1.20*
	RGSM			
	Habitat Complexity	3	13%	0.38
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	2	13%	0.25
	RGSM Score		50%	1.13
	Ecosystem Function Effectiveness Score		**100%**	**2.33**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	2	25%	0.50
	Monitoring and Evaluation	2	9%	0.18
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	1	9%	0.09
	Economics Score		**100%**	**1.86**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C4.2.1.1 Geomorphic Effects for Promote Elevation Stability

Model results indicate that 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 installed GRFs if this is the method used.

C4.2.1.2 Engineering Effectiveness Evaluation Factor for Promote Elevation Stability

This reach has experienced some incision and lateral migration, so flanking countermeasures would be required for cross channel structures to perform well over the long term. A need for grade control is anticipated for this reach based upon the SRH-1D model slope change results. 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. Downstream sediment deposition caused some of the slope change; thus the rating for the Duration and Design Life Attribute is medium.

C4.2.1.3 Ecosystem Function Evaluation Factor for Promote Elevation Stability

C4.2.1.3.1 Southwestern Willow Flycatcher

SWFL habitat in this reach would likely be not significantly affected by the strategy as this reach is highly incised and maintains a general sediment deficit. Stabilizing the bed elevation at least would prevent further degradation of SWFL habitat in this reach. Impacts from this strategy depend on implementation techniques.

C4.2.1.3.2 Rio Grande Silvery Minnow

The current distribution of RGSM and habitat within the Cochiti Dam to Angostura Diversion Dam Reach is unknown. Current conditions are entrenched and not favorable to RGSM. Any activity to promote elevation stability should maintain current conditions. Channel spanning features to promote elevation stability may impact upstream movement of RGSM if present within the reach. RGSM habitat could benefit from greater flood plain connectivity and diversity of habitat if the bed elevation is raised by the structures. Preventing further incision would prevent further loss of habitat. Construction is in the channel and bank.

C4.2.1.4 Economic Evaluation Factor for Promote Elevation Stability

Costs for six cross channel structures were estimated for this reach based upon the SRH-1D model slope change results. 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. The presence of three pueblos increases the rating for the Planning and Design Attribute to high. The presence of three pueblos will make obtaining land instruments more difficult. No SWFL or RGSM exist in this reach, but future efforts to improve habitat for these species may make environmental compliance costs high and more time consuming.

C4.2.2 Promote Alignment Stability

Table C4.2 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

Table C4.2. Effectiveness and Cost Scores for Cochiti Dam to Angostura Diversion Dam Reach, Promote Alignment Stability

Evaluation Factor	Attribute	Raw Score	Weight	Weighted Score
Effectiveness: 3 is the most effective, and 1 is the least effective.				
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	3	20%	0.60
	Level of Confidence	3	10%	0.30
	Duration and Design Life	3	13%	0.39
	Adaptability	2	7%	0.14
	Strategy Performance Score		*50%*	*1.43*
	River Maintenance Function			
	Water Delivery	1	13%	0.13
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.09*
	Engineering Effectiveness Score		**100%**	**2.52**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	1	10%	0.10
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*0.90*
	RGSM			
	Habitat Complexity	1	13%	0.13
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	1	13%	0.13
	RGSM Score		50%	0.75
	Ecosystem Function Effectiveness Score		**100%**	**1.65**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	2	15%	0.30
	Environmental Compliance	2	11%	0.22
	Implementation Cost	3	25%	0.75
	Monitoring and Evaluation	2	9%	0.18
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	2	9%	0.18
	Economics Score		**100%**	**1.94**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C4.2.2.1 Geomorphic Effects for Promote Alignment Stability

The potential for bend migration, especially in tightly constrained areas in the downstream portion of the reach, might be addressed locally through bank protection measures such as flow redirection and other methods. 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 modeled meander belt in the reach is very close to or outside of the constraints. Modeling results show potential for a small increase in overbank area and flood plain connectivity if the channel is allowed to move in the subreaches with more available space. Since little space is available for channel migration between constraints, planform stage change is unlikely.

C4.2.2.2 Engineering Effectiveness Evaluation Factor for Promote Alignment Stability

The river is confined by levees along most of both sides of the river. This strategy should be easy to implement with a high degree of effectiveness. Incision and lateral migration in this reach increases the need for flanking countermeasures for bank stabilization.

C4.2.2.3 Ecosystem Function Evaluation Factor for Promote Alignment Stability

C4.2.2.3.1 Southwestern Willow Flycatcher

SWFL habitat depends on a dynamic, meandering river system that alternately scours and deposits new sediments that regenerating habitat can colonize. Promoting alignment stability decreases the ability of the river to do this and would, in turn, decrease the opportunity for a variety of successional stages. Thus, the Variety of Successional Stages Attribute is rated as decreased. The Construction Impacts Attribute is rated medium because some work would occur both within the riparian area and within the river channel itself.

C4.4.2.2.3.2 Rio Grande Silvery Minnow

The current distribution of RGSM and habitat within the Cochiti Dam to Angostura Diversion Dam Reach is unknown. RGSM habitat and opportunity for complexity would be reduced if this strategy was implemented. The Construction Impacts Attribute is rated high, since work in the Rio Grande establishing stability could impact the edge of river-based RGSM nursery and adult habitats. Construction is on the bank.

C4.2.2.4 Economic Evaluation Factor for Promote Alignment Stability

Planning and design time increases for this strategy because of the presence of pueblos, which makes acquiring land instruments more difficult. Fixed bank line structures reduce opportunity for habitat regeneration; but because no SWFL or RGSM are found in this reach, the Environmental Compliance Attribute is rated medium. Because of the large percentage of the calculated meander belt width that does not fit within the infrastructure, the Implementation Cost Attribute is rated high. The Monitoring and Evaluation Attribute is rated medium because of the meander belt.

C4.2.3 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.

C4.2.4 Increase Available Area to the River

Table C4.3 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

Table C4.3. Effectiveness and Cost Scores for Cochiti Dam to Angostura Diversion Dam Reach, Increase Available Area to the River

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	1	7%	0.07
	Strategy Performance Score		*50%*	*0.73*
	River Maintenance Function			
	Water Delivery	1	13%	0.13
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.09*
	Engineering Effectiveness Score		**100%**	**1.82**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	3	10%	0.30
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	3	10%	0.30
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*1.20*
	RGSM			
	Habitat Complexity	3	13%	0.38
	Flood Plain Connectivity and Flood Frequency	3	13%	0.38
	Sinuosity	3	13%	0.38
	Construction Impacts[1]	3	13%	0.38
	RGSM Score		*50%*	*1.50*
	Ecosystem Function Effectiveness Score		**100%**	**2.70**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	1	11%	0.11
	Implementation Cost	3	25%	0.75
	Monitoring and Evaluation	1	9%	0.09
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	1	9%	0.09
	Economics Score		**100%**	**1.80**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C4.2.4.1 Geomorphic Effects for Increase Available Area to the River

The tightly constrained areas might be expanded by moving the outfall of the Santo Domingo East Side Riverside Drain upstream of RM 220. The constriction immediately upstream of Angostura Diversion Dam could be relieved by moving the San Felipe Riverside Drain and the Algodones Riverside Drain farther from the river; but maintaining the slope of the Algodones Riverside Drain appears harder to manage unless the setback continues upstream to where the drain begins. This extension also would help the east side of the lower portion of the constrained area near San Felipe as discussed above. Expanding the rest of the San Felipe constrained area would require moving buildings of the San Felipe Pueblo and moving the BNSF Railroad.

Should these expansions be implemented, it is possible that the percent of each planform Stage M5 (Sinuous thalweg channel)–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. Another likely outcome is a small increase in flood plain connectivity due to the increase in available area for meandering. The increase could be small because the difference between the baseline slope and the stable slope is small. The potential for increased meandering should help bring sediment transport capacity and available load closer, especially in the lower portions of the reach.

C4.2.4.2 Engineering Effectiveness Evaluation Factor for Increase Available Area to the River

The Ability to Implement Attribute is rated low because of the large land area requirement and pueblo land ownership. The strategy would provide additional area to accommodate the increased sinuosity estimated by the model. It is unlikely that enough land area would be available for all of the sinuosity increases.

C4.2.4.3 Ecosystem Function Evaluation Factor for Increase Available Area to the River

C4.2.4.3.1 Southwestern Willow Flycatcher

Impacts to SWFL habitat from this strategy should be positive by allowing the river to meander over a greater flood plain, potentially creating new and younger age classes of vegetation through scouring and deposition of sediments. The Construction Impact Attribute is rated medium since most of the work could be conducted within the flood plain but outside of the riparian area.

C4.2.4.3.2 Rio Grande Silvery Minnow

Opportunity for optimal RGSM and other native fish habitat and channel complexity would increase if this strategy is implemented; thus, the Habitat Complexity Attribute is rated as increased. Implementing projects to increase the channel area are likely to have a positive impact on habitat diversity for RGSM by increasing sinuosity and hydrologically connected surfaces.

Downstream effects are minimized by Angostura Diversion Dam. There may be temporary changes in sediment supply.

Flood Plain Connectivity and Flood Frequency Attribute is rated as increased, and allowing greater habitat connectivity with the flood plain also would provide for larval habitat. The Construction Impact Attribute is rated low, since equipment work would be done on the flood plain and terraces.

C4.2.4.4 Economic Evaluation Factor for Increase Available Area to the River

The Planning and Design Attribute is rated high for infrastructure relocation combined with pueblo land ownership. The Environmental Compliance Attribute is rated low, since low costs for environmental compliance are expected for this reach due to low importance ratings for the Habitat Value and Need Characteristic. Further, environmental compliance costs would be lower because flood plain and river habitat would be minimally affected. Flood plain and channel processes are encouraged to continue by setting back lateral constraints. The Implementation Cost Attribute is rated 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.

C4.2.5 Rehabilitate Channel and Flood Plain – Not Recommended

This strategy has a lower effectiveness-to-cost ratio and is not recommended. Table C4.4 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

C4.2.6 Manage Sediment– Not Suitable

Even though there is 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.

C4.2.7 Strategy Assessment Result Comparison Tables

The ratings for each attribute for each of the evaluation factors for each strategy are in: table C4.5 (Engineering Effectiveness Evaluation Factor), table C4.6 (Ecosystem Function Evaluation Factor), and table C4.7 (Economic Evaluation Factor).

Tables C4.8 and C4.9 summarize the effectiveness and economics scores for all suitable strategies for the reach.

For ease of comparison, figures C4.1–C4.3 graphically present the indexed scores for effectiveness divided by cost for each subevaluation factor, factor, and strategy total, respectively.

Table C4.4. Effectiveness and Cost Scores for Cochiti Dam to Angostura Diversion Dam Reach, Rehabilitate Channel and Flood Plain

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	Attribute	Raw Score	Weight	Weighted Score
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	3	7%	0.21
	Strategy Performance Score		*50%*	*0.87*
	River Maintenance Function			
	Water Delivery	1	13%	0.13
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.09*
	Engineering Effectiveness Score		**100%**	**1.96**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	3	10%	0.30
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	3	10%	0.30
	Flood Plain Elevation	3	10%	0.30
	Construction Impacts[1]	1	10%	0.10
	SWFL Score		*50%*	*1.20*
	RGSM			
	Habitat Complexity	3	13%	0.38
	Flood Plain Connectivity and Flood Frequency	3	13%	0.38
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	2	13%	0.25
	RGSM Score		*50%*	*1.25*
	Ecosystem Function Effectiveness Score		**100%**	**2.45**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	Attribute	Raw Score	Weight	Weighted Score
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	3	25%	0.75
	Monitoring and Evaluation	2	9%	0.18
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	2	9%	0.18
	Economics Score		**100%**	**2.20**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

Table C4.5. Engineering Effectiveness Evaluation Factor Attribute Ratings for the Cochiti Dam to Angostura Diversion Dam Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
Construction location	Channel and Bank	Bank		Flood Plain and Terraces	Channel, Bank, Terraces and Flood Plain	Channel, Bank, Flood Plain, and Terraces
Strategy Performance						
Ability to Implement	Low	High		Low	Low	
Level of Confidence	Medium	High		Medium	Medium	
Duration and Design Life	Medium	High		Medium	Medium	
Adaptability	Low	Medium		Low	High	
River Maintenance Function						
Water Delivery	No Change	Decrease		Decrease	Decrease	
Hydraulic Capacity	No Change	No Change		No Change	No Change	
Public Health and Safety	Increase	Increase		Increase	Increase	

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
SWFL						
Variety of Successional Stages	Increase	Decrease		Increase	Increase	
Water Table Elevation	No Change	No Change		No Change	No Change	
Flood Plain Width/Patch Availability	No Change	No Change		Increase	Increase	
Flood Plain Elevation	No Change	No Change		No Change	Increase	
Construction Impacts	Low	Medium		Medium	High	
RGSM						
Habitat Complexity	Increase	Decrease		Increase	Increase	
Flood Plain Connectivity and Frequency of Flooding	No Change	No Change		Increase	Increase	
Sinuosity	No Change	No Change		Increase	No Change	
Construction Impacts	Medium	High		Low	Medium	

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
Planning and Design	High	Medium		High	High	
Environmental Compliance	High	Medium		Low	High	
Implementation	Medium	High		High	High	
Monitoring and Evaluation	Medium	Medium		Low	Medium	
Frequency of Maintenance	Low	Low		Low	Low	
Amount of Maintenance	Low	Low		Low	Low	
Frequency of Adaptive Management	Low	Low		Low	Low	
Amount of Adaptive Management	Low	Medium		Low	Medium	

Table C4.8. Summary of Economics and Effectiveness Scores by Subevaluation Factor for the Cochiti Dam to Angostura Diversion Dam Reach

Strategy	Economics Score	Effectiveness Score			
	Cost	Strategy Performance	River Maintenance Function	SWFL	RGSM
Promote Elevation Stability	1.86	0.73	1.22	1.20	1.13
Promote Alignment Stability	1.94	1.43	1.09	0.90	0.75
Reconstruct/ Maintain Channel Capacity					
Increase Available Area	1.80	0.73	1.09	1.20	1.50
Rehabilitate Channel and Flood Plain	2.20	0.87	1.09	1.20	1.25
Manage Sediment					

Table C4.9. Summary of Economics and Effectiveness Scores for the Cochiti Dam to Angostura Diversion Dam Reach

Strategy	Cost	Engineering Effectiveness	Ecosytem Function Effectiveness	Total Effectiveness
Promote Elevation Stability	1.86	1.95	2.33	4.28
Promote Alignment Stability	1.94	2.52	1.65	4.17
Reconstruct/ Maintain Channel Capacity				
Increase Available Area	1.80	1.82	2.70	4.52
Rehabilitate Channel and Flood Plain	2.20	1.96	2.45	4.41
Manage Sediment				

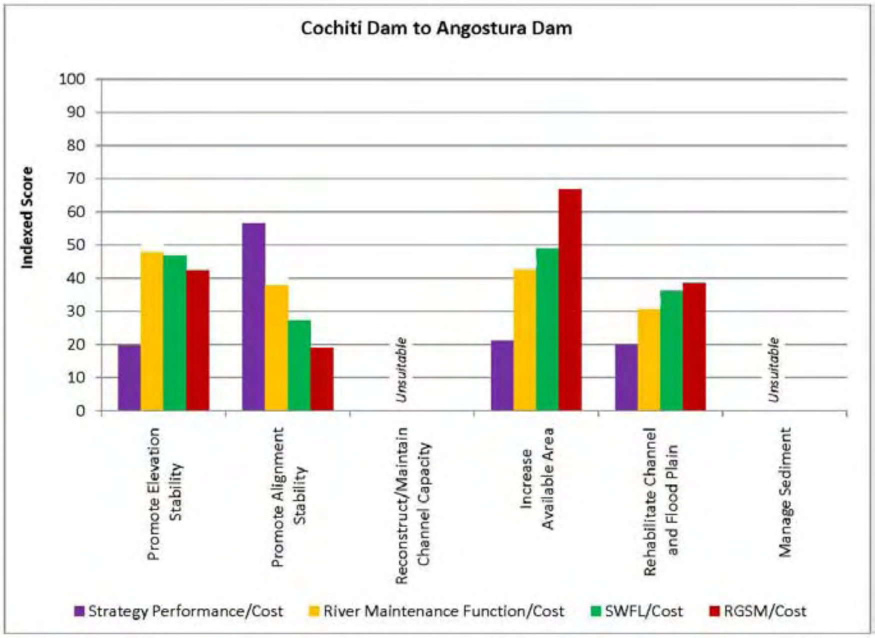

Figure C4.1. Cochiti Dam to Angostura Diversion Dam Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

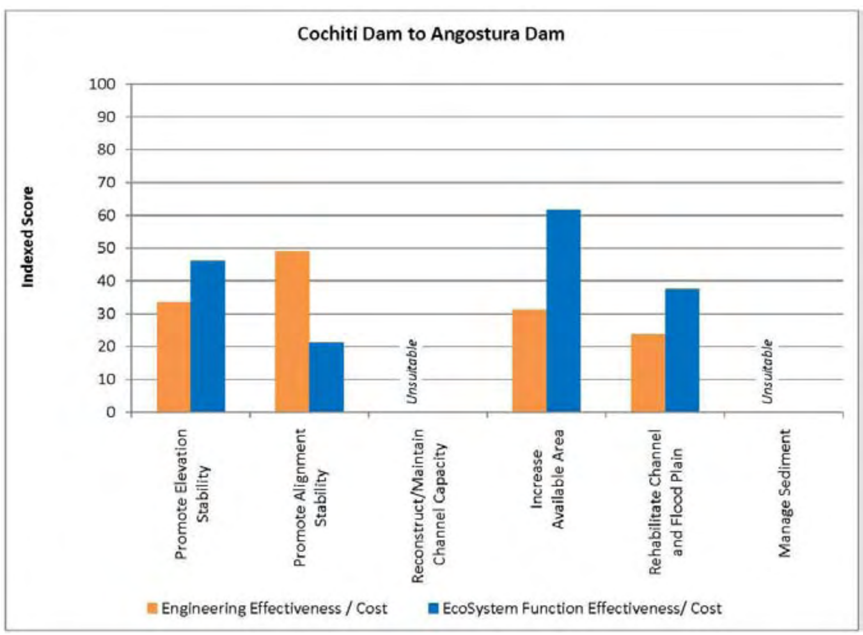

Figure C4.2. Cochiti Dam to Angostura Diversion Dam Reach effectiveness divided by cost indexed scoring results by evaluation factor.

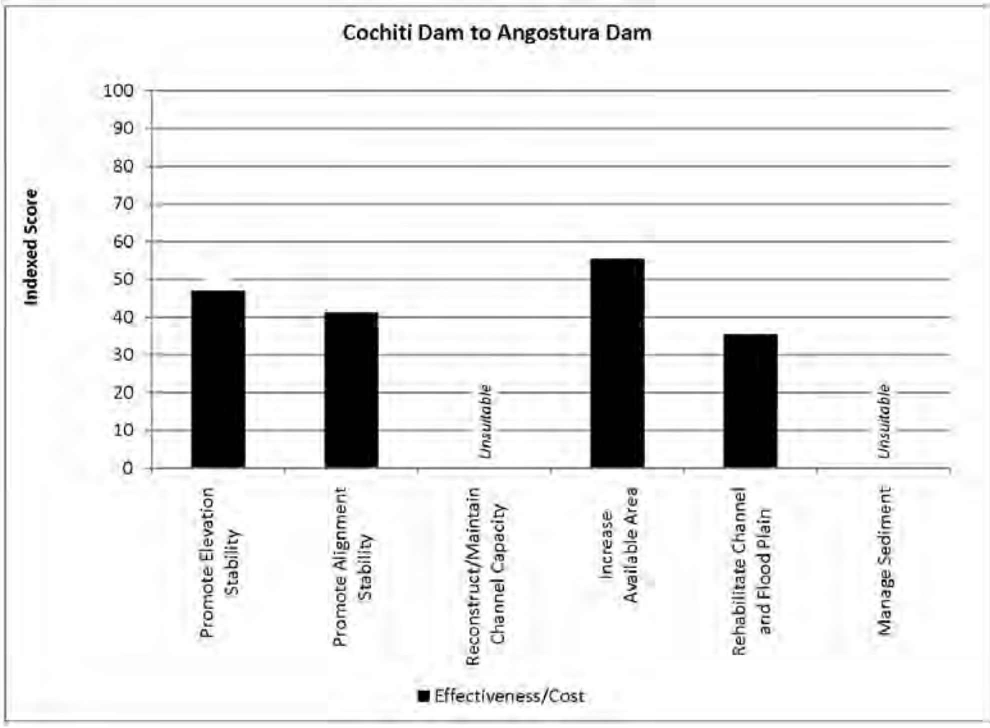

Figure C4.3. Cochiti Dam to Angostura Diversion Dam Reach total effectiveness divided by cost indexed scoring results.

C4.3 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, and 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 the Promote Elevation Stability Strategy 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.

Chapter C5. Angostura Diversion Dam to Isleta Diversion Dam (RM 209.7 to RM 169.3)

C5.1 Reach Characteristics

This reach is approximately 40 miles long with a riverbed slope of approximately 0.00094 (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, which are 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. The sediment load in this reach was reduced due to sediment storage in Jemez Canyon Dam, further tipping the sediment transport capacity load balance in this reach further toward degradation. Three GRFs and one grade control sill were constructed on the Rio Grande in the early 2000s, 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; backwater construction; ephemeral channel excavation; and removal of jetty jacks and nonnative 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 removing nonnative vegetation and creating 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. From Angostura to north Albuquerque, the channel is in Planform Stages M4 (Narrow single channel) and M5 (Sinuous thalweg channel) 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 outside channel margins. Moving downstream to about Bridge St., the planform is in Planform Stages 2 (Vegetating bar channel) to M5 (Sinuous thalweg channel) with more inundation of bars and islands, more split channels, and an increasing percentage of sand in the bed. From Bridge St. to Isleta Diversion Dam, the planform is in Planform Stages 1 (Mobile sand bed channel) through M4 (Narrow single channel) and generally sand bedded where deposition/bar formation can occur. In recent years, the reach has seen numerous habitat restoration projects. These projects have ranged from nonnative vegetation and Kellner jetty jack removal to construction intended to increase channel complexity. The cumulative effects of these projects are unknown at this time.

C5.1.1 Channel Instability Reach Characteristic – Medium Instability

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. Recent reconnection of high-flow side channels may reduce the tendency to lateral migration. Modeling results show this reach is near its stable slope, and it appears additional sediment from Jemez has at least slowed channel degradation and the downstream progression of the previously identified gravel transition zone.

Most of this reach is incised, so not much change is expected in the flows needed to overbank. There is little overbank use except in areas of active habitat restoration. A bit more than half of the calculated meander belt fits in this reach, and almost all of the area between the constraints is used. This is a very tight fit, so any new lateral channel migration is likely to impact infrastructure. Although most of the factors used to rate the Channel Instability Reach Characteristic are low, the very tight fit makes the channel instability more of a concern; thus, the rating is medium for the Angostura Diversion Dam to Isleta Diversion Dam Reach.

C5.1.2 Water Delivery Impact Reach Characteristic – High Importance

The river losses flow due to seepage from the river that exceeds drain return flows. Losses are approximately 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. There are two water utility diversions in this reach, and Angostura Diversion Dam is on the upstream of this reach, while Isleta Diversion Dam is the southern boundary of this reach. This infrastructure results in a rating of high importance for the Water Delivery Impact Reach Characteristic.

C5.1.3 Infrastructure, Public Health, and Safety Reach Characteristic – High Importance

Infrastructure in this reach includes cities of Bernalillo and Albuquerque, 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:

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

This reach also includes the pueblos of Sandia Santa Ana and Isleta, 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. This entire urban infrastructure results in a high rating for the Infrastructure, Public Health, and Safety Reach Characteristic for the Angostura Diversion Dam to Isleta Diversion Dam Reach.

C5.1.4 Habitat Value and Need Reach Characteristic

C5.1.4.1 Southwestern Willow Flycatcher – Low Importance

During the past decade, SWFL surveys in this reach have not documented territorial SWFL. The river in this reach is outside the critical habitat designation. The river is confined by berms and levees, experiences little overbank flooding, and does not have high-quality habitat.

C5.1.4.2 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. A series of beneficial water years as well as augmentation with captive propagated fish have increased the densities of RGSM within this reach. The lack of habitat diversity and low-velocity habitats above Highway 550 likely is a limiting factor for RGSM. Downstream, the river widens and becomes braided through the Albuquerque area to Isleta Diversion Dam, but high flows that would produce overbank flow conditions are limited by releases from the dam to prevent property damage in flood plain and near-bank areas. Instream restoration projects to destabilize or lower point bars and islands during high flows have created some diversity; more habitat complexity is needed to retain eggs and larvae within the reach. 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.

C5.2 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 channel migration into riverside infrastructure. Terraces 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.

This section highlights considerations for suitable strategies that should be studied further. Ratings for suitable strategies that are not recommended for further study are provided to aid analysis. Recommendations based on this analysis are in section C5.3.

C5.2.1 Promote Elevation Stability

Table C5.1 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

C5.2.1.1 Geomorphic Effects for Promote Elevation Stability

This reach appears to be near its stable slope, so significant changes in channel processes and sediment balance are not anticipated unless the channel continues to narrow. If it does not continue to narrow, this strategy may not be needed; but continued monitoring is recommended. The upstream portion of the reach is incised with little overbank flow, and modeling predicts a small slope change in the future. If the narrowing and low upstream sediment supply continue, a potential exists for additional channel incision. A modest increase in flood plain connectivity, particularly in the lower portion of the reach, is possible if grade control structures raise the bed.

C5.2.1.2 Engineering Effectiveness Evaluation Factor for Promote Elevation Stability

The potential slope change in this reach results in a need for grade control, but the future slope change is less than in the Cochiti Dam to Angostura Diversion Dam Reach. It is likely that another strategy would need to be implemented in addition to this; thus, this strategy is rated low overall for Engineering Effectiveness in this reach.

Table C5.1. Effectiveness and Cost Scores for the Angostura Diversion Dam to Isleta Diversion Dam Reach, Promote Elevation Stability

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	3	13%	0.39
	Adaptability	1	7%	0.07
	Strategy Performance Score		*50%*	*0.86*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.22*
	Engineering Effectiveness Score		**100%**	**2.08**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	2	10%	0.20
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	3	10%	0.30
	SWFL Score		*50%*	*1.10*
	RGSM			
	Habitat Complexity	2	13%	0.25
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	1	13%	0.13
	RGSM Score		*50%*	*0.88*
	Ecosystem Function Effectiveness Score		**100%**	**1.98**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	1	25%	0.25
	Monitoring and Evaluation	2	9%	0.18
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	2	9%	0.18
	Amount of Adaptive Management	2	9%	0.18
	Economics Score		**100%**	**1.79**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C5.2.1.3 Ecosystem Function Evaluation Factor for Promote Elevation Stability

Southwestern Willow Flycatcher

SWFL habitat in this reach likely would be not affected negatively or positively by the strategy since this reach is tending towards channel narrowing. Preventing channel lowering would at least prevent further degradation of SWFL habitat in this reach. Impacts from this strategy depend on implementation techniques.

Rio Grande Silvery Minnow

Any activity to promote elevation stability should maintain or improve current conditions for RGSM. Promoting elevation stability with grade control or other bank-to-bank structures probably would not change RGSM habitat complexity from existing conditions. Channel spanning features to promote elevation stability may impact upstream movement of RGSM.

Construction would be on the channel and bank. The Construction Impact Attribute was rated high because bank-to-bank construction with equipment and changes across the entire river width would be a high, short-term impact.

C5.2.1.4 Economic Evaluation Factor for Promote Elevation Stability

The Implementation Cost Attribute is rated low due to the small amount of future slope change in this reach. 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.

C5.2.2 Promote Alignment Stability

Table C5.2 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

C5.2.2.1 Geomorphic Effects for Promote Alignment Stability

The modeled meander belt fits very tightly within the infrastructure and geologic constraints in this reach. Changing sediment loads from the Jemez River and the numerous ephemeral tributaries and vegetation management appear to have slowed channel degradation and narrowing, which could reduce future channel migration. This idea is inferred from sequential photography and field observations, but more cross section surveys and sediment data with comparative analyses are needed to confirm it. Modeling shows the reach is at or near the stable slope, so this strategy may not be necessary as reach-wide strategy. However, it is likely that local bank protection may be needed; therefore, continued monitoring is recommended. There is not much space to allow the channel to migrate, so little change is expected in the balance of sediment load and capacity or flood plain connectivity.

Table C5.2. Effectiveness and Cost Scores for the Angostura Diversion Dam to Isleta Diversion Dam Reach, Promote Alignment Stability

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	3	20%	0.60
	Level of Confidence	3	10%	0.30
	Duration and Design Life	3	13%	0.39
	Adaptability	2	7%	0.14
	Strategy Performance Score		*50%*	*1.43*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.22*
	Engineering Effectiveness Score		**100%**	**2.65**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	2	10%	0.20
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*1.00*
	RGSM			
	Habitat Complexity	2	13%	0.25
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	2	13%	0.25
	RGSM Score		50%	1.00
	Ecosystem Function Effectiveness Score		**100%**	**2.00**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	1	15%	0.15
	Environmental Compliance	3	11%	0.33
	Implementation Cost	3	25%	0.75
	Monitoring and Evaluation	1	9%	0.09
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	2	9%	0.18
	Amount of Adaptive Management	2	9%	0.18
	Economics Score		**100%**	**1.90**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C5.2.3 Engineering Effectiveness Evaluation Factor for Promote Alignment Stability

The slope change in the model results shows a relatively small amount of estimated change, yet half of the length of channel fits within the computed 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.

C5.2.3.1 Ecosystem Function Evaluation Factor for Promote Alignment Stability

C5.2.3.1.1 Southwestern Willow Flycatcher

SWFL habitat depends on a dynamic, meandering river system that alternately scours and deposits new sediments that regenerating habitat can colonize. Promoting alignment stability decreases the ability of the river to do this and would, in turn, decrease the opportunity for a variety of successional stages. Based on modeled indicators, however, no significant change to SWFL habitat would occur due to this strategy. The Construction Impact Attribute is rated medium, because some work would occur both within the riparian area and within the river channel itself.

C5.2.3.1.2 Rio Grande Silvery Minnow

No changes from current conditions are expected, but minimum opportunities for improvement would be available since RGSM habitat and opportunity for complexity depends on a mobile channel. Actions to promote alignment stability may reduce habitat complexity. After implementation, the amount of sediment available from bank erosion potentially would be reduced, leading to local bed coarsening.

Construction is on the bank. The Construction Impact Attribute is rated high since work in the Rio Grande establishing stability could impact edge of river-based RGSM nursery and adult habitats.

C5.2.3.2 Economic Evaluation Factor for Promote Alignment Stability

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 extensive Reclamation experience with the methods of this strategy, results in a low rating for the Planning and Design Attribute. The high rating for the Implementation Cost Attribute is due to the large percentage of the channel length that does not fit between the infrastructure. About half of the reach length is estimated to be outside of the meander belt width. In other reaches, this strategy is usually rated low for the Frequency of Adaptive Management and Amount of Adaptive Management Attributes, but the strategy is rated medium for the Angostura Diversion Dam to Diversion Dam Reach because this reach is biologically significant for the RGSM.

C5.2.4 Reconstruct and Maintain Main 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.

C5.2.5 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 because of 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.

C5.2.6 Rehabilitate Channel and Flood Plain

Table C5.3 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

C5.2.6.1 Geomorphic Effects for Rehabilitate Channel and Flood Plain

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. Implementing this strategy is expected to increase the balance of sediment load and transport capacity and the natural channel processes of renewing habitat, attenuation of extreme events, water table interactions, channel and flood plain adjustments, and episodic sediment transport. There would be a probable decrease in the effective transport of water and sediment at higher flows. There are many habitat restoration projects ongoing in this reach that would need to be considered in any reach-wide flood plain rehabilitation.

C5.2.6.2 Engineering Effectiveness Evaluation Factor for Rehabilitate Channel and Flood Plain

As is common to this strategy, the large volumes of earthwork reduce the ability to implement. The 10,000-cfs water surface elevation after implementing this strategy will be lower than baseline. Both are contained, resulting in the no change rating for the Hydraulic Capacity Attribute. It is expected that the rate of sediment deposition in this reach would 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.

Table C5.3. Effectiveness and Cost Scores for the Angostura Diversion Dam to Isleta Diversion Dam Reach, Rehabilitate Channel and Flood Plain

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	3	7%	0.21
	Strategy Performance Score		*50%*	*0.87*
	River Maintenance Function			
	Water Delivery	1	13%	0.13
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.09*
	Engineering Effectiveness Score		**100%**	**1.96**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	3	10%	0.30
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	1	10%	0.10
	SWFL Score		*50%*	*1.00*
	RGSM			
	Habitat Complexity	3	13%	0.38
	Flood Plain Connectivity and Flood Frequency	3	13%	0.38
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	2	13%	0.25
	RGSM Score		*50%*	*1.25*
	Ecosystem Function Effectiveness Score		**100%**	**2.25**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	3	25%	0.75
	Monitoring and Evaluation	2	9%	0.18
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	2	9%	0.18
	Economics Score		**100%**	**2.20**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C5.2.6.3 Ecosystem Function Evaluation Factor for Rehabilitate Channel and Flood Plain

C5.2.6.3.1 Southwestern Willow Flycatcher

SWFL habitat within this reach would be not be affected or slightly improved by this strategy based on model outputs by providing greater opportunity for overbank flooding. The flood plain in this reach is relatively narrow and would not provide significant area for this strategy's implementation. The Construction Impact Attribute is rated high because habitat may be negatively impacted by construction activities as much of this work would occur in the flood plain. Strategy implementation would have to be designed to avoid creating a monotypic, single age-class stand of riparian vegetation.

C5.2.6.3.2 Rio Grande Silvery Minnow

Opportunity for optimal RGSM habitat and channel complexity would increase if this strategy is implemented. The Flood Plain Width/Patch Availability Attribute is rated as no change. Increased flood plain area and connectivity to the flood plain creates more nursery habitat in flooding conditions, which would be positive for RGSM. Construction is on the channel, bank, terraces, and flood plain. The Construction Impact Attribute is rated medium, as work could impact edge of river-based RGSM nursery and adult habitats. However, the majority of work would be done on the flood plain and terraces.

C5.2.6.4 Economic Evaluation Factor for Rehabilitate Channel and Flood Plain

The presence of three pueblos increases planning and design costs, giving a high rating to the Planning and Design Attribute. As stated above in Increase Available Area to the River, the cost of environmental compliance would be higher than usual for this strategy because this reach is biologically significant for the RGSM. Thus, the Environmental Compliance Attribute is also rated high.

C5.2.7 Manage Sediment

Table C5.4 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

C5.2.7.1 Geomorphic Effects for Manage Sediment

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 the river alone. Sediment stored in the banks and bars has become more accessible and could bring sediment transport capacity and supply into closer balance for the wider channel. Monitoring should document if this occurs. The newly available sediment also could increase locally the episodic sediment transport, channel and flood plain adjustments, and flood plain connectivity.

Table C5.4. Effectiveness and Cost Scores for the Angostura Diversion Dam to Isleta Diversion Dam Reach, Manage Sediment

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	2	20%	0.40
	Level of Confidence	1	10%	0.10
	Duration and Design Life	3	13%	0.39
	Adaptability	3	7%	0.21
	Strategy Performance Score		*50%*	*1.10*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	2	22%	0.44
	River Maintenance Function Score		*50%*	*1.00*
	Engineering Effectiveness Score		**100%**	**2.10**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	2	10%	0.20
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*1.00*
	RGSM			
	Habitat Complexity	3	13%	0.38
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	2	13%	0.25
	RGSM Score		50%	1.13
	Ecosystem Function Effectiveness Score		**100%**	**2.13**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	1	25%	0.25
	Monitoring and Evaluation	3	9%	0.27
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	3	9%	0.27
	Amount of Adaptive Management	3	9%	0.27
	Economics Score		**100%**	**2.06**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C5.2.7.2 Engineering Effectiveness Evaluation Factor for Manage Sediment

Sediment management in this reach involves adding sediment because there is a small deficit according to the modeling. A potential exists for the channel to incise in this reach. Augmenting sediment supply promotes equilibrium between sediment supply and transport capacity, potentially reducing the tendency for this reach to incise. In the upstream subreach where the channel has already narrowed, lateral migration still may occur with sediment augmentation, and other strategies may need to be used.

C5.2.7.3 Ecosystem Function Evaluation Factor for Manage Sediment

C5.2.7.3.1 Southwestern Willow Flycatcher

Managing sediment in this reach actually may improve SWFL habitat for the same reasons as detailed for RGSM; however, the volume of sediment added would be low. The degree of habitat improvement is likely small because of the anticipated patch size, which may not be large enough for SWFL; therefore, the Flood Plain Width/Patch Availability Attribute is rated no change.

C5.2.7.3.2 Rio Grande Silvery Minnow

Additional sediment load in this reach would be positive for RGSM by building desirable point bar habitat. This reach has low sediment load, and increasing sediment could create islands and increased shoreline habitats. 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.

Deposition of sand in the river or providing a source for increasing sand could have a low to moderate short-term construction impact; thus, the Construction Impact Attribute is rated medium.

C5.2.7.4 Economic Evaluation Factor for Manage Sediment

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

C5.2.8 Strategy Assessment Result Comparison Tables

The ratings for each attribute for each of the evaluation factors for each strategy are in: table C5.5 (Engineering Effectiveness Evaluation Factor), table C5.6 (Ecosystem Function Evaluation Factor), and table C5.7 (Economic Evaluation Factor).

Tables C5.8 and C5.9 summarize the effectiveness and economics scores for all suitable strategies for the reach.

For ease of comparison, figures C5.1–C5.3 graphically present the indexed scores for effectiveness divided by cost for each subevaluation factor, factor, and strategy total, respectively.

Table C5.5. Engineering Effectiveness Evaluation Factor Attribute Ratings for the Angostura Diversion Dam to Isleta Diversion Dam Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment[1]
Construction Location	Channel and Bank	Bank			Channel, Bank, Terraces, and Flood plain	Channel, Bank, Flood plain, and Terraces
Strategy Performance						
Ability to Implement	Low	High			Low	Medium
Level of Confidence	Medium	High			Medium	Low
Duration and Design Life	High	High			Medium	High
Adaptability	Low	Medium			High	High
River Maintenance Function						
Water Delivery	No Change	No Change			Decrease	No Change
Hydraulic Capacity	No Change	No Change			No Change	No Change
Public Health and Safety	Increase	Increase			Increase	No Change

[1] Increasing sediment supply.

Table C5.6. Ecosystem Function Evaluation Factor Attribute Ratings for the Angostura Diversion Dam to Isleta Diversion Dam Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
SWFL						
Variety of Successional Stages	No Change	No Change			Increase	No Change
Water Table Elevation	No Change	No Change			No Change	No Change
Flood Plain Width/Patch Availability	No Change	No Change			No Change	No Change
Flood Plain Elevation	No Change	No Change			No Change	No Change
Construction Impacts	Low	Medium			High	Medium
RGSM						
Flood Plain Connectivity and Frequency of Flooding	No Change	No Change			Increase	Increase
Sinuosity	No Change	No Change			Increase	No Change
Construction Impacts	No Change	No Change			No Change	No Change
Flood Plain Connectivity and Frequency of Flooding	High	Medium			Medium	Medium

Table C5.7. Economic Evaluation Factor Attribute Ratings for the Angostura Diversion Dam to Isleta Diversion Dam Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
Planning and Design	High	Low			High	High
Environmental Compliance	High	High			High	High
Implementation	Low	High			High	Low
Monitoring and Evaluation	Medium	Low			Medium	High
Frequency of Maintenance	Low	Low			Low	Low
Amount of Maintenance	Low	Low			Low	Low
Frequency of Adaptive Management	Medium	Medium			Low	High
Amount of Adaptive Management	Medium	Medium			Medium	High

Table C5.8. Summary of Economics and Effectiveness Scores by Subevaluation Factor for the Angostura Diversion Dam to Isleta Diversion Dam Reach

	Economics Score	Effectiveness Score			
Strategy	Cost	Strategy Performance	River Maintenance Function	SWFL	RGSM
Promote Elevation Stability	1.79	0.86	1.22	1.10	0.88
Promote Alignment Stability	1.90	1.43	1.22	1.00	1.00
Reconstruct/ Maintain Channel Capacity					
Increase Available Area					
Rehabilitate Channel and Flood Plain	2.20	0.87	1.09	1.00	1.25
Manage Sediment	2.06	1.10	1.00	1.00	1.13

Table C5.9. Summary of Economics and Effectiveness Scores for the Angostura Diversion Dam to Isleta Diversion Dam Reach

Strategy	Cost	Engineering Effectiveness	Ecosytem Function Effectiveness		Total Effectiveness
Promote Elevation Stability	1.79	2.08	1.98		4.06
Promote Alignment Stability	1.90	2.65	2.00		4.65
Reconstruct/ Maintain Channel Capacity					
Increase Available Area					
Rehabilitate Channel and Flood Plain	2.20	1.96	2.25		4.21
Manage Sediment	2.06	2.10	2.13		4.23

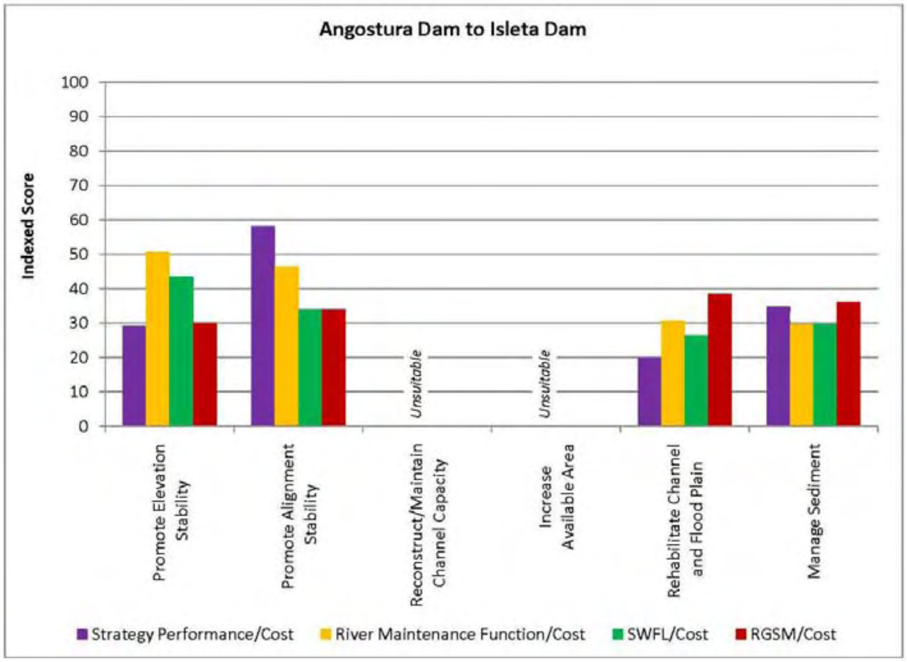

Figure C5.1. Angostura Diversion Dam to Isleta Diversion Dam Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

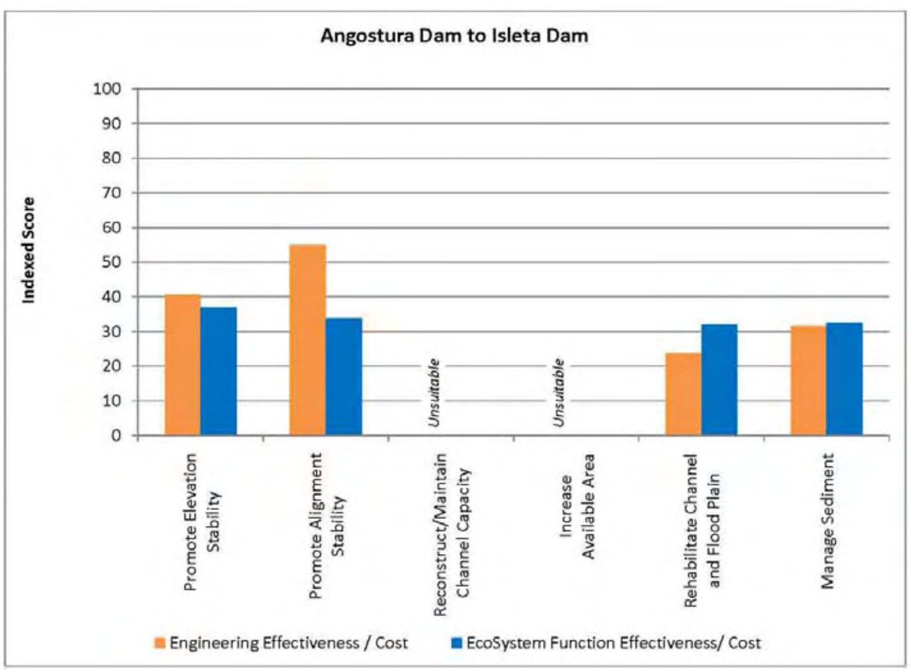

Figure C5.2. Angostura Diversion Dam to Isleta Diversion Dam Reach effectiveness divided by cost indexed scoring results by evaluation factor.

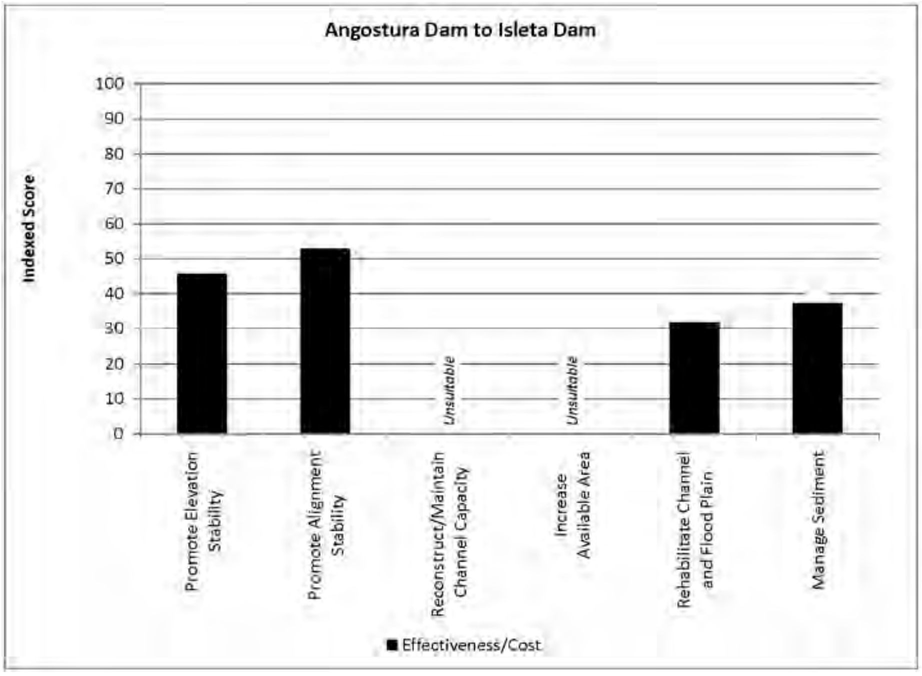

Figure C5.3. Angostura Diversion Dam to Isleta Diversion Dam Reach total effectiveness divided by cost indexed scoring results.

C5.3 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 because of 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.

Chapter C6. Isleta Diversion Dam to Rio Puerco (RM 169.3 to RM 127)

C6.1 Reach Characteristics

This reach is approximately 42 miles long with a riverbed slope of approximately.00081 (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 have 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. Documented in 2001, numerous islands and bars 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 that 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 is Stage 3 (Main channel with side channels) to M5 (Sinuous thalweg channel) with very little Stage 2 (Vegetating bar channel).

C6.1.1 Channel Instability Reach Characteristic – Medium Instability

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 that could cause increased sediment transport capacity. It is uncertain whether the effect would be in the vertical or horizontal direction. The modeling shows the stable channel slope is a bit flatter than existing conditions; therefore, planform change potential is rated medium. It should be noted that the slope and bed elevation changes are small; therefore, these factors were rated low. Bed coarsening has begun in some areas, which indicates that the potential for future incision may be less than originally discussed in the Part 1 Report. Virtually all of calculated meander belt fits, using about three-fourths of the available area; therefore, there is some room for channel migration. 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 constricted sites. The Channel Instability Reach Characteristic's overall rating is medium mainly due to the recent channel narrowing.

C6.1.2 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 Diversion Dam 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.

C6.1.3 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.

C6.1.4 Habitat Value and Need Reach Characteristic

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

C6.1.4.1 Southwestern Willow Flycatcher – High Importance

The majority of riparian habitat within this reach is unsuitable for occupation by SWFLs due to the perched active flood plain inside the levees, deep water table and exotic vegetation. Despite this fact, the nonpueblo portion of this reach is included in the critical habitat designation. A small population of SWFLs has persisted on the Isleta Pueblo for the past 15 years. Territory numbers have fluctuated between 4 and approximately 15. Habitat is composed of a mixture of native and exotic vegetation within the active flood plain, and is maintained by nearby riverside drains that provide sufficient hydrology. High river flows also periodically flood the site. During the past year or two, habitat within this site appears to be degrading and becoming more decadent.

Another small population of SWFLs has colonized the southern end of this reach, immediately upstream of the Rio Puerco. River bars and adjacent high flow channels provide native habitat adjacent to existing, older patches of salt cedar. Several territories have been located within this habitat for the past few years.

Most of this reach is unsuitable for SWFLs, and the population on the Isleta Pueblo seems to be dwindling as habitat quality declines and other areas are colonized.

C6.1.4.2 Rio Grande Silvery Minnow – Medium Importance

RGSM are common in this reach (Dudley and Platania 2011 and Reclamation data). Some augmentation has occurred, but the majority of the sampled fish are wild spawn. A substantial amount of the water is diverted above this reach at Isleta Diversion Dam. Flood plains are heavily vegetated, which confines the main channel, limiting its ability to meander and widen. Since most of this reach is occupied—though habitat quality is minimal—this reach is rated medium for the RGSM Habitat Value and Need Reach Characteristic.

C6.2 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; therefore, it is among the least studied. Five strategies were potentially suitable for this reach. Promote Alignment Stability is unsuitable because analysis results show the meander belt generally fits within the constraints but is tight in the vicinity of Bosque Farms to downstream from Abo Arroyo. These areas of local constriction may require bank protection.

This section highlights considerations for suitable strategies that should be studied further. Ratings for suitable strategies that are not recommended for further study are provided as an aid for analysis. Recommendations based on this analysis are in section C6.3.

C6.2.1 Promote Elevation Stability

Table C6.1 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

Table C6.1. Effectiveness and Cost Scores for the Isleta Diversion Dam to Rio Puerco Reach, Promote Elevation Stability

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	3	13%	0.39
	Adaptability	1	7%	0.07
	Strategy Performance Score		*50%*	*0.86*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.22*
	Engineering Effectiveness Score		**100%**	**2.08**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	2	10%	0.20
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*1.00*
	RGSM			
	Habitat Complexity	2	13%	0.25
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	1	13%	0.13
	RGSM Score		50%	0.88
	Ecosystem Function Effectiveness Score		**100%**	**1.88**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	1	25%	0.25
	Monitoring and Evaluation	2	9%	0.18
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	2	9%	0.18
	Amount of Adaptive Management	2	9%	0.18
	Economics Score		**100%**	**1.79**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C6.2.1.1 Geomorphic Effects for Promote Elevation Stability

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. Model results show the sediment balance and flood plain connectivity are unlikely to change much because little bed elevation or slope changes are shown in the modeling results. Similarly, little planform change would be expected in this reach; however, current narrowing trends may help develop a meandering thalweg that could change this condition. The small trend toward coarsening bed material may reduce the need for this strategy in the future.

C6.2.1.2 Engineering Effectiveness Evaluation for the Promote Elevation Stability

The SRH-1D model shows the potential need for grade control in this reach. The amount of future slope change is expected to be 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.

C6.2.1.3 Ecosystem Function Evaluation for the Promote Elevation Stability

C6.2.1.3.1 Southwestern Willow Flycatcher

Promoting elevation stability in this reach likely would not have a great impact on SWFL habitat, either positive or negative, although impacts are unknown and depend on methods implemented.

C6.2.1.3.2 Rio Grande Silvery Minnow

Promoting elevation stability with grade control or other bank-to-bank structures would probably not change RGSM habitat complexity. Channel spanning features to promote elevation stability may impact upstream movement of RGSM.

Construction is on the channel and bank. The Construction Impact Attribute is rated high because of the bank-to-bank construction with equipment and changes across the entire river.

C6.2.1.4 Economic Evaluation for the Promote Elevation Stability

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

C6.2.2 Promote Alignment Stability – Not Suitable

Modeling results show 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.

C6.2.3 Reconstruct and Maintain Channel Capacity – Not Recommended

Since this strategy had a low effectiveness-to-cost ratio, it is not recommended for further study on a reach-wide basis; but it may still have value at specific locations. Table C6.2 shows the weighted effectiveness scores for this strategy by evaluation factor.

Table C6.2. Effectiveness and Cost Scores for the Isleta Diversion Dam to Rio Puerco Reach, Reconstruct and Maintain Channel Capacity

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	3	7%	0.21
	Strategy Performance Score		*50%*	*0.87*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	2	22%	0.44
	River Maintenance Function Score		*50%*	*1.00*
	Engineering Effectiveness Score		**100%**	**1.87**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	2	10%	0.20
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*1.00*
	RGSM			
	Habitat Complexity	1	13%	0.13
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	1	13%	0.13
	RGSM Score		50%	0.75
	Ecosystem Function Effectiveness Score		**100%**	**1.75**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	1	25%	0.25
	Monitoring and Evaluation	3	9%	0.27
	Frequency of Maintenance	3	10%	0.30
	Amount of Maintenance	3	12%	0.36
	Frequency of Adaptive Management	3	9%	0.27
	Amount of Adaptive Management	3	9%	0.27
	Economics Score		**100%**	**2.50**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C6.2.4 Increase Available Area to the River

Table C6.3 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

Table C6.3. Effectiveness and Cost Scores for the Isleta Diversion Dam to Rio Puerco Reach, Increase Available Area to the River

Evaluation Factor	Attribute	Raw Score	Weight	Weighted Score
Effectiveness: 3 is the most effective, and 1 is the least effective.				
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	1	7%	0.07
	Strategy Performance Score		*50%*	*0.73*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.22*
	Engineering Effectiveness Score		**100%**	**1.95**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	2	10%	0.20
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*1.00*
	RGSM			
	Habitat Complexity	3	13%	0.38
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	3	13%	0.38
	Construction Impacts[1]	3	13%	0.38
	RGSM Score		50%	1.38
	Ecosystem Function Effectiveness Score		**100%**	**2.38**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	1	11%	0.11
	Implementation Cost	1	25%	0.25
	Monitoring and Evaluation	1	9%	0.09
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	1	9%	0.09
	Economics Score		**100%**	**1.30**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C6.2.4.1 Geomorphic Effects for Increase Available Area to the River

Model results show little slope or bed elevation change is expected in this reach; however, continued narrowing with the potential to develop a meandering thalweg could change this condition. Opportunities for this strategy should be explored because the calculated meander belt is very close to the constraints for much of the reach. It should be noted that there is little undeveloped land outside the levees, but agricultural uses account for more than half of the reach. Acquiring additional land along the channel is worth evaluating before land use changes.

C6.2.4.2 Engineering Effectiveness Evaluation Factor for Increase Available Area to the River

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, as described in section C6.2.4.1, there are other reasons to explore future opportunities for implementing this strategy. Even with the presence of agricultural lands and urban development, enough available land area may exist for the river to approach dynamic equilibrium because the modeled future slope change is small. Acquisition of the necessary land area may make this strategy difficult to implement; therefore, the Ability to Implement Attribute is rated low. The river most likely would reach dynamic equilibrium, increasing the effectiveness of this strategy.

C6.2.4.3 Ecosystem Function Evaluation Factor for Increase Available Area to the River

C6.2.4.3.1 Southwestern Willow Flycatcher

Impacts to SWFL habitat from this strategy could be positive if the river were to migrate to occupy the newly available area. This could create new and younger age classes of vegetation through scouring and deposition of sediments. However, the river in this reach currently fits within the present constraints, so it may not migrate; thus, the all of the attributes for SWFL are rated as no change. The Construction Impact Attribute is rated as medium, since most of work could be conducted within the flood plain but outside of the riparian area.

C6.2.4.3.2 Rio Grande Silvery Minnow

Opportunity for optimal RGSM habitat and channel complexity would increase if the river is allowed to migrate and increase sinuosity. The Construction Impact Attribute is rated low, since equipment work could be done in the flood plain and terraces.

C6.2.4.4 Economic Evaluation Factor for Increase Available Area to the River

The Implementation Cost Attribute is rated low because there is a small percentage of the channel length that does not fit between the infrastructures. If infrastructure relocation were implemented, the cost may change since canals and drains would need to be relocated in areas where the meander belt is very close to the constraints (see section C6.2.4.1).

C6.2.5 Rehabilitate Channel and Flood Plain

Table C6.4 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

Table C6.4. Effectiveness and Cost Scores for the Isleta Diversion Dam to Rio Puerco Reach, Rehabilitate Channel and Flood Plain

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	3	7%	0.21
	Strategy Performance Score		*50%*	*0.87*
	River Maintenance Function			
	Water Delivery	1	13%	0.13
	Hydraulic Capacity	3	15%	0.45
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.24*
	Engineering Effectiveness Score		**100%**	**2.11**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	3	10%	0.30
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	3	10%	0.30
	Flood Plain Elevation	3	10%	0.30
	Construction Impacts[1]	1	10%	0.10
	SWFL Score		*50%*	*1.20*
	RGSM			
	Habitat Complexity	3	13%	0.38
	Flood Plain Connectivity and Flood Frequency	3	13%	0.38
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	3	13%	0.38
	RGSM Score		50%	1.38
	Ecosystem Function Effectiveness Score		**100%**	**2.58**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	3	25%	0.75
	Monitoring and Evaluation	2	9%	0.18
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	2	9%	0.18
	Economics Score		**100%**	**2.20**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C6.2.5.1 Geomorphic Effects for Rehabilitate Channel and Flood Plain

The highlight of this strategy is the large increase in connectivity of the flood plain as discussed in section C1.6.5. Model results show little change in slope or bed elevation is expected in this reach, but there is opportunity to reconnect the flood plain in this reach. This strategy could reduce the potential for lateral migration in the future due to channel narrowing.

C6.2.5.2 Engineering Effectiveness Evaluation Factor for Rehabilitate Channel and Flood Plain

Large volumes of sediment to be removed reduce the rating for the Ability to Implement Attribute to low. The Hydraulic Capacity Attribute is rated as no change for this strategy. The rate of sediment deposition on the excavated flood plain may be greater than in the Angostura Diversion Dam to Isleta Diversion Dam Reach because of additional tributary sediment inflow.

C6.2.5.3 Ecosystem Function Evaluation Factor for Rehabilitate Channel and Flood Plain

C6.2.5.3.1 Southwestern Willow Flycatcher

SWFL habitat potentially would benefit from this strategy as, based on modeled indicators, overbank flooding would increase. However, efforts would have to be made to avoid occupied or higher quality habitat during construction activities. Strategy implementation also would have to be designed to avoid creating a monotypic, single-age class stand of riparian vegetation.

C6.2.5.3.2 Rio Grande Silvery Minnow

The opportunity for RGSM habitat and channel complexity would increase if this strategy is implemented. Increased flood plain area and connectivity to the flood plain creates more nursery habitat in flooding conditions, which would be positive for RGSM.

The Habitat Complexity and Flood Plain Connectivity and Frequency of Flooding Attributes are rated as increased. The Construction Impact Attribute is rated as low, since work could impact edge of river-based RGSM nursery and adult habitats. Construction could be done in the channel, bank, terraces, or flood plain.

C6.2.5.4 Economic Evaluation Factor for Rehabilitate Channel and Flood Plain

As is common with this strategy, the large sediment volumes move the Implementation Cost Attribute to high, considering the excavating needed to achieve overbank flows during peak discharge events.

C6.2.6 Manage Sediment

Table C6.5 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

Table C6.5. Effectiveness and Cost Scores for the Isleta Diversion Dam to Rio Puerco Reach, Manage Sediment

Evaluation Factor	Attribute	Raw Score	Weight	Weighted Score
Effectiveness: 3 is the most effective, and 1 is the least effective.				
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	1	10%	0.10
	Duration and Design Life	2	13%	0.26
	Adaptability	3	7%	0.21
	Strategy Performance Score		*50%*	*0.77*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	2	22%	0.44
	River Maintenance Function Score		*50%*	*1.00*
	Engineering Effectiveness Score		**100%**	**1.77**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	2	10%	0.20
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*1.00*
	RGSM			
	Habitat Complexity	3	13%	0.38
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	2	13%	0.25
	RGSM Score		50%	1.13
	Ecosystem Function Effectiveness Score		**100%**	**2.13**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	1	25%	0.25
	Monitoring and Evaluation	3	9%	0.27
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	3	9%	0.27
	Amount of Adaptive Management	3	9%	0.27
	Economics Score		**100%**	**2.06**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C6.2.6.1 Geomorphic Effects for Manage Sediment

Model results show that little slope or bed elevation change is expected in this reach; however, narrowing trends with the development of a meandering thalweg could change this expectation. If lateral migration increases, this strategy may be needed because the modeled meander belt is very close to the constraints for much of the reach.

C6.2.6.2 Engineering Effectiveness Evaluation Factor for Manage Sediment

SRH-1D model results show a fairly small sediment deficit in this reach; thus, adding sediment to the reach would be the strategy. Model results show the equilibrium slope is a bit flatter than baseline. Adding sediment could prevent this trend. Because the modeled slope change is relatively small, other strategies also may be needed, resulting in a medium rating for overall engineering effectiveness.

C6.2.6.3 Ecosystem Function Evaluation Factor for Manage Sediment

C6.2.6.3.1 Southwestern Willow Flycatcher

It is unknown what impact sediment management would have on SWFL habitat within this reach. Modeled indicators predict no impacts either positive or negative; however, impacts depend on type of management activity.

C6.2.6.3.2 Rio Grande Silvery Minnow

Adding sediment would be positive for RGSM by building desirable point bar habitat. This reach has low sediment load, and increasing sediment could create further sloping bank lines and islands with increased shoreline and potential to overbank and flood—providing increased habitat.

Because adding sediment is unlikely to occur since sediment load is not significantly out of balance at the existing channel width, the Habitat Complexity Attribute rated no change. The Construction Impact Attribute is rated medium because deposition of sand in the river or development of a source for increasing sand could have a low to moderate short-term construction impact. Construction could be done in the channel, bank, flood plain, or terraces.

C6.2.6.4 Economic Evaluation Factor for Manage Sediment

The Implementation Cost Attribute is rated low because of the quantity of sediment needed per year as estimated by the SRH-1D model.

C6.2.7 Strategy Assessment Result Comparison Tables

The ratings for each attribute for each of the evaluation factors for each strategy are in table C6.6 (Engineering Effectiveness Evaluation Factor), table C6.7 (Ecosystem Function Evaluation Factor), and table C6.8 (Economic Evaluation Factor).

Tables C6.9 and C6.10 summarize the effectiveness and economics scores for all suitable strategies for the reach.

For ease of comparison, figures C6.1–C6.3 graphically present the indexed scores for effectiveness divided by cost for each subevaluation factor, factor, and strategy total, respectively.

Table C6.6. Engineering Effectiveness Evaluation Factor Attribute Ratings for the Isleta Diversion Dam to Rio Puerco Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment[1]
Construction Location	Channel and Bank	Bank	Channel, Bank, and Flood Plain	Flood Plain and Terraces	Channel, Bank, Terraces, and Flood Plain	Channel, Bank, Flood Plain, and Terraces
Strategy Performance						
Ability to Implement	Low		Low	Low	Low	Low
Level of Confidence	Medium		Medium	Medium	Medium	Low
Duration and Design Life	High		Medium	Medium	Medium	Medium
Adaptability	Low		High	Low	High	High
River Maintenance Function						
Water Delivery	No Change		No Change	No Change	Decrease	No Change
Hydraulic Capacity	No Change		No Change	No Change	Increase	No Change
Public Health and Safety	Increase		No Change	Increase	Increase	No Change

[1] Increasing sediment supply.

Table C6.7. Ecosystem Function Evaluation Factor Attribute Ratings for the Isleta Diversion Dam to Rio Puerco Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
SWFL						
Variety of Successional Stages	No Change		No Change	No Change	Increase	No Change
Water Table Elevation	No Change		No Change	No Change	No Change	No Change
Flood Plain Width/Patch Availability	No Change		No Change	No Change	Increase	No Change
Flood Plain Elevation	No Change		No Change	No Change	Increase	No Change
Construction Impacts	Medium		Medium	Medium	High	Medium
RGSM						
Provides the opportunity for complexity – Indicator H2	No Change		Decrease	Increase	Increase	Increase
Flood plain connectivity and frequency of flooding- Indicators C,E2, and J	No Change		No Change	No Change	Increase	No Change
Sinuosity – Indicator F2	No Change		No Change	Increase	No Change	No Change
Construction Impacts (short term)	High		High	Low	Low	Medium

Table C6-8. Economic Evaluation Factor Attribute Ratings for the Isleta Diversion Dam to Rio Puerco Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
Planning and Design	High		High	High	High	High
Environmental Compliance	High		High	Low	High	High
Implementation	Low		Low	Low	High	Low
Monitoring and Evaluation	Medium		High	Low	Medium	High
Frequency of Maintenance	Low		High	Low	Low	Low
Amount of Maintenance	Low		High	Low	Low	Low
Frequency of Adaptive Management	Medium		High	Low	Low	High
Amount of Adaptive Management	Medium		High	Low	Medium	High

Table C6.9. Summary of Economics and Effectiveness Scores by Subevaluation Factor for the Isleta Diversion Dam to Rio Puerco Reach

	Economics Score	Effectiveness Score			
Strategy	Cost	Strategy Performance	River Maintenance Function	SWFL	RGSM
Promote Elevation Stability	1.79	0.86	1.22	1.00	0.88
Promote Alignment Stability					
Reconstruct/ Maintain Channel Capacity	2.50	0.87	1.00	1.00	0.75
Increase Available Area	1.30	0.73	1.22	1.00	1.38
Rehabilitate Channel and Flood Plain	2.20	0.87	1.24	1.20	1.38
Manage Sediment	2.06	0.77	1.00	1.00	1.13

Table C6.10. Summary of Economics and Effectiveness Scores for the Isleta Diversion Dam to Rio Puerco Reach

Strategy	Cost	Engineering Effectiveness	Ecosytem Function Effectiveness		Total Effectiveness
Promote Elevation Stability	1.79	2.08	1.88		3.96
Promote Alignment Stability					
Reconstruct/ Maintain Channel Capacity	2.50	1.87	1.75		3.62
Increase Available Area	1.30	1.95	2.38		4.33
Rehabilitate Channel and Flood Plain	2.20	2.11	2.58		4.69
Manage Sediment	2.06	1.77	2.13		3.90

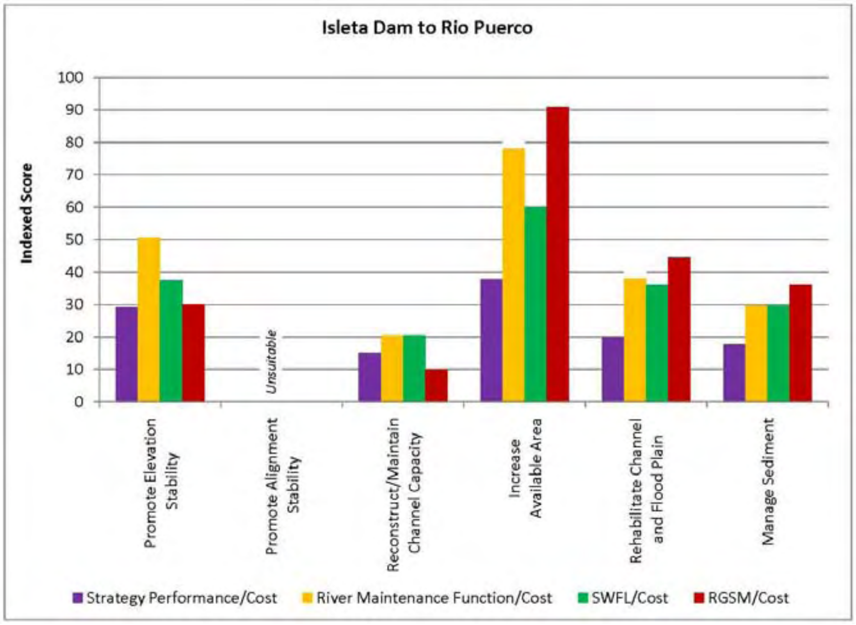

Figure C6.1. Isleta Diversion Dam to Rio Puerco Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

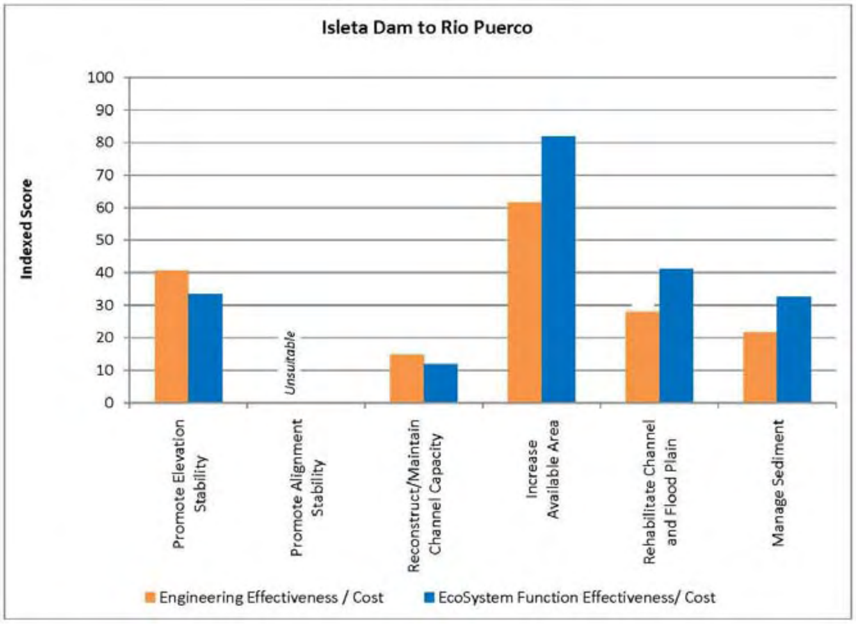

Figure C6.2. Isleta Diversion Dam to Rio Puerco Reach effectiveness divided by cost indexed scoring results by evaluation factor.

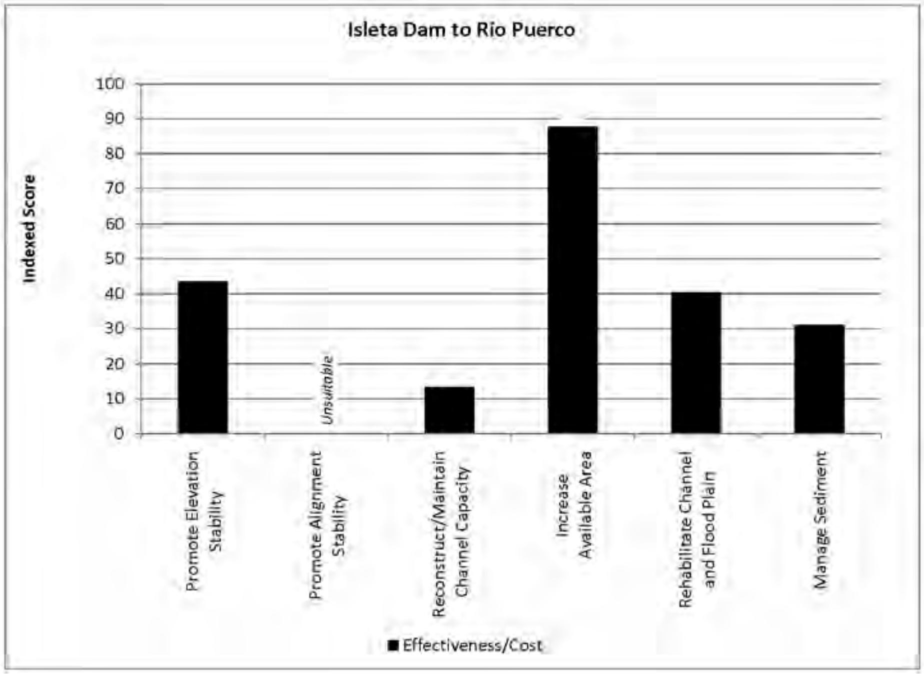

Figure C6.3. Isleta Diversion Dam to Rio Puerco Reach total effectiveness divided by cost indexed scoring results.

C6.3 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

Continuation of these trends may cause the following 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.

Chapter C7. Rio Puerco to San Acacia Diversion Dam (RM 127 to RM 116.2)

C7.1 Reach Characteristics

The Rio Puerco to San Acacia Diversion Dam reach is approximately 11 miles long, has a riverbed slope of approximately 0.00072 (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's fan acts as major grade control. The current terrace bank height is 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 and are vegetating, 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.

C7.1.1 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; therefore, the overall rating is medium. This assessment depends on the assumption that there would be little change in the Rio Puerco and Rio Salado watersheds; thus, incoming water and sediment loads would not vary much from existing levels. About three-fourths of the modeled meander belt fits between the constraints. Sevilleta bend, which is geologically controlled, is the primary location where the meander belt does not fit, which could mean adjustments are greater in other areas. About half of the available area between the constraints is used, so there is some space for the channel to migrate.

Downstream of the Salado, the channel lengthened between 2006 and 2008, but the model does not predict more flattening of the slope. There is a slope concavity above Salado that is filled with sediment by the SRH-1D modeling; but there is not much bed elevation change downstream. Therefore, the reach average slope ends up being steeper. There is an opportunity that vegetation control may help reduce channel narrowing and reactivate bars.

C7.1.2 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 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), water delivery impact is rated as high importance.

C7.1.3 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.

C7.1.4 Habitat Value and Need Reach Characteristic

This reach has been classified as biologically significant by Reclamation biologists for both SWFL and RGSM.

C7.1.4.1 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. As occupied patches, including the largest group of territories outside the Elephant Butte Reservoir pool, have declined in quality, river dynamics in this reach have provided new areas for SWFLs to occupy. These areas consist of lower flood plains and river bars that have become colonized by a mixture of willows, Russian olive, and salt cedar and receive regular floodwaters during high river flows. The SWFL population within this reach continues to expand into developing habitat and could become a significant source population for developing habitat upstream.

C7.1.4.2 Rio Grande Silvery Minnow – Medium Importance

RGSM are present throughout this reach (Dudley and Platania 2011 and Reclamation data). The channel is incised and highly constrained by thick vegetation. It is further confined on either side by drains or immovable geomorphic features. These constraints serve to deepen the channel and limit its ability to meander and widen. Increases in channel complexity could increase the habitat diversity required to maintain RGSM within the reach. This is a gaining reach—well supported with water. If fish passage is implemented at San Acacia Diversion Dam, this reach could move to a high importance rating for the RGSM Habitat Value and Need Reach Characteristic.

C7.2 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.

This section highlights considerations for suitable strategies that should be studied further. Ratings for suitable strategies that are not recommended for further study are provided as an aid for analysis. Recommendations based on this analysis are in section C7.3.

C7.2.1 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 for more information).

C7.2.2 Promote Alignment Stability

Table C7.1 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

C7.2.2.1 Geomorphic Effects for Promote Alignment Stability

The model does not predict channel lengthening, but this result depends on the current channel width. If the channel continues to narrow, migration may increase. There is some space to allow channel migration before bank stabilization is needed; therefore, this strategy could have some increase in channel and flood plain adjustments, and the balance between sediment load and transport capacity would come closer. Flood plain connectivity also could increase in the areas with local aggradation as predicted by the model.

C7.2.2.2 Engineering Effectiveness Evaluation Factor for Promote Alignment Stability

The average river width is about 250 feet in this reach, which is suitable for longitudinal and transverse features. Even though modeling results show the reach length could shorten (slope is steepening), about three-fourths of the estimated meander belt width fits within the infrastructure constraints, indicating lateral confinement. Some bank stabilization exists along Drain Unit 7 Extension.

Table C7.1. Effectiveness and Cost Scores for Rio Puerco to San Acacia Diversion Dam Reach, Promote Alignment Stability

Evaluation Factor	Attribute	Raw Score	Weight	Weighted Score
Effectiveness: 3 is the most effective, and 1 is the least effective.				
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	3	20%	0.60
	Level of Confidence	3	10%	0.30
	Duration and Design Life	3	13%	0.39
	Adaptability	2	7%	0.14
	Strategy Performance Score		*50%*	*1.43*
	River Maintenance Function			
	Water Delivery	3	13%	0.39
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.35*
	Engineering Effectiveness Score		**100%**	**2.78**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	1	10%	0.10
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	1	10%	0.10
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*0.80*
	RGSM			
	Habitat Complexity	1	13%	0.13
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	1	13%	0.13
	RGSM Score		50%	0.75
	Ecosystem Function Effectiveness Score		**100%**	**1.55**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	2	15%	0.30
	Environmental Compliance	3	11%	0.33
	Implementation Cost	2	25%	0.50
	Monitoring and Evaluation	2	9%	0.18
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	2	9%	0.18
	Amount of Adaptive Management	2	9%	0.18
	Economics Score		**100%**	**1.89**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

The total elevation change estimated by the model is less than 3 feet. This is a small enough amount of potential aggradation that this strategy would apply and can be used in this reach with high confidence. Thus, the Level of Confidence Attribute is rated as high.

C7.2.2.3 Ecosystem Function Evaluation Factor for Promote Alignment Stability

C7.2.2.3.1 Southwestern Willow Flycatcher

Promoting alignment stability decreases the ability of the river to regenerate habitat and would, in turn, decrease patch availability and the opportunity for a variety of successional stages. The Construction Impacts Attribute is rated as medium since some work would occur both within the riparian area and within the river channel itself.

C72.2.3.2 Rio Grande Silvery Minnow

RGSM habitat and opportunity for complexity would be reduced if this strategy were implemented.

Construction could occur on the banks. The Construction Impacts Attribute is rated as high, because work in Rio Grande establishing stability could impact edge of river-based RGSM nursery and adult habitats.

C7.2.2.4 Economic Evaluation Factor for Promote Alignment Stability

The Implementation Cost Attribute is rated as medium, even though Reclamation has extensive experience with the methods of this strategy and planning and design costs would normally be rated low. This elevated rating is because about one-fourth of the meander belt width is calculated to be outside of the lateral constraints. The Planning and Design Attribute is rated as medium because this reach is biologically significant for the RGSM and the SWFL.

C7.2.3 Reconstruct and Maintain Channel Capacity – Not Suitable

Historical trends do not show a large 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.

C7.2.4 Increase Available Area to the River

Table C7.2 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

Table C7.2. Effectiveness and Cost Scores for Rio Puerco to San Acacia Diversion Dam Reach, Increase Available Area to the River

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	2	20%	0.40
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	1	7%	0.07
	Strategy Performance Score		*50%*	*0.93*
	River Maintenance Function			
	Water Delivery	3	13%	0.39
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.35*
	Engineering Effectiveness Score		**100%**	**2.28**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	3	10%	0.30
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	3	10%	0.30
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*1.20*
	RGSM			
	Habitat Complexity	3	13%	0.38
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	3	13%	0.38
	Construction Impacts[1]	3	13%	0.38
	RGSM Score		50%	1.38
	Ecosystem Function Effectiveness Score		**100%**	**2.58**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	2	11%	0.22
	Implementation Cost	3	25%	0.75
	Monitoring and Evaluation	1	9%	0.09
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	1	9%	0.09
	Economics Score		**100%**	**1.91**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C7.2.4.1 Geomorphic Effects for Increase Available Area to the River

As discussed under Promote Alignment Stability, there is a possibility of channel migration. If this did occur, an increase in habitat renewal, attenuation of extreme events, water table interactions, 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, would be expected. The balance between sediment transport capacity and load would be expected to become closer, and flood plain connectivity would be expected to increase; but the rate of change may be slow enough or the area provided limited so the increases might not extend through the majority of the reach in the next decade.

There is available land to set back the Drain Unit 7 Extension to the La Joya Drain alignment for a good portion of the reach. This might help compensate for Sevilleta Bend being narrower than the calculated meander belt width of the reach by allowing additional area upstream for lateral migration.

C7.2.4.2 Engineering Effectiveness Evaluation Factor for Increase Available Area to the River

Three-fourths of the length of the calculated meander belt width fits within the infrastructure. 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.

C7.2.4.3 Ecosystem Function Evaluation Factor for Increase Available Area to the River

C7.2.4.3.1 Southwestern Willow Flycatcher

Increased habitat for SWFL is expected to occur by allowing the river to meander over a greater flood plain, potentially creating new and younger age classes of vegetation through erosion and deposition. The Construction Impacts Attribute is medium; thus, most of the construction could be conducted within the flood plain but outside of the riparian area.

C7.2.4.2.2 Rio Grande Silvery Minnow

Opportunity for optimal RGSM habitat and channel complexity would increase if this strategy is implemented; therefore the Variety of Successional Stages Attribute is rated as increased. The Construction Impacts Attribute is low, since equipment work could be done from the flood plain and terraces.

C7.2.4.4 Economic Evaluation Factor for Increase Available Area to the River

The Planning and Design Attribute is rated high because it is estimated that a large amount of infrastructure would need to be moved. The Environmental Compliance Attribute is rated medium because of the refuges. The Implementation Cost Attribute is high because a quarter of the reach has the potential to migrate laterally to the infrastructure, and infrastructure relocation costs would be high.

C7.2.5 Rehabilitate Channel and Flood Plain

Table C7.3 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

Table C7.3. Effectiveness and Cost Scores for Rio Puerco to San Acacia Diversion Dam Reach, Rehabilitate Channel and Flood Plain

Evaluation Factor	Attribute	Raw Score	Weight	Weighted Score
Effectiveness: 3 is the most effective, and 1 is the least effective.				
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	3	7%	0.21
	Strategy Performance Score		*50%*	*0.87*
	River Maintenance Function			
	Water Delivery	1	13%	0.13
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.09*
	Engineering Effectiveness Score		**100%**	**1.96**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	3	10%	0.30
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	3	10%	0.30
	Construction Impacts[1]	1	10%	0.10
	SWFL Score		*50%*	*1.10*
	RGSM			
	Habitat Complexity	3	13%	0.38
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	3	13%	0.38
	RGSM Score		50%	1.25
	Ecosystem Function Effectiveness Score		**100%**	**2.35**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	3	25%	0.75
	Monitoring and Evaluation	2	9%	0.18
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	2	9%	0.18
	Economics Score		**100%**	**2.20**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C7.2.5.1 Geomorphic Effects for Rehabilitate Channel and Flood Plain

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

C7.2.5.2 Engineering Effectiveness Evaluation Factor for Rehabilitate Channel and Flood Plain

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

C7.2.5.3 Ecosystem Function Evaluation Factor for Rehabilitate Channel and Flood Plain

C7.2.5.3.1 Southwestern Willow Flycatcher

Habitat for SWFL in this reach likely would be improved by this strategy by providing increased overbank flooding. Strategy implementation would have to be designed to avoid creating a monotypic, single-age class stand of riparian vegetation.

C7.2.5.3.2 Rio Grande Silvery Minnow

Opportunity for optimal RGSM habitat and channel complexity would increase if this strategy is implemented. Increased flood plain area and connectivity to the flood plain creates more nursery habitat in flooding conditions, which would be positive for RGSM.

The Construction Impacts Attribute is rated low, because work could impact the edge of the river-based RGSM nursery and adult habitats. While construction could occur on the channel, bank, terraces, and flood plain, most of the work could be done from the bank line.

C7.2.5.4 Economic Evaluation Factor for Rehabilitate Channel and Flood Plain

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

C7.2.6 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.

C7.2.7 Strategy Assessment Result Comparison Tables

The ratings for each attribute for each of the evaluation factors for each strategy are in table C7.4 (Engineering Effectiveness Evaluation Factor), table C7.5 (Ecosystem Function Evaluation Factor), and table C7.6 (Economic Evaluation Factor).

Tables C7.7 and C7.8 summarize the effectiveness and economics scores for all suitable strategies for the reach.

For ease of comparison, figures C4.1–C4.3 graphically present the indexed scores for effectiveness divided by cost for each subevaluation factor, factor, and strategy total, respectively.

C7.3 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 (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.

Table C7.4. Engineering Effectiveness Evaluation Factor Attribute Ratings for the Rio Puerco to San Acacia Diversion Dam Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
Construction Location		Bank		Flood Plain and Terraces	Channel, Bank, Terraces, and Flood Plain	
Strategy Performance						
Ability to Implement		High		Medium	Low	
Level of Confidence		High		Medium	Medium	
Duration and Design Life		High		Medium	Medium	
Adaptability		Medium		Low	High	
River Maintenance Function						
Water Delivery		Increase		Increase	Decrease	
Hydraulic Capacity		No Change		No Change	No Change	
Public Health and Safety		Increase		Increase	Increase	

Table C7.5. Ecosystem Function Evaluation Factor Attribute Ratings for the Rio Puerco to San Acacia Diversion Dam Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
SWFL						
Variety of Successional Stages		Decrease		Increase	Increase	
Water Table Elevation		No Change		No Change	No Change	
Flood Plain Width/Patch Availability		Decrease		Increase	No Change	
Flood Plain Elevation		No Change		No Change	Increase	
Construction Impacts		Medium		Medium	High	
RGSM						
Habitat Complexity		Decrease		Increase	Increase	
Flood Plain Connectivity and Frequency of Flooding		No Change		No Change	No Change	
Sinuosity		No Change		Increase	No Change	
Construction Impacts		High		Low	Low	

Table C7.6. Economic Evaluation Factor Attribute Ratings for the Rio Puerco to San Acacia Diversion Dam Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
Planning and Design		Medium		High	High	
Environmental Compliance		High		Medium[1]	High	
Implementation		Medium		High	High[1]	
Monitoring and Evaluation		Medium		Low	Medium	
Frequency of Maintenance		Low		Low	Low	
Amount of Maintenance		Low		Low	Low	
Frequency of Adaptive Management		Medium		Low	Low	
Amount of Adaptive Management		Medium		Low	Medium	

[1] Ladd S. Gordon Waterfowl Management Area-La Joya and Sevilleta National Wildlife Refuge.

Table C7.7. Summary of Economics and Effectiveness Scores by Subevaluation Factor for the Rio Puerco to San Acacia Diversion Dam Reach

	Economics Score	Effectiveness Score			
Strategy	Cost	Strategy Performance	River Maintenance Function	SWFL	RGSM
Promote Elevation Stability					
Promote Alignment Stability	1.89	1.43	1.35	0.80	0.75
Reconstruct/ Maintain Channel Capacity					
Increase Available Area	1.91	0.93	1.35	1.20	1.38
Rehabilitate Channel and Flood Plain	2.20	0.87	1.09	1.10	1.25
Manage Sediment					

Table C7.8. Summary of Economics and Effectiveness Scores for the Rio Puerco to San Acacia Diversion Dam Reach

Strategy	Cost	Engineering Effectiveness	Ecosytem Function Effectiveness		Total Effectiveness
Promote Elevation Stability					
Promote Alignment Stability	1.89	2.78	1.55		4.33
Reconstruct/ Maintain Channel Capacity					
Increase Available Area	1.91	2.28	2.58		4.86
Rehabilitate Channel and Flood Plain	2.20	1.96	2.35		4.31
Manage Sediment					

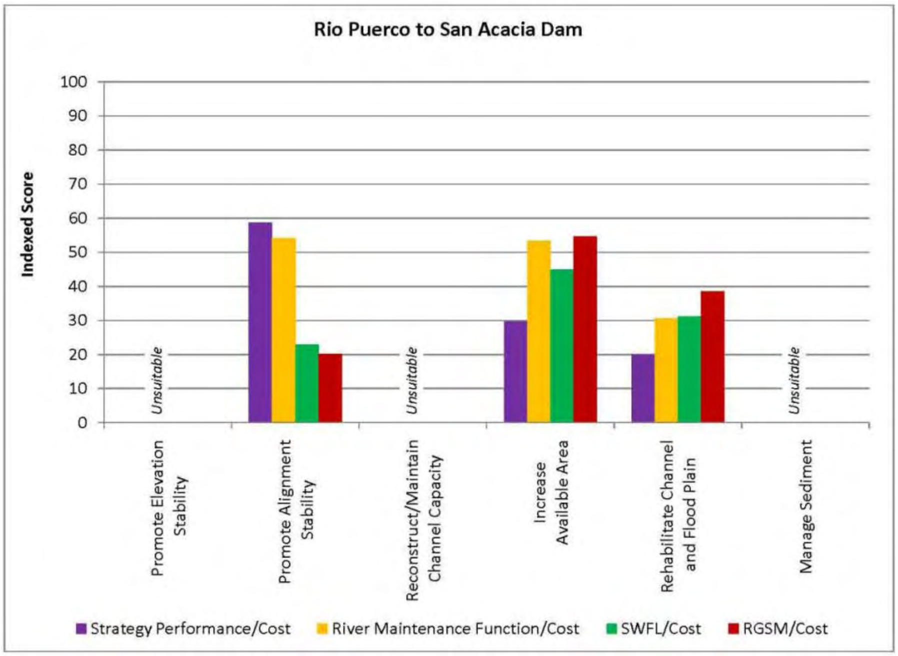

Figure C7.1. Rio Puerco to San Acacia Diversion Dam Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

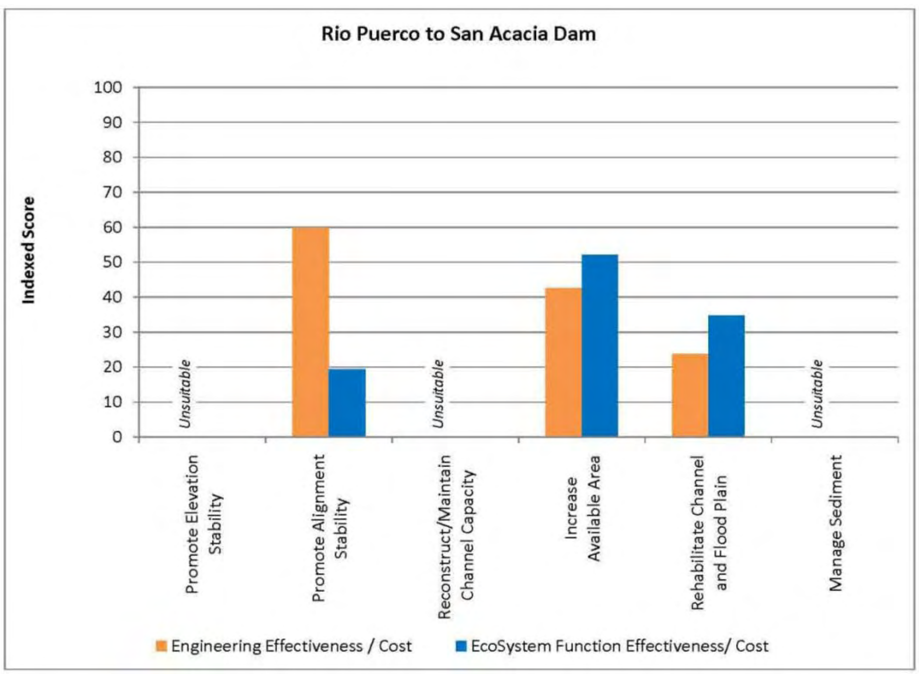

Figure C7.2. Rio Puerco to San Acacia Diversion Dam Reach effectiveness divided by cost indexed scoring results by evaluation factor.

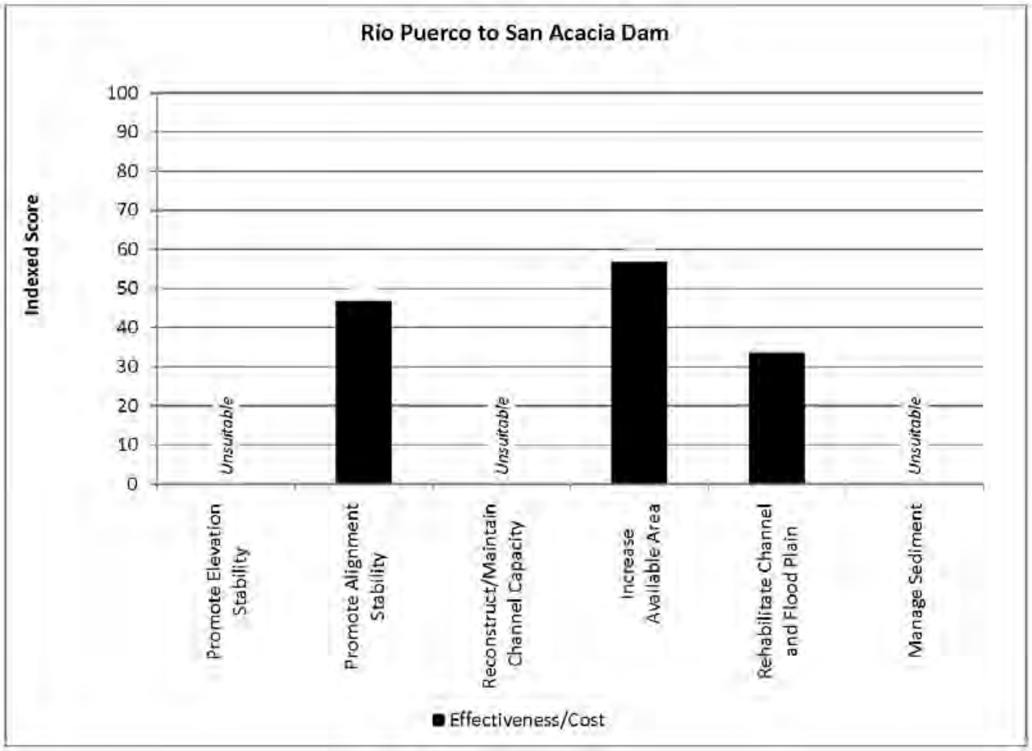

Figure C7.3. Rio Puerco to San Acacia Diversion Dam Reach total effectiveness divided by cost indexed scoring results.

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.

Chapter C8. San Acacia Diversion Dam to Arroyo de las Cañas (RM 116.2 to RM 95)

C8.1 Reach Characteristics

This reach is about 21 miles long with a riverbed slope of approximately 0.0008 (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 stormwater 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 layer. Several arroyos have been reconnected to the Rio Grande by removing vegetation, 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 (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, where the bed elevation 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 braid plain available to the river, but there are still areas where it is cut off. There is new vegetation growing on the low bars, with the vegetation maturing and thickening on the higher bars. The channel has straightened in several of the largest bends, steepening the locally overly lengthened/flattened slope in those bends.

C8.1.1 Channel Instability Reach Characteristic – Medium Instability

Many bends are active in this reach, especially between San Acacia Diversion Dam and Escondida, and the most active bends have moved to Stages M7 (Migrating with cutoff channel) and M8 (Cutoff is now main channel), 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 due to aggradation at the lower end. This may be due to predicted aggradation in the next downstream reaches, so caution is advised in drawing conclusions for this reach. Further study on whether the amount of aggradation expected to occur downstream is as great as predicted with the model would be very helpful in determining the appropriate maintenance strategies for this reach. Also of note is that sediment modeling of a smaller reach near San Acacia showed approximately an additional 7 feet of degradation from 2002 estimated elevations (Greimann 2005). Virtually all of the calculated meander belt fits between the constraints, but it uses most of the available area so that there is little extra area to absorb any increase in channel migration. The medium rating for channel instability in the San Acacia Diversion Dam to Arroyo de las Cañas Reach is based on historical trends and model results.

C8.1.2 Water Delivery Impact Reach Characteristic – High Importance

The Water Delivery Impact Reach Characteristic 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 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).

C8.1.3 Infrastructure, Public Health, and Safety Reach Characteristic – Medium Importance

Infrastructure in this reach includes agricultural cropland; a 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).

C8.1.4 Habitat Value and Need Reach Characteristic

C8.1.4.1 Southwestern Willow Flycatcher – Low Importance

Although this entire reach is included in the critical habitat designation, as noted above, the river channel in this reach is severely degraded and rarely, if ever, overbanks. Habitat consists mainly of sparse stands of primarily exotic vegetation that is not suitable for inhabitation by breeding SWFLs. Several small patches of moderate or high quality habitat are present on lower terraces and river bars. However, resident SWFLs rarely have been documented in this reach, and no pairing or nesting has occurred during the past 14 years of surveying. For these reasons, efforts directed at promoting SWFL habitat should be directed elsewhere.

C8.1.4.2 Rio Grande Silvery Minnow – High Importance

In the upper portion of this reach, the river is confined by stable geomorphic features to the east and the LFCC on the west. Banks are high, and the channel is narrow and deep with fast moving water. Large numbers of young-of-year fishes are often present in this reach that may have drifted from above reaches (Dudley and Platania 2011 and Reclamation data). Drying occurs in the lower portions of this reach, though leakage through the dam provides permanent water immediately below it. Because the dam is a barrier to upstream movement, fish tend to congregate below the dam. The channel widens several miles below the dam providing greater habitat complexity. Due to the high population densities within this area and likelihood of drying, habitat actions to maintain channel connectivity and wetted habitats throughout the year would be high priority. Fish passage would only increase habitat value as a corridor.

C8.2 Strategy Assessment Results

Five strategies are potentially suitable for this reach:

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

Promote Elevation Stability Strategy could address the bed degradation that also might help reduce channel migration. Promote Alignment Stability, Increase Available Area to the River (beyond two current 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 meet transport capacity from bed and/or bank erosion.

This chapter highlights considerations for suitable strategies that should be studied further. Ratings for suitable strategies that are not recommended for further study are provided as an aid for analysis. Recommendations based on this analysis are in section C8.3.

C8.2.1 Promote Elevation Stability

Table C8.1 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

Table C8.1. Effectiveness and Cost Scores for San Acacia Diversion Dam to Arroyo del las Cañas Reach, Promote Elevation Stability

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	Attribute	Raw Score	Weight	Weighted Score
Engineering Effectiveness	Strategy Performance			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	3	13%	0.39
	Adaptability	1	7%	0.07
	Strategy Performance Score		*50%*	*0.86*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.22*
	Engineering Effectiveness Score		**100%**	**2.08**
Ecosystem Function Effectiveness	SWFL			
	Variety of Successional Stages	2	10%	0.20
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*1.00*
	RGSM			
	Habitat Complexity	2	13%	0.25
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	1	13%	0.13
	RGSM Score		50%	0.88
	Ecosystem Function Effectiveness Score		**100%**	**1.88**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	Attribute	Raw Score	Weight	Weighted Score
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	2	25%	0.50
	Monitoring and Evaluation	2	9%	0.18
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	2	9%	0.18
	Amount of Adaptive Management	2	9%	0.18
	Economics Score		**100%**	**2.04**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C8.2.1.1 Geomorphic Effects for Promote Elevation Stability

This strategy could be necessary for the upper portion of this reach, especially if fish passage is constructed at the San Acacia Diversion Dam. Model results show the stable slope is flatter than the existing slope, but there is uncertainty whether there would be degradation at the upper end, aggradation at the lower end, or lateral migration to achieve this (see section C8.1.1.). This reach is incised enough that flood plain connectivity and attenuation of extreme events are unlikely to change.

C8.2.1.2 Engineering Effectiveness Evaluation Factor for Promote Elevation Stability

This reach has experienced about 12 feet of channel incision at the San Acacia Diversion Dam and lateral migration between San Acacia and Escondida. Flanking countermeasures would be required for cross channel structures to perform well over the long term. The SRH-1D model shows the potential need for grade control in this reach. The amount of future slope change is fairly small, and some of the slope change was due to downstream sediment deposition. Thus, the rating for the Duration and Design Life Attribute is medium. However, 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.

C8.2.1.3 Ecosystem Function Evaluation Factor for Promote Elevation Stability

C8.2.1.3.1 Southwestern Willow Flycatcher

Although preventing further channel incision in this reach would prevent additional drops in the water table and keep habitat in its current state, it would not have a positive effect or promote regeneration of younger age classes. This strategy would not have a significant impact on SWFL habitat.

C8.2.1.3.2 Rio Grande Silvery Minnow

Promoting elevation stability with grade control or other bank-to-bank structures probably would not change much of the RGSM habitat complexity, which results in a no change determination. 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 RGSM use.

Construction is in the channel and bank. The Construction Impact Attribute is rated high due to bank-to-bank construction with equipment and changes across the entire river.

C8.2.1.4 Economic Evaluation Factor for Promote Elevation Stability

The Implementation Cost Attribute is rated medium due to the fairly small amount of future slope change in this reach.

C8.2.2 Promote Alignment Stability

Table C8.2 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

Table C8.2. Effectiveness and Cost Scores for San Acacia Diversion Dam to Arroyo del las Cañas Reach, Promote Alignment Stability

Evaluation Factor	Attribute	Raw Score	Weight	Weighted Score
Effectiveness: 3 is the most effective, and 1 is the least effective.				
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	3	20%	0.60
	Level of Confidence	3	10%	0.30
	Duration and Design Life	3	13%	0.39
	Adaptability	2	7%	0.14
	Strategy Performance Score		*50%*	*1.43*
	River Maintenance Function			
	Water Delivery	1	13%	0.13
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.09*
	Engineering Effectiveness Score		**100%**	**2.52**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	2	10%	0.20
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*1.00*
	RGSM			
	Habitat Complexity	2	13%	0.25
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	1	13%	0.13
	RGSM Score		50%	0.88
	Ecosystem Function Effectiveness Score		**100%**	**1.88**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	2	15%	0.30
	Environmental Compliance	3	11%	0.33
	Implementation Cost	2	25%	0.50
	Monitoring and Evaluation	2	9%	0.18
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	2	9%	0.18
	Amount of Adaptive Management	2	9%	0.18
	Economics Score		**100%**	**1.89**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C8.2.2.1 Geomorphic Effects for Promote Alignment Stability

This reach has actively eroding large bends but does not have much space to accommodate more channel migration. This means that this strategy would generally decrease the channel and flood plain adjustments because the channel would need to remain close to its current alignment. There is a possible decrease in episodic sediment transport with the loss of bank interaction.

C8.2.2.2 Engineering Effectiveness Evaluation Factor for Promote Alignment Stability

A small percent of the calculated meander belt width is outside of the infrastructure, and the estimated amount of vertical change in the reach is also relatively small. The potential slope change and percentage of the channel outside of the meander belt width indicate that this strategy can be used with confidence in this reach. Model results show an increase in sinuosity, and water delivery may be slightly reduced.

C8.2.2.3 Ecosystem Function Evaluation Factor for Promote Alignment Stability

C8.2.2.3.1 Southwestern Willow Flycatcher

SWFL habitat depends on a dynamic, meandering river system that alternately scours and deposits new sediments that regenerating habitat can colonize. Promoting alignment stability tends to decrease the ability of the river to do this and would, in turn, decrease patch availability and the opportunity for a variety of successional stages. Within this reach, lateral migration would be allowed, if there is room within the infrastructure. The Construction Impacts Attribute would be rated medium because some work would occur both within the riparian area and within the river channel itself.

C8.2.2.3.2 Rio Grande Silvery Minnow

Minimal change to RGSM habitat and opportunity for complexity would take place if some lateral migration is possible. Construction is on the bank. The Construction Impacts Attribute is rated high because work in the Rio Grande establishing stability could impact edge of river-based RGSM nursery and adult habitats.

C8.2.2.4 Economic Evaluation Factor for Promote Alignment Stability

This reach is rated medium for the Implementation Cost Attribute because a portion of the length of the meander belt width is outside of the limits of the adjacent lateral constraints. The Environmental Compliance Attribute is rated high because the San Acacia Diversion Dam to Arroyo de las Cañas Reach is biologically significant for the SWFL and RGSM.

C8.2.3 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.

C8.2.4 Increase Available Area to the River

Table C8.3 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

Table C8.3. Effectiveness and Cost Scores for San Acacia Diversion Dam to Arroyo del las Cañas Reach, Increase Available Area to the River

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	1	7%	0.07
	Strategy Performance Score		*50%*	*0.73*
	River Maintenance Function			
	Water Delivery	1	13%	0.13
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.09*
	Engineering Effectiveness Score		**100%**	**1.82**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	3	10%	0.30
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	3	10%	0.30
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*1.20*
	RGSM			
	Habitat Complexity	3	13%	0.38
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	3	13%	0.38
	Construction Impacts[1]	3	13%	0.38
	RGSM Score		*50%*	*1.38*
	Ecosystem Function Effectiveness Score		**100%**	**2.58**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	1	11%	0.11
	Implementation Cost	2	25%	0.50
	Monitoring and Evaluation	1	9%	0.09
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	1	9%	0.09
	Economics Score		**100%**	**1.55**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C8.2.4.1 Geomorphic Effects for Increase Available Area to the River

The modeling shows flattening of the slope, so this strategy may continue to be useful, even though levee setbacks already have been implemented for two areas in this reach. Meander analysis shows that there are other areas where this would be geomorphically useful—around RM 108 and near Escondida and Bosquecito. Land is available near RM 108, but this is a much longer setback that would open up less area than the two already constructed. More space would allow the river to adjust as needed, thus increasing the natural channel processes and balance of sediment load and transport capacity. An increase in flood plain connectivity would be expected based on historical trends and model results.

C8.2.4.2 Engineering Effectiveness Evaluation Factor for Increase Available Area to the River

Because a significant portion of the calculated meander belt width is not within the infrastructure and geologic constraints, this strategy would be more effective in the San Acacia Diversion Dam to Arroyo de las Cañas Reach than in many other reaches.

C8.2.4.3 Ecosystem Function Evaluation Factor for Increase Available Area to the River

C8.2.4.3.1 Southwestern Willow Flycatcher

This strategy also increases the possibility of a more dynamic river system and would allow for destruction and creation of habitat via scouring and deposition of sediments. Thus, it can be considered to have positive impacts to SWFL habitat. However, construction activities are also in the flood plain and would have to be designed to minimize impacts to habitat.

C8.2.4.3.2 Rio Grande Silvery Minnow

Opportunity for optimal RGSM habitat and channel complexity would increase if this strategy is implemented. This reach has lateral migration with potential for increasing sinuosity. The Construction Impact Attribute is rated low because equipment work could be done from the flood plain and terraces.

C8.2.4.4 Economic Evaluation Factor for Increase Available Area to the River

The Implementation Cost Attribute is rated medium because 16 percent of the reach is outside the calculated meander belt width. 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.

C8.2.5 Rehabilitate Channel and Flood Plain

Table C8.4 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

Table C8.4. Effectiveness and Cost Scores for San Acacia Diversion Dam to Arroyo del las Cañas Reach, Rehabilitate Channel and Flood Plain

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	3	7%	0.21
	Strategy Performance Score		*50%*	*0.87*
	River Maintenance Function			
	Water Delivery	1	13%	0.13
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.09*
	Engineering Effectiveness Score		**100%**	**1.96**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	3	10%	0.30
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	3	10%	0.30
	Flood Plain Elevation	3	10%	0.30
	Construction Impacts[1]	1	10%	0.10
	SWFL Score		*50%*	*1.20*
	RGSM			
	Habitat Complexity	3	13%	0.38
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	3	13%	0.38
	RGSM Score		50%	1.25
	Ecosystem Function Effectiveness Score		**100%**	**2.45**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	3	25%	0.75
	Monitoring and Evaluation	2	9%	0.18
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	2	9%	0.18
	Economics Score		**100%**	**2.20**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C8.2.5.1 Geomorphic Effects for Rehabilitate Channel and Flood Plain

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

C8.2.5.2 Engineering Effectiveness Evaluation Factor for Rehabilitate Channel and Flood Plain

This reach has experienced channel incision and lateral migration as briefly described in the Promote Elevation Stability section above. The model predicts sediment deposition in the lower part of the reach from about the Socorro North Diversion Channel to Arroyo de las Cañas, while the bed elevation doesn't change upstream. This results in a flatter slope with an excess sediment supply. Since the goal of this strategy is to decrease sediment transport capacity, overall engineering effectiveness is rated low.

C8.2.5.3 Ecosystem Function Evaluation Factor for Rehabilitate Channel and Flood Plain

C8.2.5.3.1 Southwestern Willow Flycatcher

Depending on the exact location of construction work, this strategy could have a positive impact on SWFL habitat via the increased likelihood of overbank flooding. Careful design of on-the-ground construction activities can ensure minimized negative impact to flood plain habitat. Strategy implementation would also have to be designed to avoid creating a monotypic, single-age class stand of riparian vegetation.

C8.2.5.3.2 Rio Grande Silvery Minnow

Opportunity for optimal RGSM habitat and channel complexity would increase if this strategy is implemented. Increased flood plain area and connectivity to the flood plain creates more nursery habitat in flooding conditions that would be positive for RGSM.

The Construction Impact Attribute is rated low because work could impact edge of river-based RGSM nursery and adult habitats. However, the majority of work could be done from the bank line.

C8.2.5.4 Economic Evaluation Factor for Rehabilitate Channel and Flood Plain

A high cost is estimated. Most strategy ratings are the same as those common for this strategy found in the main report in sections 3.1.1–3.1.7 are not influenced by reach characteristics.

C8.2.6 Manage Sediment – Not Recommended

Model results show managing sediment in this reach could be very difficult. If sediment is managed to reduce aggradation downstream, then there could be more degradation upstream and if sediment is added to reduce upstream degradation, then the downstream aggradation should increase. Neither is a desirable outcome.

Given the low amount of sediment and the fact that this reach has experienced incision and lateral migration in the past and sinuosity is expected to increase, it is likely that other strategies would need to be used at a later time if this were the only strategy implemented. Table C8.5 shows the weighted effectiveness and cost scores for this strategy by evaluation factor.

C8.2.7 Strategy Assessment Result Comparison Tables

The ratings for each attribute for each of the evaluation factors for each strategy are in table C8.6 (Engineering Effectiveness Evaluation Factor), table C8.7 (Ecosystem Function Evaluation Factor), and table C8.8 (Economic Evaluation Factor).

Tables C8.9 and C8.10 summarize the effectiveness and economics scores for all suitable strategies for the reach.

For ease of comparison, figures C4.1–C4.3 graphically present the indexed scores for effectiveness divided by cost for each subevaluation factor, factor, and strategy total, respectively.

C8.3 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 of high importance because there are no diversions into MRGCD's system in this reach. The SWFL Habitat Value and Need Reach Characteristic is rated of low importance, but the RGSM Habitat Value and Need Reach Characteristic importance is rated of high importance. Leakage through the dam provides a permanent water source, and fish tend to congregate below the dam. Fish passage only would increase habitat value as a corridor.

Table C8.5. Effectiveness and Cost Scores for San Acacia Diversion Dam to Arroyo del las Cañas Reach, Manage Sediment

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	2	20%	0.40
	Level of Confidence	1	10%	0.10
	Duration and Design Life	1	13%	0.13
	Adaptability	3	7%	0.21
	Strategy Performance Score		*50%*	*0.84*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	2	22%	0.44
	River Maintenance Function Score		*50%*	*1.00*
	Engineering Effectiveness Score		**100%**	**1.84**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	2	10%	0.20
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*1.00*
	RGSM			
	Habitat Complexity	3	13%	0.38
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	2	13%	0.25
	RGSM Score		50%	1.13
	Ecosystem Function Effectiveness Score		**100%**	**2.13**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	1	25%	0.25
	Monitoring and Evaluation	3	9%	0.27
	Frequency of Maintenance	3	10%	0.30
	Amount of Maintenance	3	12%	0.36
	Frequency of Adaptive Management	3	9%	0.27
	Amount of Adaptive Management	3	9%	0.27
	Economics Score		**100%**	**2.50**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

Table C8-6. Engineering Effectiveness Evaluation Factor Attribute Ratings for the San Acacia Diversion Dam to Arroyo de las Cañas Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment[1]
Construction location	Channel and Bank	Bank		Flood Plain and Terraces	Channel, Bank, Flood Plain, and Terraces	Channel, Bank, Flood Plain, and Terraces
Strategy Performance						
Ability to Implement	Low	High		Low	Low	Medium
Level of Confidence	Medium	High		Medium	Medium	Low
Duration and Design Life	High	High		Medium	Medium	Low
Adaptability	Low	Medium		Low	High	High
River Maintenance Function						
Water delivery	No Change	Decrease		Decrease	Decrease	No Change
Hydraulic capacity	No Change	No Change		No Change	No Change	No Change
Public health and safety	Increase	Increase		Increase	Increase	No Change

[1] Sediment removal.

Table C8.7. Ecosystem Function Evaluation Factor Attribute Ratings for the San Acacia Diversion Dam to Arroyo de las Cañas Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
SWFL						
Variety of Successional Stages	No Change	No Change		Increase	Increase	No Change
Water Table Elevation	No Change	No Change		No Change	No Change	No Change
Flood Plain Width/Patch Availability	No Change	No Change		Increase	Increase	No Change
Flood Plain Elevation	No Change	No Change		No Change	Increase	No Change
Construction Impacts	Medium	Medium		Medium	High	Medium
RGSM						
Habitat Complexity	No Change	No Change		Increase	Increase	Increase
Flood Plain Connectivity and Frequency of Flooding	No Change	No Change		No Change	No Change	No Change
Sinuosity	No Change	No Change		Increase	No Change	No Change
Construction Impacts	High	High		Low	Low	Medium

Table C8-8. Economic Evaluation Factor Attribute Ratings for the San Acacia Diversion Dam to Arroyo de las Cañas Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment[1]
Planning and design	High	Medium		High	High	High
Environmental compliance	High	High		Low	High	High
Implementation	Medium	Medium		Medium	High	Low
Monitoring and Evaluation	Medium	Medium		Low	Medium	High
Frequency of maintenance	Low	Low		Low	Low	High
Amount of maintenance	Low	Low		Low	Low	High
Frequency of adaptive management	Medium	Medium		Low	Low	High
Amount of adaptive management	Medium	Medium		Low	Medium	High

[1] Sediment removal.

Table C8.9. Summary of Economics and Effectiveness Scores by Subevaluation Factor for the San Acacia Diversion Dam to Arroyo de las Cañas Reach

	Economics Score	Effectiveness Score			
Strategy	Cost	Strategy Performance	River Maintenance Function	SWFL	RGSM
Promote Elevation Stability	2.04	0.86	1.22	1.00	0.88
Promote Alignment Stability	1.89	1.43	1.09	1.00	0.88
Reconstruct/ Maintain Channel Capacity					
Increase Available Area	1.55	0.73	1.09	1.20	1.38
Rehabilitate Channel and Flood Plain	2.20	0.87	1.09	1.20	1.25
Manage Sediment	2.50	0.84	1.00	1.00	1.13

Table C8.10. Summary of Economics and Effectiveness Scores for the San Acacia Diversion Dam to Arroyo de las Cañas Reach

Strategy	Cost	Engineering Effectiveness	Ecosytem Function Effectiveness		Total Effectiveness
Promote Elevation Stability	2.04	2.08	1.88		3.96
Promote Alignment Stability	1.89	2.52	1.88		4.40
Reconstruct/ Maintain Channel Capacity					
Increase Available Area	1.55	1.82	2.58		4.40
Rehabilitate Channel and Flood Plain	2.20	1.96	2.45		4.41
Manage Sediment	2.50	1.84	2.13		3.97

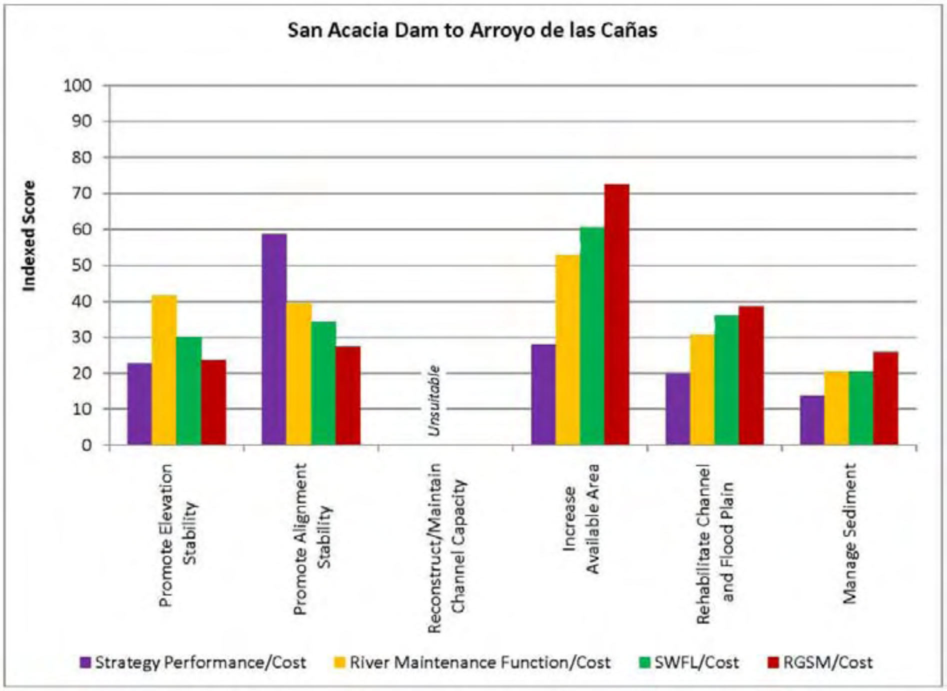

Figure C8.1. San Acacia Diversion Dam to Arroyo de las Cañas Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

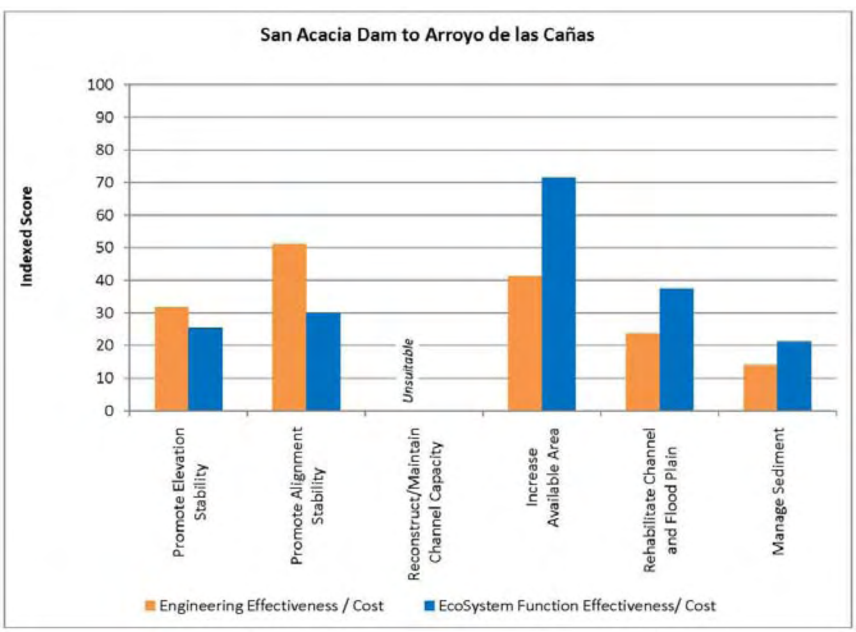

Figure C8.2. San Acacia Diversion Dam to Arroyo de las Cañas Reach effectiveness divided by cost indexed scoring results by evaluation factor.

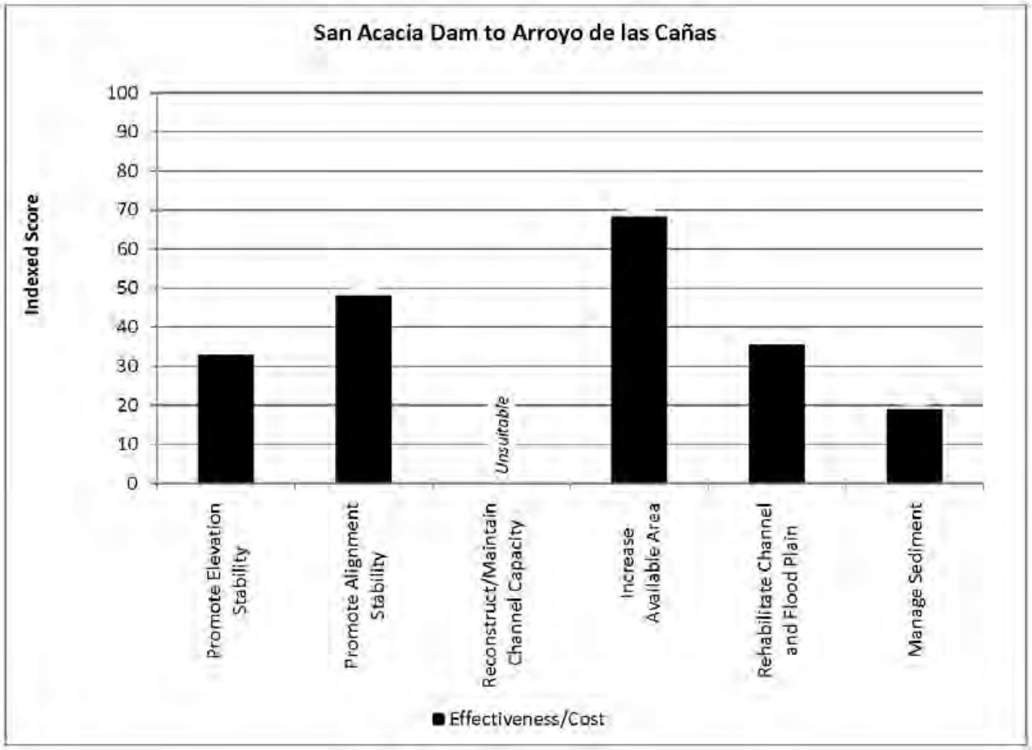

Figure C8.3. San Acacia Diversion Dam to Arroyo de las Cañas Reach total effectiveness divided by cost indexed scoring results.

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 it 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.

Chapter C9. Arroyo de las Cañas to San Antonio Bridge (RM 95 to RM 87.1)

C9.1 Reach Characteristics

This reach is approximately 8 miles long with a riverbed slope of approximately 0.00081 (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 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.

C9.1.1 Channel Instability Reach Characteristic – Medium Instability

Recent channel aggradation extending upstream of the lower end of reach has been documented. Modeling results show a high volume of sediment deposition, bed elevation change, and predict a stable slope that is steeper than existing conditions. These model results require interpretation. This reach has been more stable in profile than others over time and has more variability in channel widths than captured in the model cross sections (variability was minimized to help model convergence). It should be noted that the channel widths have been becoming more uniform. The extent of aggradation shown by the model is unlikely, but channel filling extending upstream from lower end of reach has been documented. Most of the calculated meander belt fits within the constraints, and less than half of the available area is used. The area between the constraints around Bosquecito is too narrow for the calculated meander belt. Some risk exists of a LFCC Levee breach in this reach, but the risk is lower than in the downstream reaches. The rest of the factors for channel instability fall in the medium range.

C9.1.2 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).

C9.1.3 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 constructed by Reclamation parallel 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).

C9.1.4 Habitat Value and Need Reach Characteristic

C9.1.4.1 Southwestern Willow Flycatcher – Low Importance

Similar to the San Acacia Diversion Dam to Arroyo de las Cañas Reach, the river channel in this reach is degraded, narrowing, and rarely, if ever, overbanks. Habitat consists mainly of sparse stands of primarily exotic vegetation that is unsuitable for inhabitation by breeding SWFLs. Several small patches of moderate or high quality habitat are present on lower terraces and river bars. However, even though this reach is included in the critical habitat designation, resident SWFLs rarely have been documented in this reach, and no pairing or nesting has occurred during the past 14 years of surveying. For these reasons, efforts to promote SWFL habitat should be directed elsewhere.

C9.1.4.2 Rio Grande Silvery Minnow – High Importance

Seasonally, RGSM are abundant in this reach (Dudley and Platania 2011 and Reclamation data). Drying occurs most years within this reach. Due to the high population densities within this area and likelihood of drying, habitat improvement work to maintain channel connectivity and wetted habitats throughout the year may be needed.

C9.2 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.

This section highlights considerations for suitable strategies that should be studied further. Recommendations based on this analysis are in section C9.3.

C9.2.1 Promote Elevation Stability – Not Analyzed

Grade control, GRFs, and rock sills are applicable in reaches where the slope is flattening and a sediment deficit is identified. Modeling results show aggradation; therefore, this strategy was not analyzed because aggradation is addressed through other complementary strategies (see table C1.4 for more information).

C9.2.2 Promote Alignment Stability – Not Suitable

Historical trends and modeling results do not show a tendency toward lateral migration; thus, 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 de las Cañas.

C9.2.3 Reconstruct and Maintain Channel Capacity

Table C9.1 shows the weighted effectiveness and cost scores for this strategy.

C9.2.3.1 Geomorphic Effects for Reconstruct and Maintain Channel Capacity

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

C9.2.3.2 Engineering Effectiveness Evaluation Factor for Reconstruct and Maintain Channel Capacity

With the amount of sediment accumulation calculated by the model and experienced in the river over the last few years, this is an important strategy for this reach. However, this strategy promotes dynamic equilibrium for a relatively short period of time, and frequent maintenance is required. Continued aggradation makes the levee increasingly vulnerable to overtopping.

Table C9.1. Effectiveness and Cost Scores for Arroyo de las Cañas to San Antonio Bridge Reach, Reconstruct and Maintain Channel Capacity

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	2	20%	0.40
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	3	7%	0.21
	Strategy Performance Score		*50%*	*1.07*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.22*
	Engineering Effectiveness Score		**100%**	**2.29**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	1	10%	0.10
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*0.90*
	RGSM			
	Habitat Complexity	1	13%	0.13
	Flood Plain Connectivity and Flood Frequency	1	13%	0.13
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	1	13%	0.13
	RGSM Score		50%	0.63
	Ecosystem Function Effectiveness Score		**100%**	**1.53**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	2	25%	0.50
	Monitoring and Evaluation	3	9%	0.27
	Frequency of Maintenance	3	10%	0.30
	Amount of Maintenance	3	12%	0.36
	Frequency of Adaptive Management	3	9%	0.27
	Amount of Adaptive Management	3	9%	0.27
	Economics Score		**100%**	**2.75**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

Continued levee raising increases the level of potential damage to the riverside infrastructure. Elevation stability in the sense of maintaining the current slope and reducing bed elevation rise is an important goal for this strategy.

These methods have a medium level of confidence, and the mobile features promote dynamic equilibrium for a limited time period. The Level of Confidence and Duration and Design Life Attributes are rated medium, as is the overall Engineering Effectiveness Evaluation Factor.

C9.2.3.3 Ecosystem Function Evaluation Factor for Reconstruct and Maintain Channel Capacity

C9.2.3.3.1 Southwestern Willow Flycatcher

Overall, this strategy is not expected to change SWFL habitat significantly within this reach based on model outputs. Construction activities are in-channel; therefore, the Construction Impact Attribute is rated medium. However, certain model outputs show individual detrimental effects to SWFL habitat (i.e., tending towards coarser substrate), and these occurrences should be avoided. If management activities are taken that allow aggradation, benefits to SWFL habitat would occur.

C9.2.3.3.2 Rio Grande Silvery Minnow

If the channel is altered to maintain capacity, overbank flooding may decrease, reducing the availability of flood plain habitat to RGSM. If the same amount of water is sent downstream in multiple channels, rather than single thread, then this strategy has potential to somewhat increase complexity. Because re-establishing the channel to ensure water could be delivered should include construction diversity and variations that consider RGSM habitat, this is given a no change. Increased water and sediment delivery to lower reaches may change likelihood of drying in those reaches.

Construction work could be in the channel, bank, and flood plain. The Construction Impacts Attribute is rated high because reconstruction work in the Rio Grande to maintain capacity could have impacts on RGSM edge of river habitat.

C9.2.3.4 Economic Evaluation Factor for Reconstruct and Maintain Channel Capacity

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.

C9.2.4 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 allow space for possible channel relocation.

C9.2.5 Rehabilitate Channel and Flood Plain – Not Suitable

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

C9.2.6 Manage Sediment

Table C9.2 shows the weighted effectiveness and cost scores for this strategy.

Table C9.2. Effectiveness and Cost Scores for Arroyo de las Cañas to San Antonio Bridge Reach, Manage Sediment

Evaluation Factor	Attribute	Raw Score	Weight	Weighted Score
Effectiveness: 3 is the most effective, and 1 is the least effective.				
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	2	7%	0.14
	Strategy Performance Score		*50%*	*0.80*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	2	22%	0.44
	River Maintenance Function Score		*50%*	*1.00*
	Engineering Effectiveness Score		**100%**	**1.80**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	1	10%	0.10
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*0.90*
	RGSM			
	Habitat Complexity	1	13%	0.13
	Flood Plain Connectivity and Flood Frequency	1	13%	0.13
	Sinuosity	1	13%	0.13
	Construction Impacts[1]	2	13%	0.25
	RGSM Score		50%	0.63
	Ecosystem Function Effectiveness Score		**100%**	**1.53**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	3	25%	0.75
	Monitoring and Evaluation	3	9%	0.27
	Frequency of Maintenance	3	10%	0.30
	Amount of Maintenance	3	12%	0.36
	Frequency of Adaptive Management	3	9%	0.27
	Amount of Adaptive Management	3	9%	0.27
	Economics Score		**100%**	**3.00**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C9.2.6.1 Geomorphic Effects for Manage Sediment

This reach appears to have an excess of sediment load, so implementing sediment reduction should bring the balance between sediment supply and transport capacity closer and maintain the channel in current configuration.

C9.2.6.2 Engineering Effectiveness Evaluation Factor for Manage Sediment

The strategy for this reach includes sediment removal. Downstream deposition may cause sediment accumulation in this reach. Given the high volume of sediment removal predicted by the model, the ability to implement this strategy is rated low. Effectiveness and design life are difficult to assess. This strategy works to achieve dynamic equilibrium, but the amount of sediment is relatively large, causing potential large channel effects. This results in a medium rating for the Duration and Design Life Attribute.

C9.2.6.3 Ecosystem Function Evaluation Factor for Manage Sediment

C9.2.6.3.1 Southwestern Willow Flycatcher

This strategy would not significantly change SWFL habitat from current conditions. Modeled indicators show a slight negative impact to development of various successional stages if sediment supply is reduced. Sediment management in this reach should be conducted so as to not negatively impact SWFL habitat.

C9.2.6.3.2 Rio Grande Silvery Minnow

Managing sediment by removal would be negative for RGSM by reducing complexity.

Construction could be in the channel, bank, flood plain, and terraces. The Construction Impact Attribute is rated medium because removing sand in the river could have a low to moderate short-term construction impact.

C9.2.6.4 Economic Evaluation Factor for Manage Sediment

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).

C9.2.7 Strategy Assessment Result Comparison Tables

The ratings for each attribute for each of the evaluation factors for each strategy are in table C9.3 (Engineering Effectiveness Evaluation Factor), table C9.4 (Ecosystem Function Evaluation Factor), and table C9.5 (Economic Evaluation Factor).

Tables C9.6 and C9.7 summarize the effectiveness and economics scores for all suitable strategies for the reach.

Table C9.3. Engineering Effectiveness Evaluation Factor Attribute Ratings for the Arroyo de las Cañas to San Antonio Bridge Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment[1]
Construction location			Channel, Bank and Flood Plain			Channel, Bank, Flood Plain, and Terraces
Strategy Performance						
Ability to Implement			Medium			Low
Level of Confidence			Medium			Medium
Duration and Design Life			Medium			Medium
Adaptability			High			Medium
River Maintenance						
Water Delivery[2]			No Change			No Change
Hydraulic Capacity			No Change			No Change
Public Health and Safety			Increase			No Change

[1] Sediment removal was not modeled.
[2] Water delivery attributes were only qualitatively evaluated.

Table C9.4. Ecosystem Function Evaluation Factor Attribute Ratings for the Arroyo de las Cañas to San Antonio Bridge Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
SWFL						
Variety of Successional Stages			Decrease			Decrease
Water Table Elevation			No Change			No Change
Flood Plain Width/Patch Availability			No Change			No Change
Flood Plain Elevation			No Change			No Change
Construction Impacts			Medium			Medium
RGSM						
Habitat Complexity			Decrease			Decrease
Flood Plain Connectivity and Frequency of Flooding			Decrease			Decrease
Sinuosity			No Change			Decrease
Construction Impacts			High			Medium

Table C9.5. Economic Evaluation Factor Attribute Ratings for the Arroyo de las Cañas to San AntonioBridge Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment[1]
Planning and Design			High			High
Environmental Compliance			High			High
Implementation			Medium			High
Monitoring and Evaluation			High			High
Frequency of Maintenance			High			High
Amount of Maintenance			High			High
Frequency of Adaptive Management			High			High
Amount of Adaptive Management			High			High

[1] Sediment removal.

Table C9.6. Summary of Economics and Effectiveness Scores by Subevaluation Factor for the Arroyo de las Cañas to San Antonio Bridge Reach

	Economics Score	Effectiveness Score			
Strategy	Cost	Strategy Performance	River Maintenance Function	SWFL	RGSM
Promote Elevation Stability					
Promote Alignment Stability					
Reconstruct/ Maintain Channel Capacity	2.75	1.07	1.22	0.90	0.63
Increase Available Area					
Rehabilitate Channel and Flood Plain					
Manage Sediment	3.00	0.80	1.00	0.90	0.63

Table C9.7. Summary of Economics and Effectiveness Scores for the Arroyo de las Cañas to San Antonio Bridge Reach

Strategy	Cost	Engineering Effectiveness	Ecosytem Function Effectiveness	Total Effectiveness
Promote Elevation Stability				
Promote Alignment Stability				
Reconstruct/ Maintain Channel Capacity	2.75	2.29	1.53	3.82
Increase Available Area				
Rehabilitate Channel and Flood Plain				
Manage Sediment	3.00	1.80	1.53	3.33

For ease of comparison, figures C9.1–C9.3 graphically present the indexed scores for effectiveness divided by cost for each subevaluation factor, factor, and strategy total, respectively.

C9.3 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 fall 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.

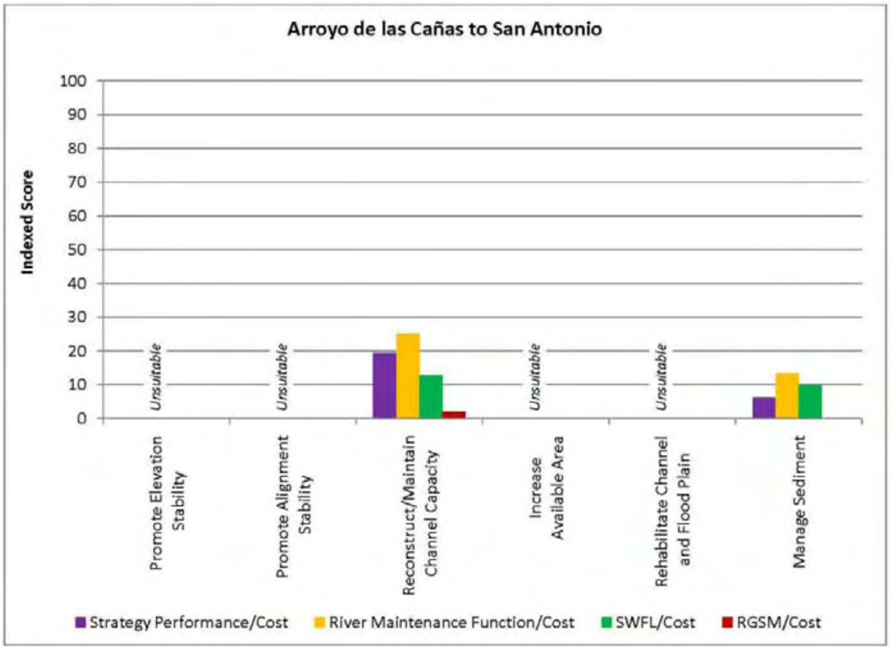

Figure C9.1. Arroyo de las Cañas to San Antonio Bridge Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

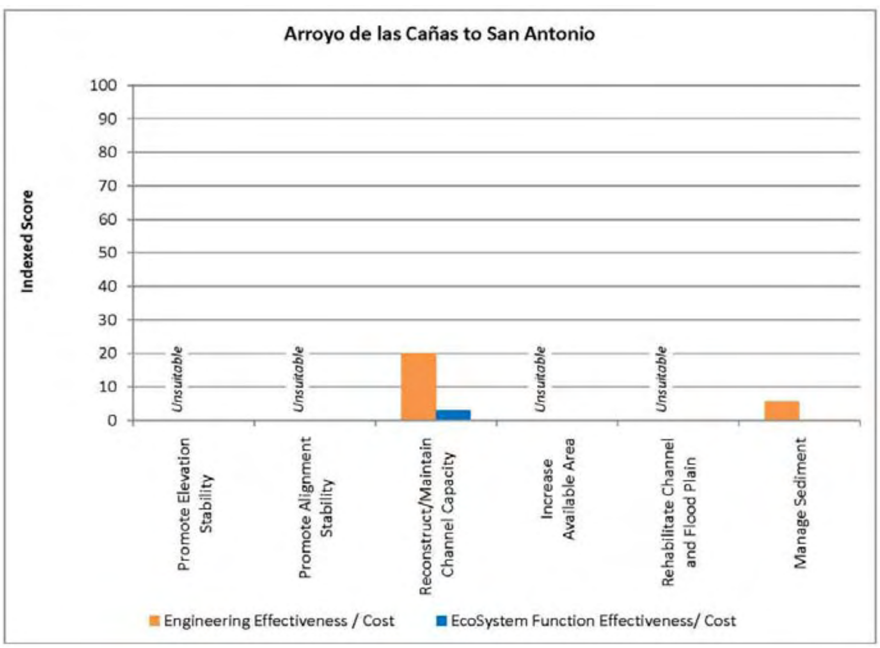

Figure C9.2. Arroyo de las Cañas to San Antonio Bridge Reach effectiveness divided by cost indexed scoring results by evaluation factor.

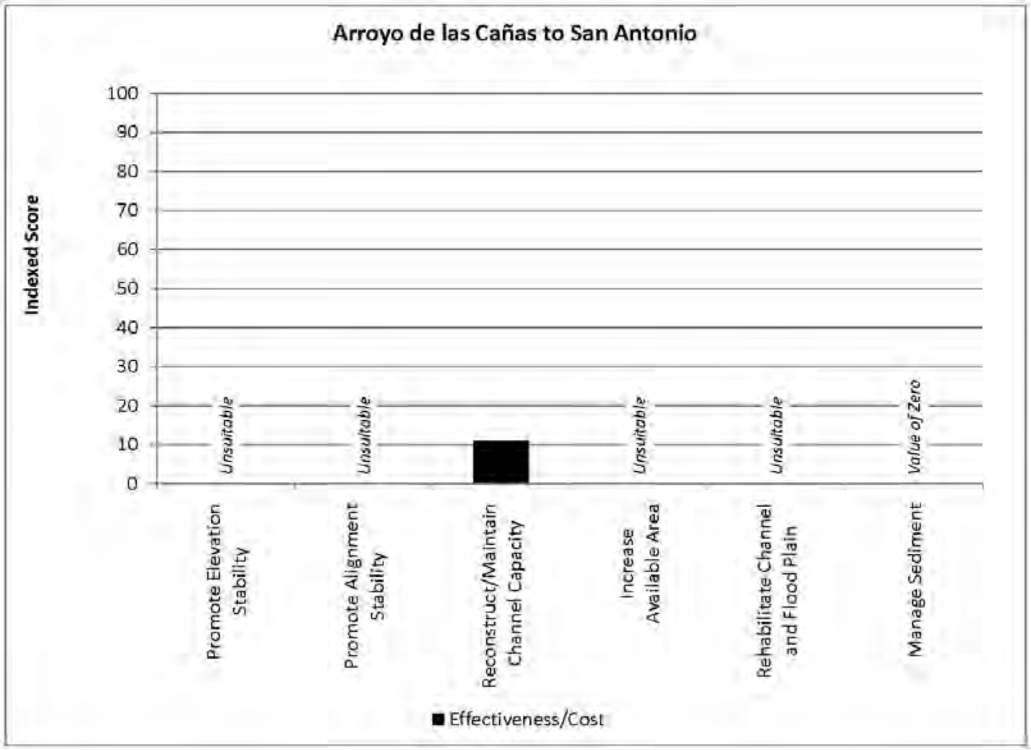

Figure C9.3. Arroyo de las Cañas to San Antonio Bridge Reach total effectiveness divided by cost indexed scoring results.

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 currently are not suitable for this reach. Due to the potential for continued channel aggradation, strategies may need adaptive management after implementation.

Chapter C10. San Antonio Bridge to River Mile 78 (RM 87.1 to RM 78)

C10.1 Reach Characteristics

This reach is approximately 9 miles long with a riverbed slope of approximately 0.00069 (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 (RM 84). Habitat restoration in the Bosque Del Apache National Wildlife Refuge channel area includes vegetation clearing, 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 length of the pilot channel was 1.4 miles. The river widened the pilot channel excavation fairly quickly. The lower end of this reach currently appears 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 Elephant Butte Reservoir pool since the late 1990s.

In the last few years, the reach has responded to the recent drought with a significant reduction in channel width due to 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. In 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 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, 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.

C10.1.1 Channel Instability Reach Characteristic – High Instability

Modeling results for the factors of the Channel Instability Reach Characteristic, except for bed level change, which is high, fall into the medium category. 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. The main channel was completely plugged with sediment for a length of one-half mile and partially plugged upstream of that for a distance of over 1 mile. Flow collected along the edges of the flood plain and the LFCC and, in some sections, appeared to be forming a competent channel. The flow returned to the original channel at various spots, especially at the south boundary of the Bosque Del Apache National Wildlife Refuge on the west side. It is unlikely the main channel flow would have reestablished its former alignment without construction of the pilot channel.

C10.1.2 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 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).

C10.1.3 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. This reach is rated medium. The LFCC and LFCC Levee (constructed and maintained by Reclamation) parallel the river in this reach. The LFCC intercepts most of the 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).

C10.1.4 Habitat Value and Need Reach Characteristic

C10.1.4.1 Southwestern Willow Flycatcher – High Importance

Riparian habitat within this reach, for the most part, is unsuitable for breeding SWFLs, with the exception of two large patches adjacent to the sediment plug at RM 81. These areas consist of dense vegetation in the form of native *Salix spp.*, Russian olive and salt cedar. The sediment plug forces river water into these areas at higher flows, flushing salts from the soil and keeping the vegetation lush and healthy. Thirty-five SWFL territories were documented in this reach during the 2010 breeding season, 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.

C10.1.4.2 Rio Grande Silvery Minnow – High Importance

Seasonally, RGSM are abundant in this reach (Dudley and Platania 2011 and Reclamation data). Drying occurs in this reach. Due to the high population densities within this area and likelihood of drying, habitat actions to maintain channel connectivity and wetted habitats throughout the year would be a high priority. Also, any actions to maintain channel complexity and retain young RGSM within this reach would minimize the amount of drift into the reservoir section below.

C10.2 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.

This section highlights considerations for suitable strategies that should be studied further. Ratings for suitable strategies that are not recommended for further study are provided as an analytic aid. Recommendations based on this analysis are in section C10.3.

C10.2.1 Promote Elevation Stability – Not Analyzed

Historical trends show long term aggradation; therefore, this strategy was not analyzed because aggradation is addressed through other strategies. Local applications of grade control to address recent temporary degradation can be problematic in generally aggrading reaches. Complementary strategies (table C1.4) could be used for elevation stability of the aggrading bed.

C10.2.2 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.

C10.2.3 Reconstruct and Maintain Channel Capacity

Table C10.1 shows the weighted effectiveness and cost scores for this strategy.

C10.2.3.1 Geomorphic Effects for Reconstruct and Maintain Channel Capacity

This strategy was recently used to manage the 2008 sediment plug. Returning the flow to the previous channel decreases the opportunity for channel and flood plain adjustments. Continuity of water and sediment transport remains a concern for this reach. This strategy does not appear to be a long-term solution for this reach and likely would have to be repeated.

C10.2.3.2 Engineering Effectiveness Evaluation Factor for Reconstruct and Maintain Channel Capacity

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 likely would 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; given the long-term aggradational trend of the river, continued levee raising increases the risk of levee failure and associated damage to riverside infrastructure and land use.

C10.2.3.3 Ecosystem Function Evaluation Factor for Reconstruct and Maintain Channel Capacity

C10.2.3.3.1 Southwestern Willow Flycatcher

Modeled indicators show that this strategy would be both positive and negative to SWFL habitat in this reach. This is likely because both aggradation and degradation are occurring within different portions of the reach. Site-specific impacts should be assessed prior to implementing this strategy.

Table C10-1. Effectiveness and Cost Scores for the San Antonio Bridge to River Mile 78 Reach, Reconstruct and Maintain Channel Capacity

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	2	20%	0.40
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	3	7%	0.21
	Strategy Performance Score		*50%*	*1.07*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	2	22%	0.44
	River Maintenance Function Score		*50%*	*1.00*
	Engineering Effectiveness Score		**100%**	**2.07**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	1	10%	0.10
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	3	10%	0.30
	Flood Plain Elevation	3	10%	0.30
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*1.10*
	RGSM			
	Habitat Complexity	1	13%	0.13
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	1	13%	0.13
	RGSM Score		50%	0.75
	Ecosystem Function Effectiveness Score		**100%**	**1.85**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	2	25%	0.50
	Monitoring and Evaluation	3	9%	0.27
	Frequency of Maintenance	3	10%	0.30
	Amount of Maintenance	3	12%	0.36
	Frequency of Adaptive Management	3	9%	0.27
	Amount of Adaptive Management	3	9%	0.27
	Economics Score		**100%**	**2.75**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C10.2.3.3.2 Rio Grande Silvery Minnow

Reconstructing the existing channel probably would not change existing RGSM habitat complexity. Increased water and sediment delivery to lower reaches may change the likelihood of drying in those reaches.

Construction could be in the channel, bank, and flood plain. The Construction Impacts Attribute would be rated high due to dredging in the channel.

C10.2.3.4 Economic Evaluation Factor for Reconstruct and Maintain Channel Capacity

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 are likely to be high.

C10.2.4 Increase Available Area to the River

Table C10.2 shows the weighted effectiveness and cost scores for this strategy.

C10.2.4.1 Geomorphic Effects for Increase Available Area to the River

This strategy's usefulness results from both the perched nature of the channel and the very low elevation of the flood plain along much of the toe of the LFCC Levee and along the border of the eastern terraces. As discussed above, there is a high risk of channel avulsion to either location. Setting the levee back would avoid erosion of the toe if the channel avulsed there. If the channel were allowed to follow these alignments, there would be an increase in attenuation of flood peaks, channel and flood plain adjustments, and episodic sediment transport. There would be a temporary decrease of effective transport of water and sediment and water table interactions. In the long term, it is expected that the balance between sediment load and transport capacity would become closer, and 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.

C10.2.4.2 Engineering Effectiveness Evaluation Factor for Increase Available Area to the River

Analysis results show that the calculated meander belt width is contained within the infrastructure constraints. This reach is perched above the valley floor. Moving the levee to create more room for the river to occupy would result in an area of sediment deposition for a period of time that would eventually fill with sediment. For a period of time, hydraulic capacity would increase but then decrease to be about the same as before levee relocation; thus, the Hydraulic Capacity Attribute is rated as no change.

Table C10.2. Effectiveness and Cost Scores for San Antonio Bridge to River Mile 78 Reach, Increase Available Area to the River

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	1	13%	0.13
	Adaptability	1	7%	0.07
	Strategy Performance Score		*50%*	*0.60*
	River Maintenance Function			
	Water Delivery	1	13%	0.13
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.09*
	Engineering Effectiveness Score		**100%**	**1.69**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	3	10%	0.30
	Water Table Elevation	3	10%	0.30
	Flood Plain Width/Patch Availability	3	10%	0.30
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	3	10%	0.30
	SWFL Score		*50%*	*1.40*
	RGSM			
	Habitat Complexity	2	13%	0.25
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	3	13%	0.38
	Construction Impacts[1]	3	13%	0.38
	RGSM Score		50%	1.25
	Ecosystem Function Effectiveness Score		**100%**	**2.65**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	1	25%	0.25
	Monitoring and Evaluation	1	9%	0.09
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	1	9%	0.09
	Economics Score		**100%**	**1.52**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

Water delivery also would go down for a period of time and then return to about the current level; therefore, the Water Delivery Attribute also is rated as no change. Because there is opportunity to add sediment storage area in an aggrading reach, this strategy should be considered for future implementation.

C10.2.4.3 Ecosystem Function Evaluation Factor for Increase Available Area to the River

C10.2.4.3.1 Southwestern Willow Flycatcher

Because portions of this reach are aggrading and the potential for sediment plugs and avulsions is high, this strategy would be beneficial to SWFL habitat by allowing the river to aggrade and potentially move into a larger flood plain. This would both create and remove habitat through scouring, sediment deposition, and terraces/bar formation. Allowing continued aggradation also would raise water table elevations. The Construction Impact Attribute is rated low because work could occur outside of the active flood plain.

C10.2.4.3.2 Rio Grande Silvery Minnow

The Habitat Complexity Attribute is rated as no change because the impacts depend on what type of channel establishes. There may be changes in downstream bed elevation that may change the likelihood of drying.

The Construction Impact Attribute is rated as low because equipment work could occur on the flood plain and terraces.

C10.2.4.4 Economic Evaluation Factor for Increase Available Area to the River

The SRH-1D model results show continued sediment accumulation in this reach. The meander belt width is within the infrastructure constraints, so the Implementation Cost Attribute is rated low. However should the levee fail, potentially, there would be significant costly damage to the LFCC and levee infrastructure. Moving the river to the west would involve potential significant expenses to move these infrastructures or reinforce them. Relocating the LFCC and levee infrastructure in this reach would provide for additional sediment storage locations and would involve potential significant expenses.

C10.2.5 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.

C10.2.6 Manage Sediment

Table C10.3 shows the weighted effectiveness and cost scores for this strategy.

Table C10.3. Effectiveness and Cost Scores for San Antonio Bridge to River Mile 78 Reach, Manage Sediment

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	2	7%	0.14
	Strategy Performance Score		*50%*	*0.80*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	2	22%	0.44
	River Maintenance Function Score		*50%*	*1.00*
	Engineering Effectiveness Score		**100%**	**1.80**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	2	10%	0.20
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*1.00*
	RGSM			
	Habitat Complexity	1	13%	0.13
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	2	13%	0.25
	RGSM Score		50%	0.88
	Ecosystem Function Effectiveness Score		**100%**	**1.88**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	2	25%	0.50
	Monitoring and Evaluation	3	9%	0.27
	Frequency of Maintenance	3	10%	0.30
	Amount of Maintenance	3	12%	0.36
	Frequency of Adaptive Management	3	9%	0.27
	Amount of Adaptive Management	3	9%	0.27
	Economics Score		**100%**	**2.75**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C10.2.6.1 Geomorphic Effects for Manage Sediment

This reach has an excess of sediment load, so reducing sediment should bring the sediment load and transport capacity more into balance, but it would not increase flood plain connectivity in the temporarily degraded section. This is because the sediment balance should maintain the channel in the current configuration and that this reach is already well connected. Channel morphology would be expected to change less under this strategy than current rates.

C10.2.6.2 Engineering Effectiveness Evaluation Factor for Manage Sediment

This strategy in this reach is sediment removal. Given the volume of sediment needing to be removed from this reach estimated by the SRH-1D model, the Ability to Implement Attribute is rated low. The Duration and Design Life Attribute is difficult to assess, because there is a relatively large amount of sediment to be removed. This would have a large impact upon the channel; therefore, it is rated medium.

C10.2.6.3 Ecosystem Function Evaluation Factor for Manage Sediment

C10.2.6.3.1 Southwestern Willow Flycatcher

Modeled indicators show that this strategy could be both positive and negative to SWFL habitat in this reach. This is probably because both aggradation and degradation are occurring within different portions of the reach. Site-specific impacts should be assessed prior to implementation of this strategy. Sediment management in this reach likely would include removal of plugs and a decrease in aggradation, which would negatively impact existing and developing SWFL habitat; thus, the Construction Impacts Attribute was rated medium.

C10.2.6.3.2 Rio Grande Silvery Minnow

Removing sediment would create low habitat complexity and be a negative effect on RGSM.

Construction could be in the channel, bank, flood plain, and terraces. However, construction methods can be used that consider RGSM habitat, so the Habitat Complexity Attribute was rated as no change. Removing sediment would have a moderate short-term construction impact; therefore, the Construction Impacts Attribute was rated medium.

C10.2.6.4 Economic Evaluation Factor for Manage Sediment

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

C10.2.7 Strategy Assessment Result Comparison Tables

The ratings for each attribute for each of the evaluation factors for each strategy are in table C10.4 (Engineering Effectiveness Evaluation Factor), table C10.5 (Ecosystem Function Evaluation Factor), and table C10.6 (Economic Evaluation Factor).

Tables C10.7 and C10.8 summarize the effectiveness and economics scores for all suitable strategies for the reach.

For ease of comparison, figures C4.1–C4.3 graphically present the indexed scores for effectiveness divided by cost for each subevaluation factor, factor, and strategy total, respectively.

Table C10.4. Engineering Effectiveness Evaluation Factor Attribute Ratings for the San Antonio Bridge to River Mile 78 Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment[1]
Construction Location			Channel, Bank, and Flood Plain	Flood Plain and Terraces		Channel, Bank, Flood Plain, and Terraces
Strategy Performance						
Ability to Implement			Medium	Low		Low
Level of Confidence			Medium	Medium		Medium
Duration and Design Life			Medium	Low		Medium
Adaptability			High	Low		Medium
River Maintenance						
Water Delivery			No Change	Decrease		No Change
Hydraulic Capacity			No Change	No Change		No Change
Public Health and Safety			No Change	Increase		No Change

[1] Sediment removal was not modeled.
[2] Water delivery attributes were only qualitatively evaluated.

Table C10.5. Ecosystem Function Evaluation Factor Attribute Ratings for the San Antonio Bridge to River Mile 78 Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
SWFL						
Variety of Successional Stages			Decrease	Increase		No Change
Water Table Elevation			No Change	Increase		No Change
Flood Plain Width/Patch Availability			Increase	Increase		No Change
Flood Plain Elevation			Increase	No Change		No Change
Construction Impacts			Medium	Low		Medium
R**GSM**						
Habitat Complexity			Decrease	No Change		Decrease
Flood Plain Connectivity and Frequency of Flooding			No Change	No Change		No Change
Sinuosity			No Change	Increase		No Change
Construction Impacts			High	Low		Medium

Table C10.6. Economic Evaluation Factor Attribute Ratings for the San Antonio Bridge to River Mile 78 Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
Planning and Design			High	High		High
Environmental Compliance			High	High[1]		High
Implementation			Medium	Low		Medium
Monitoring and Evaluation			High	Low		High
Frequency of Maintenance			High	Low		High
Amount of Maintenance			High	Low		High
Frequency of Adaptive Management			High	Low		High
Amount of Adaptive Management			High	Low		High

[1] Bosque del Apache National Wildlife Refuge.

Table C10.7. Summary of Economics and Effectiveness Scores by Subevaluation Factor for the San Antonio Bridge to River Mile 78 Reach

	Economics Score	Effectiveness Score			
Strategy	Cost	Strategy Performance	River Maintenance Function	SWFL	RGSM
Promote Elevation Stability					
Promote Alignment Stability					
Reconstruct/ Maintain Channel Capacity	2.75	1.07	1.00	1.10	0.75
Increase Available Area	1.52	0.60	1.09	1.40	1.25
Rehabilitate Channel and Flood Plain					
Manage Sediment	2.75	0.80	1.00	1.00	0.88

Table C10.8. Summary of Economics and Effectiveness Scores for the San Antonio Bridge to River Mile 78 Reach

Strategy	Cost	Engineering Effectiveness	Ecosytem Function Effectiveness		Total Effectiveness
Promote Elevation Stability					
Promote Alignment Stability					
Reconstruct/ Maintain Channel Capacity	2.75	2.07	1.85		3.92
Increase Available Area	1.52	1.69	2.65		4.34
Rehabilitate Channel and Flood Plain					
Manage Sediment	2.75	1.80	1.88		3.68

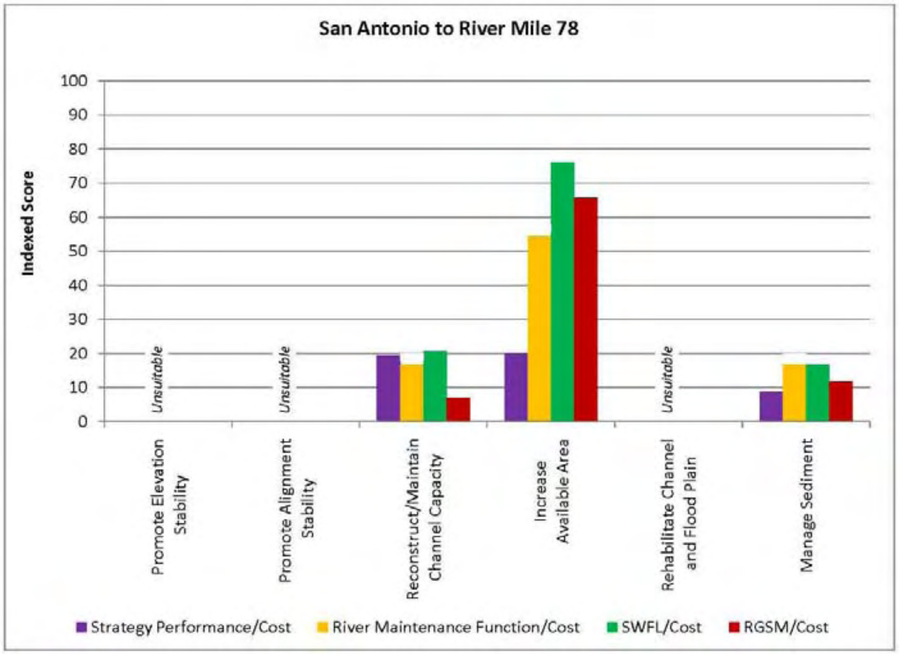

Figure C10.1. San Antonio Bridge to River Mile 78 Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

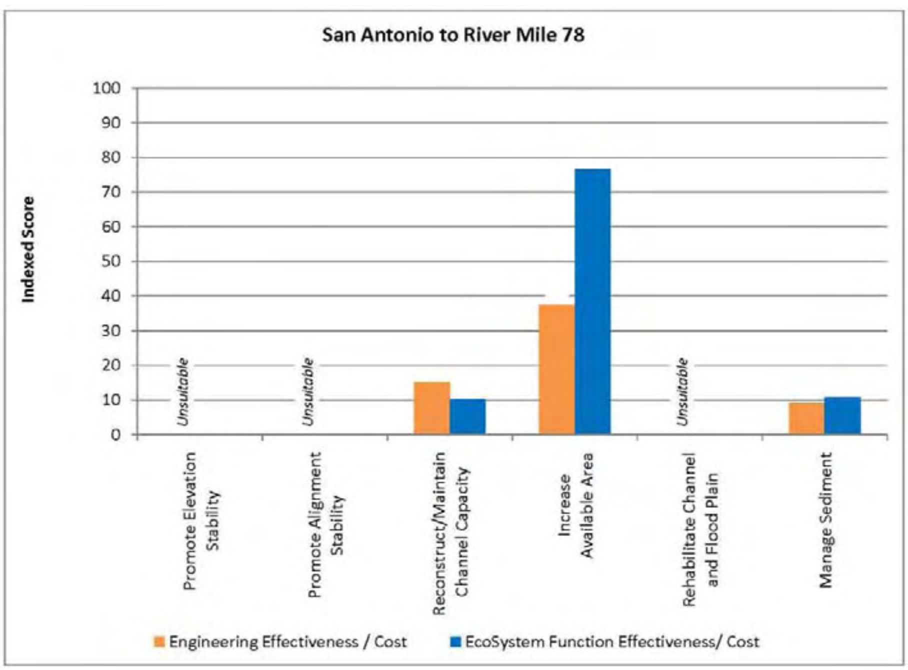

Figure C10.2. San Antonio Bridge to River Mile 78 Reach effectiveness divided by cost indexed scoring results by evaluation factor.

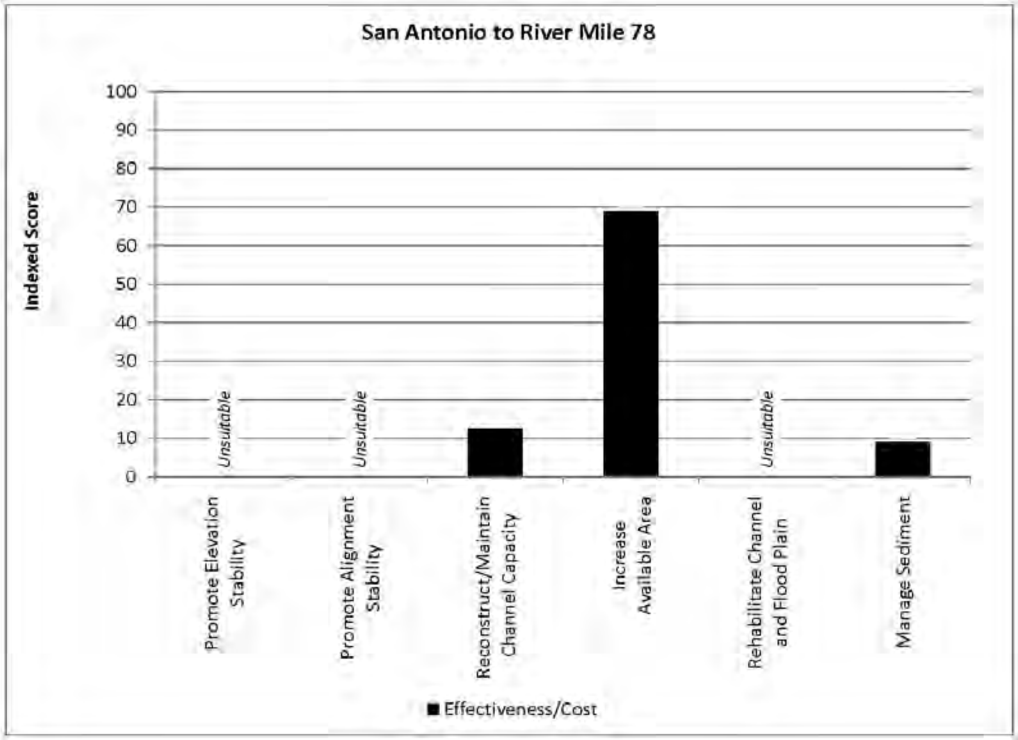

Figure C10.3. San Antonio Bridge to River Mile 78 Reach total effectiveness divided by cost indexed scoring results.

C10.3 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.

Chapter C11. River Mile 78 to Elephant Butte Reservoir (RM 78 to RM 46)

C11.1 Reach Characteristics

This reach is approximately 32 miles long with a riverbed slope of approximately 0.00063 (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. The reach has no major tributaries, and 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 Bosque Del Apache National Wildlife Refuge (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 Planform Stages M5 (Sinuous thalweg channel) to M7 (Migrating with cutoff channel) through most of the reach, but there have been plugs in the most downstream portion.

Model results show that the stable slope is flatter than existing and predicts aggradation downstream and degradation upstream. These results are based on the reservoir pool staying below the Narrows, and aggradation is expected to begin upstream when the reservoir pool comes up. The meander belt does fit within the constraints. However, there is not much space between the meander belt and the constraints in this upstream portion of the reach. Downstream, the space between the geologic constraints not used by the modeled meander belt is quite large.

C11.1.1 Channel Instability Reach Characteristic – High Instability

This reach is strongly influenced by the pool elevation of Elephant Butte Reservoir. It generally has been historically aggrading with brief periods of degradation when the pool elevation is low. The modeling shows that continued slope and bed level changes can be expected if the reservoir stays below the Narrows. In the past, the reservoir's water surface level has come up fairly rapidly when the drought periods ended. This is expected to happen again, but climate change scenarios (Gangopadhyay and Pruitt, 2011) show runoff below the median for this area; therefore, historical trends may not be fully applicable. These factors push the rating for Channel Instability Reach Characteristic to high for this reach.

C11.1.2 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 reduced while the LFCC continues to convey flow in the downstream direction. However, this reach is aggradational over the long term, which would have the potential for long-term high seepage loss rates.

C11.1.3 Infrastructure, Public Health, and Safety Reach Characteristic – Low Importance

Most of 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).

C11.1.4 Habitat Value and Need Reach Characteristic

This reach has been classified as biologically significant by Reclamation biologists for both SWFL and RGSM.

C11.1.4.1 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. Areas within the conservation pool of Elephant Butte Reservoir that were once bare mineral soil upon recession of reservoir water were colonized by native willows and now form a vast expanse of highly suitable SWFL breeding habitat. These areas are also provided with almost perennial water from the LFCC outfall on the west side of the flood plain. Very little of the high quality habitat in this reach is associated with the river itself due to severe degradation of the channel, particularly in the downstream portion of the reach. Habitat that was once suitable and occupied by breeding SWFLs has declined in quality due to over-maturity and a lowering of the water table. Even perpetually flooded habitat in the upper end of the reservoir pool has begun to decline in quality and has been abandoned by the SWFL. For these reasons, it is crucial that habitat be protected in this reach and regeneration of habitat be promoted.

C11.1.4.2 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.

C11.2 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. Promote Elevation Stability, Promote Alignment Stability, and Rehabilitate Channel and Flood Plain may be considered for local implementation in this reach if the Elephant Butte pool remains very low.

This section highlights considerations for suitable strategies that should be studied further. Ratings for suitable strategies not recommended for further study are provided as an analytic aid. Recommendations based on this analysis are in section C11.3.

C11.2.1 Promote Elevation Stability – Not Analyzed

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

C11.2.2 Promote Alignment Stability – Not Suitable

This strategy is not effective because the bank protection measures probably 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, levee, and LFCC.

C11.2.3 Reconstruct and Maintain Channel Capacity Strategy

Table C11.1 shows the weighted effectiveness and cost scores for this strategy.

C11.2.3.1 Geomorphic Effects for Reconstruct and Maintain Channel Capacity

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

C11.2.3.2 Engineering Effectiveness Evaluation Factor for Reconstruct and Maintain Channel Capacity

The current model results show that this reach will incise. Over the long term, this reach has a larger sediment supply than transport capacity, resulting in aggradation. The Ability to Implement Attribute is rated medium because equipment work in the river channel requires more environmental compliance. The Duration and Design Life Attribute is rated medium because any reach where reconstructing and maintaining channel capacity is required means that there is a sediment imbalance. If the channel reconstruction brings the channel back into balance, then the Duration and Design Life Attribute rating would increase to high. It is more than likely that a single action will not completely achieve a sediment balance.

Table C11.1. Effectiveness and Cost Scores for River Mile 78 to Elephant Butte Reservoir, Reconstruct and Maintain Channel Capacity

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	2	20%	0.40
	Level of Confidence	2	10%	0.20
	Duration and Design Life	2	13%	0.26
	Adaptability	3	7%	0.21
	Strategy Performance Score		*50%*	*1.07*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	2	22%	0.44
	River Maintenance Function Score		*50%*	*1.00*
	Engineering Effectiveness Score		**100%**	**2.07**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	1	10%	0.10
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	1	10%	0.10
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*0.80*
	RGSM			
	Habitat Complexity	1	13%	0.13
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	1	13%	0.13
	RGSM Score		50%	0.75
	Ecosystem Function Effectiveness Score		**100%**	**1.55**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	2	25%	0.50
	Monitoring and Evaluation	3	9%	0.27
	Frequency of Maintenance	3	10%	0.30
	Amount of Maintenance	3	12%	0.36
	Frequency of Adaptive Management	3	9%	0.27
	Amount of Adaptive Management	3	9%	0.27
	Economics Score		**100%**	**2.75**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C11.2.3.3 Ecosystem Function Evaluation Factor for Reconstruct and Maintain Channel Capacity

C11.2.3.3.1 Southwestern Willow Flycatcher

Altering the channel in this reach to increase capacity would reduce the potential for overbank flows. The avulsions that have developed during the past several years in this reach have promoted overbank flooding and rejuvenated aging vegetation. Preventing this would be a detriment to this habitat; thus, the Variety of Successional Stages Attribute is rated as decreased.

C11.2.3.3.2 Rio Grande Silvery Minnow

This reach has avulsions that provide a high degree of complexity, and a strategy could be moving the river channel to a single channel alignment. If the channel is altered to maintain original capacity, overbank flooding likely will decrease, reducing the availability of flood plain habitat to RGSM. Increased water and sediment delivery to lower reaches may change likelihood of drying in those reaches. Because re-establishment of the channel to ensure water delivery could be done with construction diversity and variations that consider RGSM habitat, the Habitat Complexity Attribute is rated as decreased.

Construction could occur on the channel, bank, and flood plain. The Construction Impacts Attribute is rated high because reconstruction work in the Rio Grande maintaining capacity could have impacts on RGSM edge of river habitat.

C11.2.3.4 Economic Evaluation Factor for Reconstruct and Maintain Channel Capacity

The Planning and Design and the Environmental Compliance Attributes are rated high because the river response is uncertain, and this reach is biologically significant for the RGSM. The Implementation Cost Attribute is rated medium due to the low number of features estimated for this reach.

C11.2.4 Increase Available Area to the River

Table C11.2 shows the weighted effectiveness and cost scores for this strategy.

C11.2.4.1 Geomorphic Effects for Increase Available Area to the River

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 occur 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 11.1).

Table C11.2. Effectiveness and Cost Scores for River Mile 78 to Elephant Butte Reservoir, Increase Available Area to the River

Evaluation Factor	Attribute	Raw Score	Weight	Weighted Score
Effectiveness: 3 is the most effective, and 1 is the least effective.				
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	2	20%	0.40
	Level of Confidence	3	10%	0.30
	Duration and Design Life	2	13%	0.26
	Adaptability	1	7%	0.07
	Strategy Performance Score		*50%*	*1.03*
	River Maintenance Function			
	Water Delivery	1	13%	0.13
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.09*
	Engineering Effectiveness Score		**100%**	**2.12**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	3	10%	0.30
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*1.10*
	RGSM			
	Habitat Complexity	3	13%	0.38
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	3	13%	0.38
	Construction Impacts[1]	3	13%	0.38
	RGSM Score		50%	1.38
	Ecosystem Function Effectiveness Score		**100%**	**2.48**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	2	11%	0.22
	Implementation Cost	2	25%	0.50
	Monitoring and Evaluation	2	9%	0.18
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	2	9%	0.18
	Amount of Adaptive Management	2	9%	0.18
	Economics Score		**100%**	**1.93**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

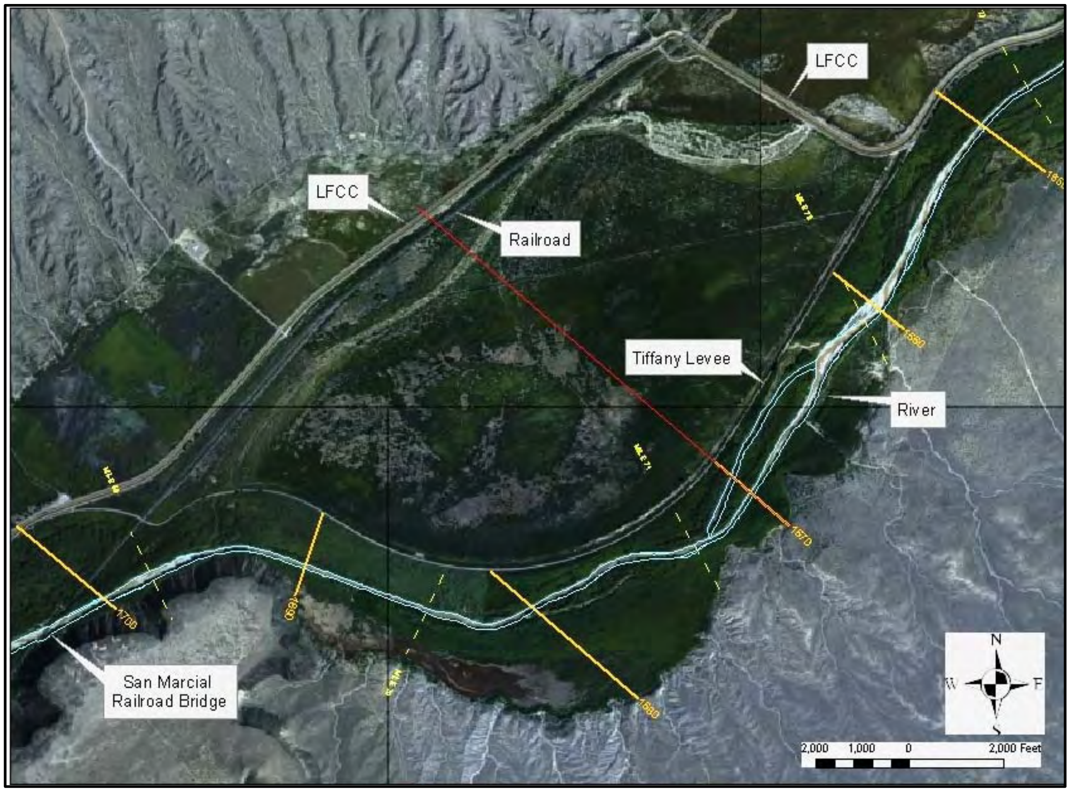

Figure C11.1. Area near San Marcial Railroad Bridge and Tiffany Levee.

C11.2.4.2 Engineering Effectiveness Evaluation Factor for Increase Available Area to the River

It would be difficult to obtain lands instruments upstream of the San Marcial Railroad Bridge. Reclamation-controlled lands are found downstream from the San Marcial Railroad Bridge. Lands west of the LFCC and levee are not developed Reclamation lands, while the upper part of this reach is in the Bosque del Apache National Wildlife Refuge. Moving infrastructure in a situation where the river is perched above the valley floor can be difficult. Because the levee confines the river to about one-third of the valley width downstream from the San Marcial Railroad Bridge, this strategy would result in activation of a large portion of the flood plain currently disconnected from the river. This would provide a large new area for sediment storage. While the analysis results show that the calculated meander belt width lies within the lateral constraints, this reach should receive special consideration for activating this large, disconnected flood plain area. This strategy would promote dynamic equilibrium as much as possible in a long-term aggrading reach.

C11.2.4.3 Ecosystem Function Evaluation Factor for Increase Available Area to the River

C11.2.4.3.1 Southwestern Willow Flycatcher

Generally, this can be considered a positive impact to SWFL habitat by allowing an increase in diversity and patch availability. However, if this is not accompanied by sediment management that promotes aggradation in the severely degraded downstream portion of this reach, the effort basically would be in vain due to the low water table. The San Marcial Railroad Bridge presents difficulties for this strategy.

C11.2.4.3.2 Rio Grande Silvery Minnow

Opportunity for optimal RGSM habitat and channel complexity would increase if this strategy is implemented. There is an existing tendency for river meandering in this reach, so implementation of this strategy likely would have positive effects for increasing sinuosity.

Construction could occur in the channel, bank, flood plain, and terraces. The Construction Impact Attribute is rated low because little or no equipment work is expected in the channel.

C11.2.4.4 Economic Evaluation Factor for Increase Available Area to the River

The Implementation Cost Attribute is rated low because the calculated meander belt width fits within the lateral constraints. However, in view of the comments above under engineering effectiveness, this reach should receive special consideration for this strategy. If infrastructure were relocated, the cost likely would be high because of the LFCC and associated levee. Chapter 16 of the Part 1 Report contains much more information on the LFCC. However, future maintenance costs would be very low; thus, the Amount of Maintenance Attribute is rated low.

C11.2.5 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.

C11.2.6 Manage Sediment

Table C11.3 shows the weighted effectiveness and cost scores for this strategy.

Table C11.3. Effectiveness and Cost Scores for River Mile 78 to Elephant Butte Reservoir, Manage Sediment

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	1	10%	0.10
	Duration and Design Life	1	13%	0.13
	Adaptability	2	7%	0.14
	Strategy Performance Score		*50%*	*0.57*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	2	22%	0.44
	River Maintenance Function Score		*50%*	*1.00*
	Engineering Effectiveness Score		**100%**	**1.57**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	3	10%	0.30
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	1	10%	0.10
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*1.00*
	RGSM			
	Habitat Complexity	2	13%	0.25
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	2	13%	0.25
	RGSM Score		50%	1.00
	Ecosystem Function Effectiveness Score		**100%**	**2.00**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	1	25%	0.25
	Monitoring and Evaluation	3	9%	0.27
	Frequency of Maintenance	3	10%	0.30
	Amount of Maintenance	3	12%	0.36
	Frequency of Adaptive Management	3	9%	0.27
	Amount of Adaptive Management	3	9%	0.27
	Economics Score		**100%**	**2.50**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C11.2.6.1 Geomorphic Effects for Manage Sediment

Adding sediment to a reach that has been historically aggrading is not expected to provide long-term benefits. Removing sediment through settling basins was proposed for this reach before the most recent drought that resulted in channel degradation. Theoretically, this strategy could result in balancing the sediment load and transport capacity of the reach and could reduce the rate of water storage capacity loss in Elephant Butte Reservoir when aggradation returns. A climate change effects study may be needed to determine how long a sediment management strategy would provide benefits.

C11.2.6.2 Engineering Effectiveness Evaluation Factor for Manage Sediment

Based upon model results, this strategy would be sediment addition. Adding sediment to a reach that is long-term aggradation would not be advisable. Thus, this strategy in the form of adding sediment to the delta of Elephant Butte Reservoir does not apply, but sediment removal should be considered.

C11.2.6.3 Ecosystem Function Evaluation Factor for Manage Sediment

C11.2.6.3.1 Southwestern Willow Flycatcher

Sediment management, depending on technique, could improve SWFL habitat in downstream portions of this reach by filling in the degraded river channel and providing an increased likelihood of overbank flood events. Conversely, settling basins or otherwise removing sediment would have the opposite effect. This strategy is very site specific and is confounded by the model assumption that Elephant Butte Reservoir will remain low.

C11.2.6.3.2 Rio Grande Silvery Minnow

Removing sediment could create low habitat complexity and be a negative effect on RGSM.

Construction methods can be used that consider RGSM habitat requirements so the Habitat Complexity Attribute was rated as no change. Removing sediment results in a rating of medium for the Construction Impact Attribute.

C11.2.6.4 Economic Evaluation Factor for Manage Sediment

Implementation costs are rated low because adding sediment to the delta of a reservoir is not advisable. Implementation costs for removing sediment (as suggested in section C11.2.6.2, Engineering Effectiveness) have not been estimated.

C11.2.7 Strategy Assessment Result Comparison Tables

The ratings for each attribute for each of the evaluation factors for each strategy are in table C11.4 (Engineering Effectiveness Evaluation Factor), table C11.5 (Ecosystem Function Evaluation Factor), and table C11.6 (Economic Evaluation Factor).

Table C11.4. Engineering Effectiveness Evaluation Factor Attribute Ratings for the River Mile 78 to Elephant Butte Reservoir Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment[1]
Construction Location			Channel, Bank, and Flood Plain	Flood Plain		Channel, Bank, Flood Plain, and Terraces
Strategy Performance						
Ability to Implement			Medium	Medium		Low
Level of Confidence			Medium	High		Low
Duration and Design Life			Medium	Medium		Low
Adaptability			High	Low		Medium
River Maintenance Function						
Water Delivery			No Change	Decrease		No Change
Hydraulic Capacity			No Change	No Change		No Change
Public Health and Safety			No Change	Increase		No Change

[1] Sediment augmentation.

Table C11.5. Ecosystem Function Evaluation Factor Attribute Ratings for the River Mile 78 to Elephant Butte Reservoir Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
SWFL						
Variety of Successional Stages			Decrease	Increase		Increase
Water Table Elevation			No Change	No Change		No Change
Flood Plain Width/Patch Availability			Decrease	No Change		Decrease
Flood Plain Elevation			No Change	No Change		No Change
Construction Impacts			Medium	Medium		Medium
RGSM						
Habitat Complexity			Decrease	Increase		No Change
Flood Plain Connectivity and Frequency of Flooding			No change	No Change		No Change
Sinuosity			No Change	Increase		No Change
Construction Impacts			High	Low		Medium

Tables C11.7 and C11.8 summarize the effectiveness and economics scores for all suitable strategies for the reach.

For ease of comparison, figures C11.2–C11.4 graphically present the indexed scores for effectiveness divided by cost for each subevaluation factor, factor, and strategy total, respectively.

C11.3 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 high importance for 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. 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.

Table C11.6. Economics for the River Mile 78 to Elephant Butte Reservoir Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability[1]	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
Planning and Design			High	High		High
Environmental Compliance			High	Medium		High
Implementation			Medium	Medium		Low
Monitoring and Evaluation			High	Medium		High
Frequency of Maintenance			High	Low		High
Amount of Maintenance			High	Low		High
Frequency of Adaptive Management			High	Medium		High
Amount of Adaptive Management			High	Medium		High

[1] The percent fit is above 90 percent. Above 90 percent is considered to be 100 percent fit because this is within the accuracy of the estimating method.

Table C11.7. Summary of Economics and Effectiveness Scores by Subevaluation Factor for the River Mile 78 to Elephant Butte Reservoir Reach

	Economics Score	Effectiveness Score			
Strategy	Cost	Strategy Performance	River Maintenance Function	SWFL	RGSM
Promote Elevation Stability					
Promote Alignment Stability					
Reconstruct/ Maintain Channel Capacity	2.75	1.07	1.00	0.80	0.75
Increase Available Area	1.93	1.03	1.09	1.10	1.38
Rehabilitate Channel and Flood Plain					
Manage Sediment	2.50	0.57	1.00	1.00	1.00

Table C11.8. Summary of Economics and Effectiveness Scores for the River Mile 78 to Elephant Butte Reservoir Reach

Strategy	Cost	Engineering Effectiveness	Ecosytem Function Effectiveness	Total Effectiveness
Promote Elevation Stability				
Promote Alignment Stability				
Reconstruct/ Maintain Channel Capacity	2.75	2.07	1.55	3.62
Increase Available Area	1.93	2.12	2.48	4.60
Rehabilitate Channel and Flood Plain				
Manage Sediment	2.50	1.57	2.00	3.57

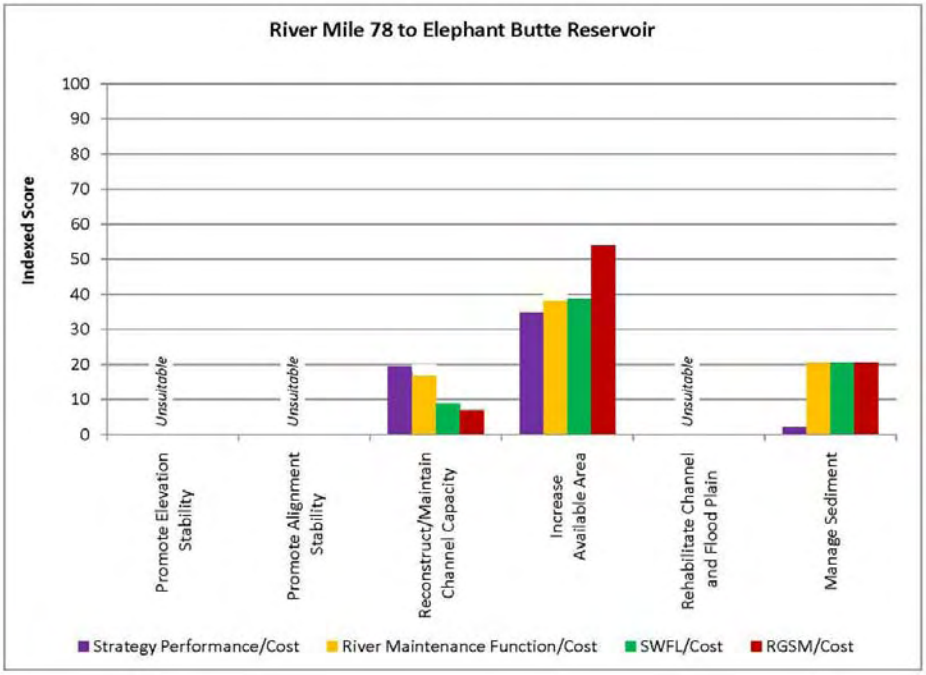

Figure C11.2. River Mile 78 to Elephant Butte Reservoir Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

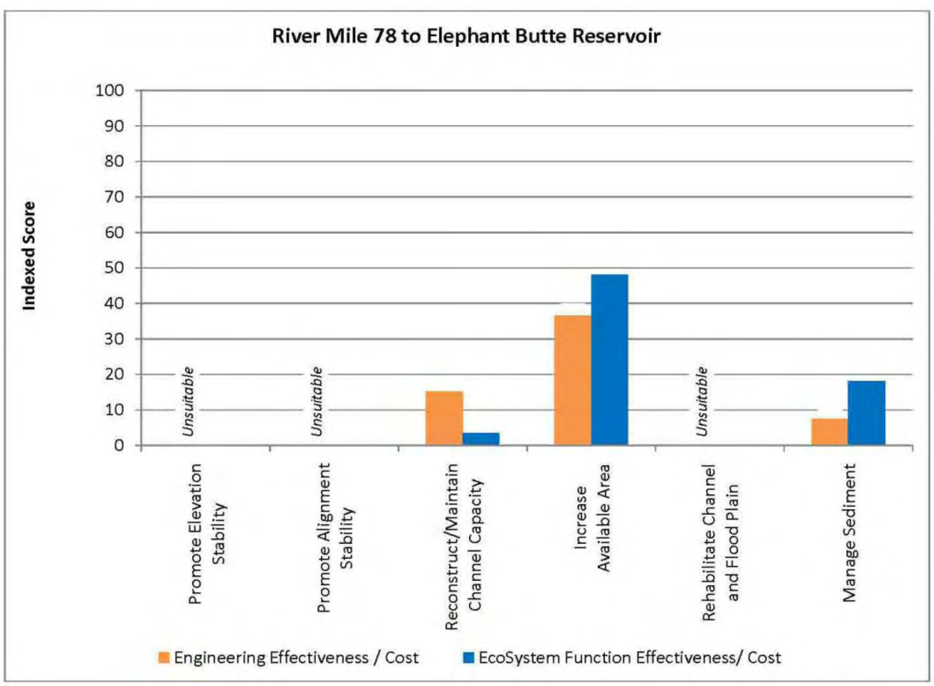

Figure C11.3. River Mile 78 to Elephant Butte Reservoir Reach effectiveness divided by cost indexed scoring results by evaluation factor.

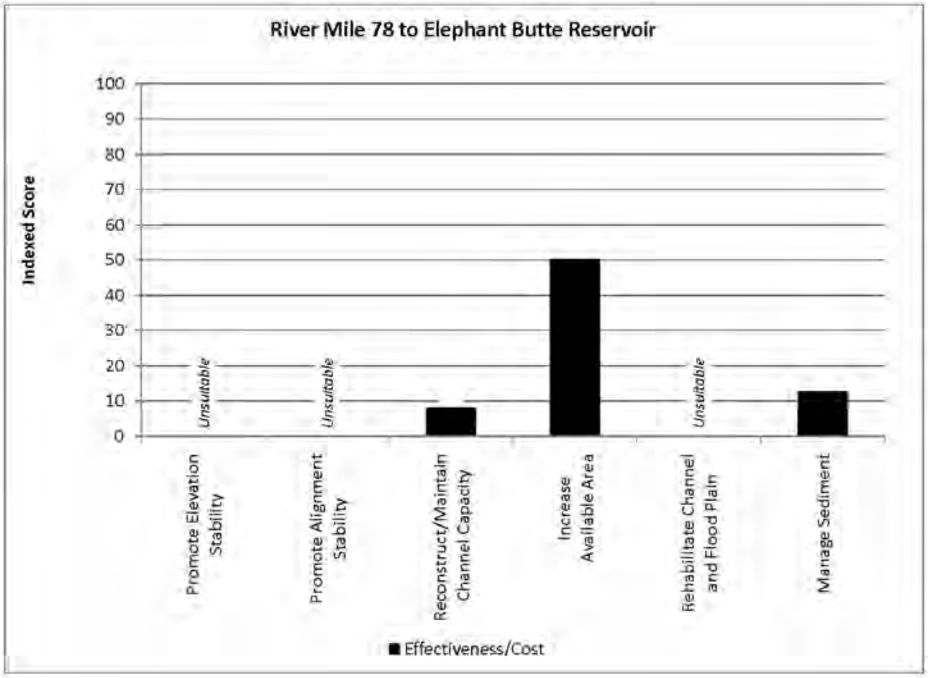

Figure C11.4. River Mile 78 to Elephant Butte Reservoir Reach total effectiveness divided by cost indexed scoring results.

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. 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

Chapter C12. Elephant Butte Dam to Caballo Reservoir (RM 26.6 to RM 12)

C12.1 Reach Characteristics

The Elephant Butte Dam to Caballo Reservoir Reach is approximately 14.6 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 (located at RM 21.4) during the winter (when flow is shut off) to raise the stage in the river, which increases hot springs flow. Sediment accumulates from tributary arroyos, and Reclamation annually excavates sediment deposits to restore the 5,000-cfs channel capacity.

C12.1.1 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.

C12.1.2 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 waters for diversions south of Caballo Reservoir such as Elephant Butte Irrigation District, city of El Paso, Texas, etc.

C12.1.3 Infrastructure, Public Health, and Safety Reach Characteristic – High Importance

The city of Truth or Consequences lies along the Rio Grande in this reach. The Census Bureau recorded 7,289 people in this city in 2000 and estimated the 2009 population at 7,111, which is below the 10,000 population threshold for a high rating (Census Bureau 2009). Lands along the river are urban and are not agricultural. Urban development lies along the river in this reach; therefore, even though the population is less than 10,000, the rating is high. 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. Further, there are homes, roads, and other infrastructure along the west bank of the river in this reach.

C12.1.4 Habitat Value and Need Reach Characteristic

C12.1.4.1 Southwestern Willow Flycatcher – Low Importance

Operational impacts to this reach of the river have prevented significant growth of riparian habitat. Although bird surveys have not been conducted, the lack of suitable SWFL habitat is obvious.

C12.1.4.2 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. Occasionally, water discharges are toxic due to high concentrations of sulfur dioxide. The reach is shorter than would be optimal for RGSM to complete their life cycle without drifting into Caballo Reservoir. Few recent surveys have taken place within this reach; in 1987, a survey was conducted that 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.

C12.2 Strategy Assessment Results

Three strategies are potentially suitable for this reach:

- Promote Alignment Stability
- Reconstruct and Maintain Channel Capacity
- Manage Sediment

Promote Alignment Stability may be necessary due to the narrow space between lateral constraints. Reconstruct and Maintain Channel Capacity addresses the sediment deposits from tributaries to the reach that reduce channel capacity as could Manage Sediment.

This section highlights considerations for suitable strategies that should be studied further. Ratings for suitable strategies that are not recommended for further study are provided as an analytic aid. Recommendations based on this analysis are in section C12.3.

C12.2.1 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.

C12.2.2 Promote Alignment Stability

Table C12.1 shows the weighted effectiveness and cost scores for this strategy.

C12.2.2.1 Geomorphic Effects for Promote Alignment Stability

Reclamation has placed riprap bank protection for property developed before 1985 in the cities of Truth or Consequences and Williamsburg. This strategy would continue to protect homes and other infrastructure along the river by using riprap.

C12.2.2.2 Engineering Effectiveness Evaluation Factor for Promote Alignment Stability

Residential and commercial development exists along the riverbanks within this reach. Landowners usually are interested in bank protection to preserve their property making access and obtaining land instruments is relatively straight forward. Many areas do not have a riparian zone and aquatic habitat is generally sport fisheries, making environmental compliance relatively straightforward. Thus, the Ability to Implement Attribute is rated high. The likelihood of needing other strategies in this reach at a later time is low.

C12.2.2.3 Ecosystem Function Evaluation Factor for Promote Alignment Stability

C12.2.2.3.1 Southwestern Willow Flycatcher

This strategy would reduce SWFL habitat suitability in this reach by reducing the potential for lateral migration and habitat creation and by keeping the water table at a reduced level by dredging. However, suitable SWFL habitat is already lacking in this reach, so impacts can be considered negligible. The Construction Impacts Attribute is rated medium because most of the work could occur within the active river channel, but there would be some work in the riparian area.

Table C12.1. Effectiveness and Cost Scores for Elephant Butte Dam to Caballo Reservoir, Promote Alignment Stability

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	3	20%	0.60
	Level of Confidence	3	10%	0.30
	Duration and Design Life	3	13%	0.39
	Adaptability	2	7%	0.14
	Strategy Performance Score		*50%*	*1.43*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	3	22%	0.66
	River Maintenance Function Score		*50%*	*1.22*
	Engineering Effectiveness Score		**100%**	**2.65**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	1	10%	0.10
	Water Table Elevation	2	10%	0.20
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*0.90*
	RGSM			
	Habitat Complexity	2	13%	0.25
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	2	13%	0.25
	RGSM Score		50%	1.00
	Ecosystem Function Effectiveness Score		**100%**	**1.90**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	1	15%	0.15
	Environmental Compliance	1	11%	0.11
	Implementation Cost	2	25%	0.50
	Monitoring and Evaluation	1	9%	0.09
	Frequency of Maintenance	1	10%	0.10
	Amount of Maintenance	1	12%	0.12
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	1	9%	0.09
	Economics Score		**100%**	**1.25**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C12.2.2.3.2 Rio Grande Silvery Minnow

Ecosystem assessment for this reach is based on the native fishery as opposed to RGSM, since they have been extirpated from this reach. Habitat is currently poor for native fish species, and this strategy would not change this. Construction could be on the bank. The Construction Impacts Attribute is rated medium, because work in the Rio Grande establishing stability would be primarily shore-based, and minimal construction would be in river.

C12.2.2.4 Economic Evaluation Factor for Promote Alignment Stability

The Planning and Development 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. No listed endangered species exist in this reach, so the Environmental Compliance Attribute is rated low. The medium rating for the Implementation Cost Attribute is based on the number and sites estimated from a qualitative analysis.

C12.2.3 Reconstruct and Maintain Channel Capacity

Table C12.2 shows the weighted effectiveness and cost scores for this strategy.

C12.2.3.1 Geomorphic Effects for Reconstruct and Maintain Channel Capacity

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 practice is expected to continue.

C12.2.3.2 Engineering Effectiveness Evaluation Factor for Reconstruct and Maintain Channel Capacity

This strategy is included in this reach as a result of deposition of sediments in the main channel from ephemeral tributaries. 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.

C12.2.3.3 Ecosystem Function Evaluation Factor for Reconstruct and Maintain Channel Capacity

C12.2.3.3.1 Southwestern Willow Flycatcher

Maintaining the channel capacity in this reach reduces the potential for overbank flooding, which would be a detriment to any developing or existing SWFL habitat. The Variety of Successional Stages Attribute is rated as decreased.

Table C12.2. Effectiveness and Cost Scores for Elephant Butte Dam to Caballo Reservoir, Reconstruct and Maintain Channel Capacity

Evaluation Factor	Attribute	Raw Score	Weight	Weighted Score
Effectiveness: 3 is the most effective, and 1 is the least effective.				
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	3	20%	0.60
	Level of Confidence	3	10%	0.30
	Duration and Design Life	1	13%	0.13
	Adaptability	3	7%	0.21
	Strategy Performance Score		*50%*	*1.24*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	2	22%	0.44
	River Maintenance Function Score		*50%*	*1.00*
	Engineering Effectiveness Score		**100%**	**2.24**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	1	10%	0.10
	Water Table Elevation	1	10%	0.10
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*0.80*
	RGSM			
	Habitat Complexity	1	13%	0.13
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	2	13%	0.25
	RGSM Score		50%	0.88
	Ecosystem Function Effectiveness Score		**100%**	**1.68**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	1	15%	0.15
	Environmental Compliance	2	11%	0.22
	Implementation Cost	1	25%	0.25
	Monitoring and Evaluation	3	9%	0.27
	Frequency of Maintenance	3	10%	0.30
	Amount of Maintenance	3	12%	0.36
	Frequency of Adaptive Management	1	9%	0.09
	Amount of Adaptive Management	1	9%	0.09
	Economics Score		**100%**	**1.73**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

C12.2.3.3.2 Rio Grande Silvery Minnow

This strategy could reduce complexity, which could be negative for the native fish community. Construction could be in the channel. The Construction Impacts Attribute is rated medium due to in-river placement of sediment control structures and bank stabilization.

C12.2.3.4 Economic Evaluation Factor for Reconstruct and Maintain Channel Capacity

The Planning and Design Attribute is low because the design channel geometry is restored by sediment removal. Sediments can be removed when there are no flow releases from the reservoir, making environmental compliance relatively straightforward; thus, the Environmental Compliance Attribute is rated low. The Implementation Costs Attribute is low because sediment removal is fairly localized.

C12.2.4 Increase Available Area to River – Not Suitable

Urban development makes this strategy not suitable for this reach.

C12.2.5 Rehabilitate Channel and Flood Plain – Not Suitable

Urban development makes this strategy not suitable for this reach.

C12.2.6 Manage Sediment – Not Recommended

This strategy had a low effectiveness-to-cost ratio; therefore, it is not recommended for further study. Table C12.3 shows the weighted effectiveness and cost scores for this strategy.

C12.2.7 Strategy Assessment Result Comparison Tables

The ratings for each attribute for each of the evaluation factors for each strategy are in table C12.4 (Engineering Effectiveness Evaluation Factor), table C12.5 (Ecosystem Function Evaluation Factor), and table C12.6 (Economic Evaluation Factor).

Tables C12.7 and C12.8 summarize the effectiveness and economics scores for all suitable strategies for the reach.

For ease of comparison, figures C12.1–C12.3 graphically present the indexed scores for effectiveness divided by cost for each subevaluation factor, factor, and strategy total, respectively.

Table C12.3. Effectiveness and Cost Scores for Elephant Butte Dam to Caballo Reservoir, Manage Sediment

Effectiveness: 3 is the most effective, and 1 is the least effective.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Engineering Effectiveness	**Strategy Performance**			
	Ability to Implement	1	20%	0.20
	Level of Confidence	1	10%	0.10
	Duration and Design Life	2	13%	0.26
	Adaptability	2	7%	0.14
	Strategy Performance Score		*50%*	*0.70*
	River Maintenance Function			
	Water Delivery	2	13%	0.26
	Hydraulic Capacity	2	15%	0.30
	Public Health and Safety	2	22%	0.44
	River Maintenance Function Score		*50%*	*1.00*
	Engineering Effectiveness Score		**100%**	**1.70**
Ecosystem Function Effectiveness	**SWFL**			
	Variety of Successional Stages	2	10%	0.20
	Water Table Elevation	1	10%	0.10
	Flood Plain Width/Patch Availability	2	10%	0.20
	Flood Plain Elevation	2	10%	0.20
	Construction Impacts[1]	2	10%	0.20
	SWFL Score		*50%*	*0.90*
	RGSM			
	Habitat Complexity	1	13%	0.13
	Flood Plain Connectivity and Flood Frequency	2	13%	0.25
	Sinuosity	2	13%	0.25
	Construction Impacts[1]	2	13%	0.25
	RGSM Score		50%	0.88
	Ecosystem Function Effectiveness Score		**100%**	**1.78**
Cost: 3 is the highest cost, and 1 is the lowest cost.				
Evaluation Factor	**Attribute**	**Raw Score**	**Weight**	**Weighted Score**
Economics	Planning and Design	3	15%	0.45
	Environmental Compliance	3	11%	0.33
	Implementation Cost	1	25%	0.25
	Monitoring and Evaluation	3	9%	0.27
	Frequency of Maintenance	3	10%	0.30
	Amount of Maintenance	3	12%	0.36
	Frequency of Adaptive Management	3	9%	0.27
	Amount of Adaptive Management	3	9%	0.27
	Economics Score		**100%**	**2.50**

[1] Construction impacts are short term only. These use "high, medium, and low" ratings. A "high" rating for this attribute translates into a raw score of "1" as the greater the construction impacts, the lower the effectiveness for the ecosystem.

Table C12.4. Engineering Effectiveness Evaluation Factor Attribute Ratings for the Elephant Butte Dam to Caballo Reservoir Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment[1]
Construction location		Bank	Channel			Flood Plain, and Terraces
Strategy Performance						
Ability to Implement		High	High			Low
Level of Confidence		High	High			Low
Duration and Design Life		High	Low			Medium
Adaptability		Medium	High			Medium
River Maintenance Function						
Water Delivery		No Change	No Change			No Change
Hydraulic Capacity		No Change	No Change			No Change
Public Health and Safety		Increase	No Change			No Change

[1] Sediment supply reduction in tributaries.

Table C12.5. Ecosystem Function Evaluation Factor Attribute Ratings for the Elephant Butte Dam to Caballo Reservoir Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
SWFL						
Variety of Successional Stages		Decrease	Decrease			No Change
Water Table Elevation		No Change	Decrease			Decrease
Flood Plain Width/Patch Availability		No Change	No Change			No Change
Flood Plain Elevation		No Change	No Change			No Change
Construction Impacts		Medium	Medium			Medium
RGSM[1]						
Habitat Complexity		No Change	Decrease			Decrease
Flood Plain Connectivity and Frequency of Flooding		No Change	No Change			No Change
Sinuosity		No Change	No Change			No Change
Construction Impacts		Medium	Medium			Medium

[1] No endangered species present. Assessment is an indication of ecologic health for general fish and wildlife benefit.

Table C12.6. Economic Evaluation Factor Attribute Ratings for the Elephant Butte Dam to Caballo Reservoir Reach

Attribute	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to the River	Rehabilitate Channel and Flood Plain	Manage Sediment
Planning and Design		Low	Low			High
Environmental Compliance		Low	Medium			High
Implementation		Medium	Low			Low
Monitoring and Evaluation		Low	High			High
Frequency of Maintenance		Low	High			High
Amount of Maintenance		Low	High			High
Frequency of Adaptive Management		Low	Low			High
Amount of Adaptive Management		Low	Low			High

Table C12.7. Summary of Economics and Effectiveness Scores by Subevaluation Factor for the Elephant Butte Dam to Caballo Reservoir Reach

	Economics Score	Effectiveness Score			
Strategy	Cost	Strategy Performance	River Maintenance Function	SWFL	RGSM
Promote Elevation Stability					
Promote Alignment Stability	1.25	1.43	1.22	0.90	1.00
Reconstruct/ Maintain Channel Capacity	1.73	1.24	1.00	0.80	0.88
Increase Available Area					
Rehabilitate Channel and Flood Plain					
Manage Sediment	2.50	0.70	1.00	0.90	0.88

Table C12.8. Summary of Economics and Effectiveness Scores for the Elephant Butte Dam to Caballo Reservoir Reach

Strategy	Cost	Engineering Effectiveness	Ecosytem Function Effectiveness		Total Effectiveness
Promote Elevation Stability					
Promote Alignment Stability	1.25	2.65	1.90		4.55
Reconstruct/ Maintain Channel Capacity	1.73	2.24	1.68		3.92
Increase Available Area					
Rehabilitate Channel and Flood Plain					
Manage Sediment	2.50	1.70	1.78		3.48

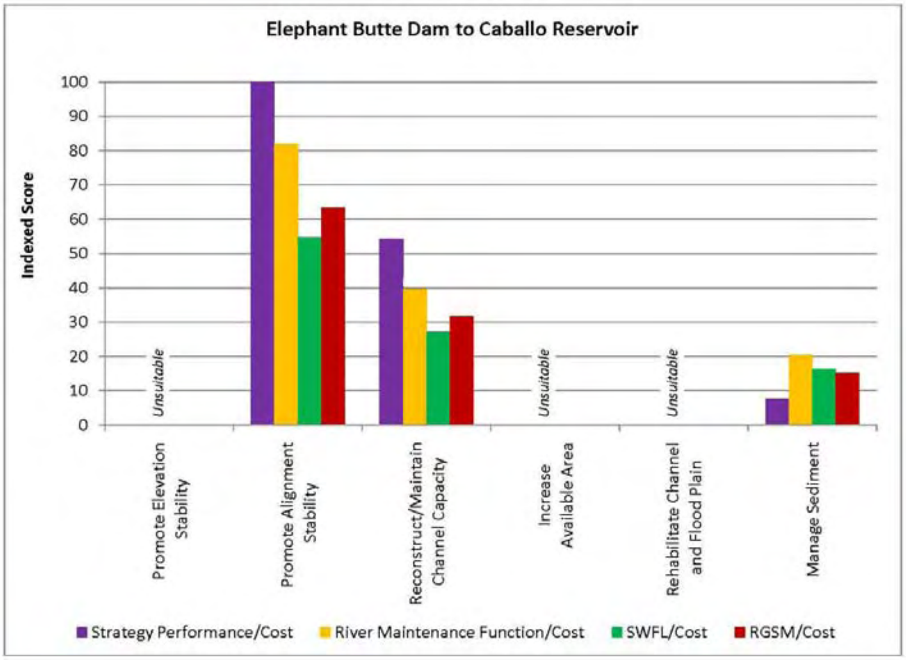

Figure C12.1. Elephant Butte Dam to Caballo Reservoir Reach effectiveness divided by cost indexed scoring results by subevaluation factor.

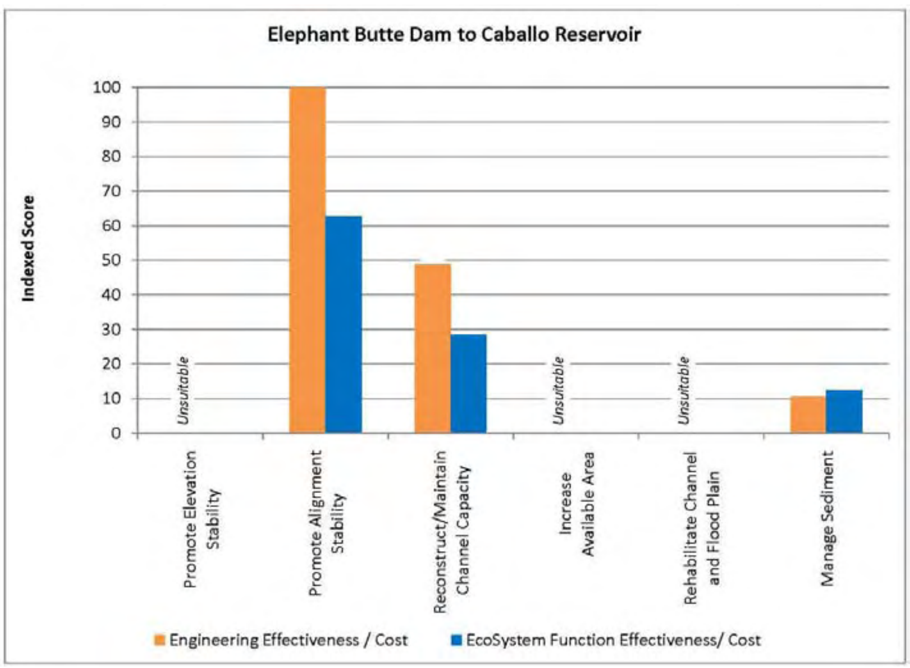

Figure C12.2. Elephant Butte Dam to Caballo Reservoir Reach effectiveness divided by cost indexed scoring results by evaluation factor.

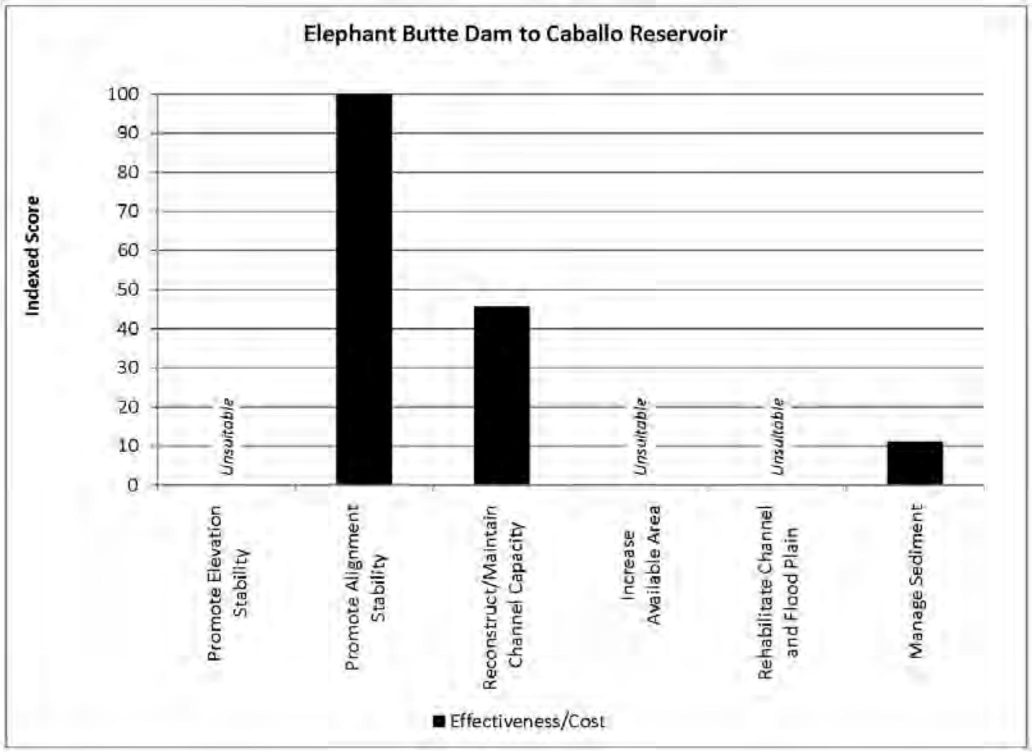

Figure C12.3. Elephant Butte Dam to Caballo Reservoir Reach total effectiveness divided by cost indexed scoring results.

C12.3 Recommendations

This reach is strongly influenced by historical channelization work and the presence of multiple ephemeral tributaries that have 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 low instability for the Channel Instability Reach Characteristic, and 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.

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Unique Terms

The analysis approach is discussed in the main report, section 4.1.

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