RECLAMATION

Managing Water in the West

Middle Rio Grande River Maintenance Program Comprehensive Plan and Guide

Appendix B: One-Dimensional Modeling and Indicator Results for the Middle Rio Grande

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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Middle Rio Grande Project, New Mexico
Upper Colorado Region

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Abstract

This report documents the modeling of the Middle Rio Grande River from Cochiti Dam to the Narrows of Elephant Butte, which will be used to help plan future maintenance actions. Six strategies – which define reach-scale management approaches – have been formulated to more holistically integrate river maintenance actions with the physical processes occurring on the Middle Rio Grande. A mobile bed model was employed to help understand the balance between sediment transport capacity and sediment supply of each reach. The results of the sediment routing model show that the Middle Rio Grande between Cochiti Dam and the Rio Puerco appear to be near a state of relative equilibrium under current water and sediment loads. The reach between the Rio Puerco and San Acacia Diversion Dam encompasses significant geologic and geomorphic transitions such that the reaches upstream of the Rio Puerco are characteristically different from the reaches downstream from San Acacia Diversion Dam. The Rio Grande downstream from the Rio Puerco has high incoming sediment loads and tends to be depositional, except for the reach downstream from river mile 78, which is strongly affected by the water surface elevation of Elephant Butte and so alternates between aggradation and degradation. Results of the modeling also provide for each reach a likely future equilibrium slope, change in bed elevation, and change in bed sediment size.

Hydraulic modeling provides, by reach, hydraulic characteristics for the representative flow of 4,700 cubic feet per second and an assessment of very high flow capacity for strategy geometries. The meander belt assessment is a comparison of the sine-generated-curve meander belt after strategy implementation to the existing lateral constraints in a reach, and it provides information on how well a meandering channel will fit within the lateral constraints of a reach.

Twenty descriptive indicators have been defined to help compare physical properties of a reach after strategy implementation. Reach-specific indicator values for each strategy are developed from the modeling results. These indicator values are further classified into similar groupings, or bins, such that those that vary about a mean are classified together and those that are significantly different are identified.

The indicator values documented in this report were used to help assess the effectiveness of strategies by reach at a screening level and helped identify which strategies for a given reach should be further studied in more detail. This set of information is intended to be combined with other geomorphic information and modeling results, as interpreted with professional judgment, to help select strategies that allow for the most effective allocation of resources for the greatest positive net benefits, resulting in a more effective river maintenance approach.

Acknowledgements

We would like to acknowledge the following people for their invaluable assistance in this modeling effort:

- Travis Bauer for developing the geometry dataset and for input and guidance in modeling the Middle Rio Grande
- Kurt Wille for writing VBA script for meander plotting along a digitized centerline
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Acronyms and Abbreviations

agg/deg	aggradation/degradation
ASCE	American Society of Civil Engineers
BORAMEP	Bureau of Reclamation Automated Modified Einstein Procedure
cfs	cubic feet per second
EH	Engelund-Hansen
ft	foot
ft/s	feet per second
HEC-RAS	Hydrologic Engineering Centers River Analysis System
MBW	meander belt width
MLR	meander length ratio
mm	millimeters
NMF	No Maintenance Future
NMF-H	No Maintenance Future horizontal
NMF-V	No Maintenance Future vertical
Parker-EH	Parker sediment transport equation coupled with Engelund-Hansen sediment transport equation
Reclamation	Bureau of Reclamation
RGSM	Rio Grande silvery minnow
RM	river mile
RTI	Resource Technology, Inc.
SRH-1D	Sedimentation and River Hydraulics One-Dimensional Sediment Transport Dynamics Model
SRH-Capacity	Sedimentation and River Hydraulics Capacity Model
SWFL	southwestern willow flycatcher
USGS	U.S. Geological Survey
WSE	water surface elevation
1D	one-dimensional
2D	two-dimensional

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1 Introduction

This report documents the modeling of the Middle Rio Grande River from Cochiti Dam to the Narrows of Elephant Butte, which will be used to help plan future maintenance actions. Strategies have been defined to more holistically integrate the physical processes occurring on the Middle Rio Grande with river maintenance actions, resulting in a more effective river maintenance approach. The modeling effort documented in this report will be used to help assess the effectiveness of strategies by reach at a screening level, and the results can be used to help identify which strategies for a given reach should be further studied in more detail.

1.1 River Maintenance Strategies

Strategies define reach-scale management approaches to address the physical and biological processes understood to be driving the current and predicted river trends that may result in river maintenance actions. On the Middle Rio Grande, these reach-scale trends include:

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

The following reach strategies were developed to address these trends:

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

Each strategy has different methods, geomorphic responses, and effects upon a reach. Each reach generally has multiple constraints such as water delivery, protection of riverside infrastructure, local variations in geology, and endangered species habitat.

1.1.1 Promote Elevation Stability

The objective of this strategy is to reduce the extent and rate of bed elevation changes. It is mainly implemented through cross channel structures that reduce or prevent channel incision and degradation to maintain bed elevations. This strategy also includes minimization of aggradation where appropriate, but river maintenance actions are likely to be implemented through other strategies that directly address aggradation such as "Reconstruct/Maintain Channel Capacity," "Increase Available Area to the River," and "Manage Sediment."

This strategy can help address the following reach scale trends: increased bank height, incision or channel bed degradation, coarsening of bed material, and aggradation.

1.1.2 Promote Alignment Stability

The objective of this strategy is to allow the river channel to adjust as much as possible horizontally while monitoring bank line movement. When the safety or integrity of riverside facilities and structures is likely to be compromised within the next few years, then bank protection measures are provided to protect infrastructure and reduce the risk of future migration.

Under perched channel conditions, the historical river maintenance approach has maintained the current alignment and has typically addressed the situation with other strategies such as "Reconstruct/Maintain Channel Capacity," "Increase Available Area to the River," and "Manage Sediment."

This strategy can help address the following reach scale trends: bank erosion, channel plugging with sediment, and perched channel conditions.

1.1.3 Reconstruct/Maintain Channel Capacity

The objective of this strategy is to provide the channel capacity needed to protect riverside infrastructure and resources and meet water delivery obligations. It is implemented primarily through excavation of sediment, but confining overbank flow to increase transport capacity or strengthening/raising levees can create the same effect.

This strategy can help address the following reach scale trends: channel narrowing, vegetation encroachment, aggradation, channel plugging with sediment, and perched channel conditions.

1.1.4 Increase Available Area to the River

The objective of this strategy is to provide more area for the river to evolve in response to changing conditions and minimize the need for additional future river maintenance actions. The ideal condition would be for the river and flood plain area to be large enough to accommodate more than the expected width of potential lateral migration. It would be implemented through infrastructure setback or changes in land use.

This strategy can help address the following reach scale trends: channel narrowing, increased bank height, incision or channel bed degradation, bank erosion, coarsening of bed material, aggradation, channel plugging with sediment, and perched channel conditions.

1.1.5 Rehabilitate Channel and Flood Plain

The objective of this strategy is to reduce the sediment transport capacity of high flows by allowing flow to go over bank at lower discharges. It is primarily implemented by lowering bank height through removal of flood plain sediments, but channel realignment could create a similar effect.

This strategy can help address the following reach scale trends: channel narrowing, vegetation encroachment, increased bank height, incision or channel bed degradation, bank erosion, and coarsening of bed material.

1.1.6 Manage Sediment

The objective of this strategy is to balance sediment transport capacity with available sediment supply to the extent possible. Currently, there is an excess of sediment transport capacity in most of the reaches, so implementation would involve the addition of sediment into the system. Where the supply exceeds the transport capacity, sediment settling basins are used to reduce the sediment load.

This strategy can help address the following reach scale trends: increased bank height, incision or channel bed degradation, coarsening of bed material, aggradation, channel plugging with sediment, and perched channel conditions.

1.2 No Maintenance Future Conditions

To help understand the future trends on the Middle Rio Grande, modeling was conducted to estimate future conditions if there were no maintenance performed. This scenario is called the No Maintenance Future (NMF). Ideally, the NMF assessment would be made using a two-dimensional (2D) model, but due to the length of the study area, two one-dimensional (1D) models are considered. These two one-dimensional models are necessary to create an envelope of potential changes: one for vertical adjustment and one for the horizontal alignment. In one model, all of the channel adjustments are made in the No Maintenance Future vertical (NMF-V) direction with no change in width or channel alignment, and in the other model, all of the channel adjustments are made in the No Maintenance Future horizontal (NMF-H) planform alignment (river length) with no change in width or elevation.

The NMF is not considered a viable strategy due to constraints such as public health and safety, protection of infrastructure, water compact delivery requirements, and endangered species needs, politics, etc. However, the NMF provides a basis for comparing the strategies. Both NMF-V and NMF-H scenarios assume that the sediment and flow inputs are known and that the channel will respond to create a transport capacity that reflects the sediment supply. Both scenarios assume that the channel width remains essentially constant and that the change in sediment transport capacity comes from a change in channel slope. The slope change comes from one of two mechanisms: vertical bed change for NMF-V and planform realignment (change in channel length) for NMF-H.

A 1D mobile bed sediment model was used to predict a future “equilibrium” slope in which the model allows for vertical bed change, but the channel width and length remain unchanged. This equilibrium slope for each reach developed for the NMF-V scenario was used to change the length of the reaches to determine the NMF-H conditions.

2 Data Preprocessing

Sedimentation and River Hydraulics One-Dimensional Sediment Transport Dynamics Model (SRH-1D) (Huang et al. 2007) is a 1D, mobile bed sediment routing model that was employed to obtain a likely future equilibrium slope of the Middle Rio Grande. The Middle Rio Grande extends from Velarde, New Mexico, to Caballo Reservoir near Truth or Consequences, New Mexico. The Middle Rio Grande is broken into reaches, "based on differences in hydrology, river planform, slope, sediment size, channel capacity, biological needs, institutional needs, and other factors," (Martin et al. 2007). Due to data limitations, only the river from Cochiti Dam to Elephant Butte Reservoir is considered in the numerical modeling. Table B2.1 locates the reaches by river mile (RM) along with the numerical modeling reach number. The river miles in table B2.1 may be slightly different than those described in other documents due to the location of model cross sections. Figure B2.1 presents an overview of the reach locations. Applying this model to the large area of interest necessitated a number of preprocessing steps. These steps reflect the inputs relating to hydrology (section 2.1), geometry (section 2.2), bed material (section 2.3), and sediment transport (section 2.4).

Table B2.1. Middle Rio Grande Reaches by RM

Reach	Approximate Model RM	Model Reach Number
Velarde to Rio Chama[1]	N/A	N/A
Rio Chama to Otowi Bridge[1]	N/A	N/A
Cochiti Dam to Angostura Diversion Dam	233 to 210	1
Angostura Diversion Dam to Isleta Diversion Dam	210 to 169	2
Isleta Diversion Dam to Rio Puerco	169 to 127	3
Rio Puerco to San Acacia Diversion Dam	127 to 116	4
San Acacia Diversion Dam to Arroyo de las Cañas	116 to 95	5
Arroyo de las Cañas to San Antonio Bridge	95 to 87	6
San Antonio Bridge to River Mile 78	87 to 78	7
River Mile 78 to Elephant Butte Reservoir	78 to 50	8
Elephant Butte Dam to Caballo Reservoir[1]	N/A	N/A

[1] These reaches were not modeled.

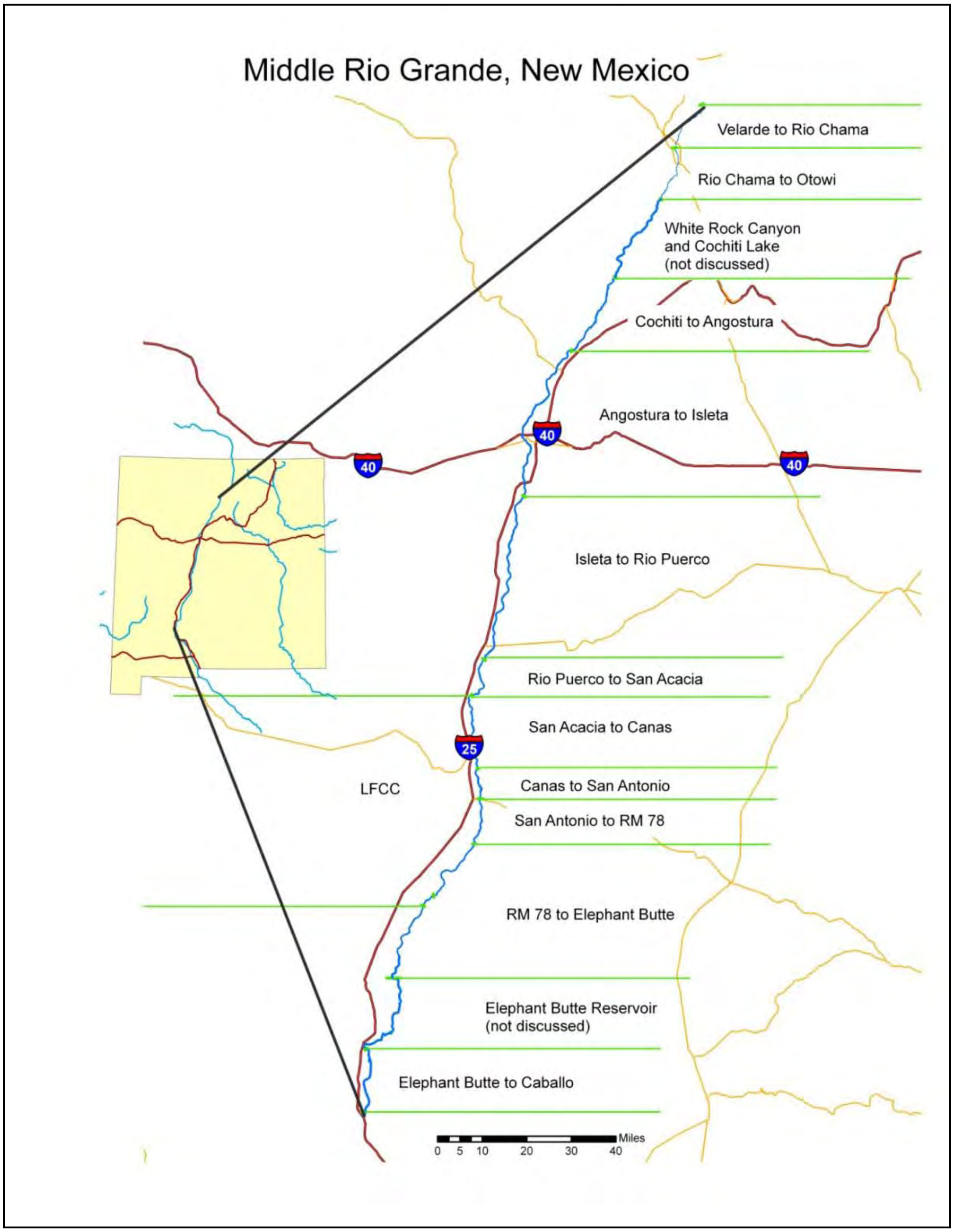


Figure B2.1. Overview of Middle Rio Grande reaches.

2.1 Hydrology Analysis

A quasi-steady state approach to the Middle Rio Grande allowed for a variety of goals to be met. A fully unsteady model is likely more accurate, but it would require both more data as well as more computational time to complete a model run. A model consisting of a series of incremental steady-state flows can reflect natural temporal flow variation while reducing data and computational resources.

Identification of a single, “dominant,” “bank-full,” or “effective” discharge has been shown to represent the morphology of a natural flow hydrograph in certain instances (Watson et al. 2005). However, the morphology of the Middle Rio Grande, which has undergone significant and continuous alterations for decades, is as much a reflection of anthropogenic influences as it is a reflection of the water and sediment transport characteristics. Therefore, a selection of a single representative discharge would be inappropriate.

Alternatively, using a historical gauge record of a significant temporal scale (e.g., decades) would likely not converge to an equilibrium state, although no verification of this assertion is made. A repeated, representative water year hydrograph allows for both temporal flow variation as well as increasing the likelihood of a convergent model solution.

Six U.S. Geological Survey (USGS) gauges <http://waterdata.usgs.gov/nwis/> provide sufficient data to be used in a hydrological analysis for the Middle Rio Grande. These records and locations are San Felipe (08319000), Albuquerque (08330000), San Acacia (08354900 and 08354800), and San Marcial (08358300 and 08358400). In two instances (San Acacia and San Marcial), two gauge records (channel and floodway) are combined in order to create a single hydrograph for a specific locale. Two criteria (cumulative water volume and peak discharge) were used to determine a single water year that was representative for the listed sites above. The representative water year needed to be after Cochiti Dam started operations in 1973 to reflect that future conditions would include the effects of Cochiti Dam operations for flood control. As expected, there was no single water year that was the best match in terms of volume and instantaneous peaks at all of the gauges considered. However, the water year 1975 (October 1, 1974 – September 30, 1975) proved to be the most representative water year for the gauges listed above in terms of both cumulative water volume and peak discharge.

As an example, figure B2.2 presents the 1975 water year as compared to the average annual water year at San Felipe (USGS gauge 08319000), and figure B2.3 presents the instantaneous peaks for this gauge with the 1975 peak highlighted. The total volume for water year 1975 is about 8 percent higher than the volume for the average water year, and as can be seen in figure B2.3, the peak is about 10 percent lower than the median peak flow.

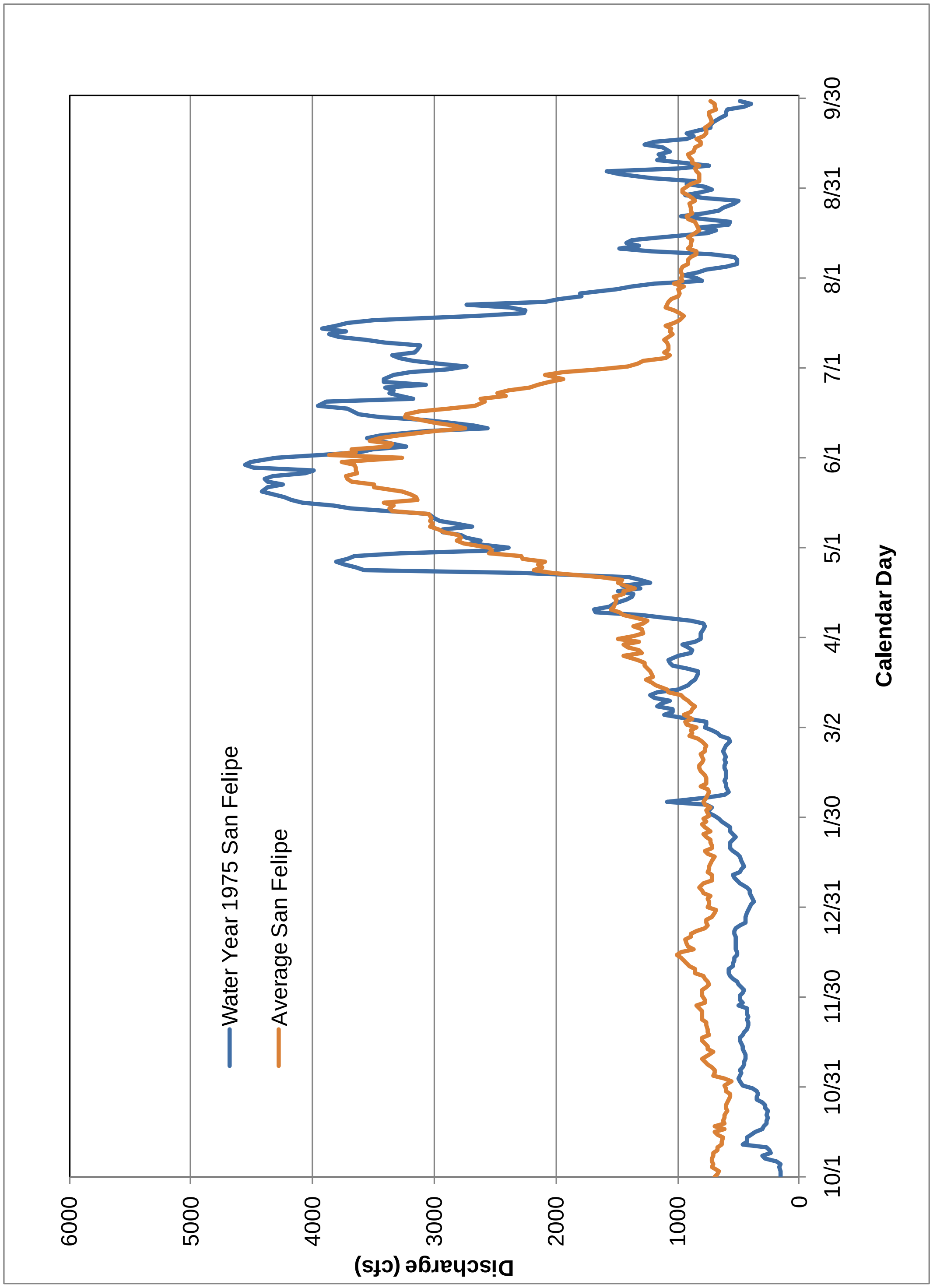


Figure B2.2. Single-year hydrographs for San Felipe gauge (USGS 08319000).

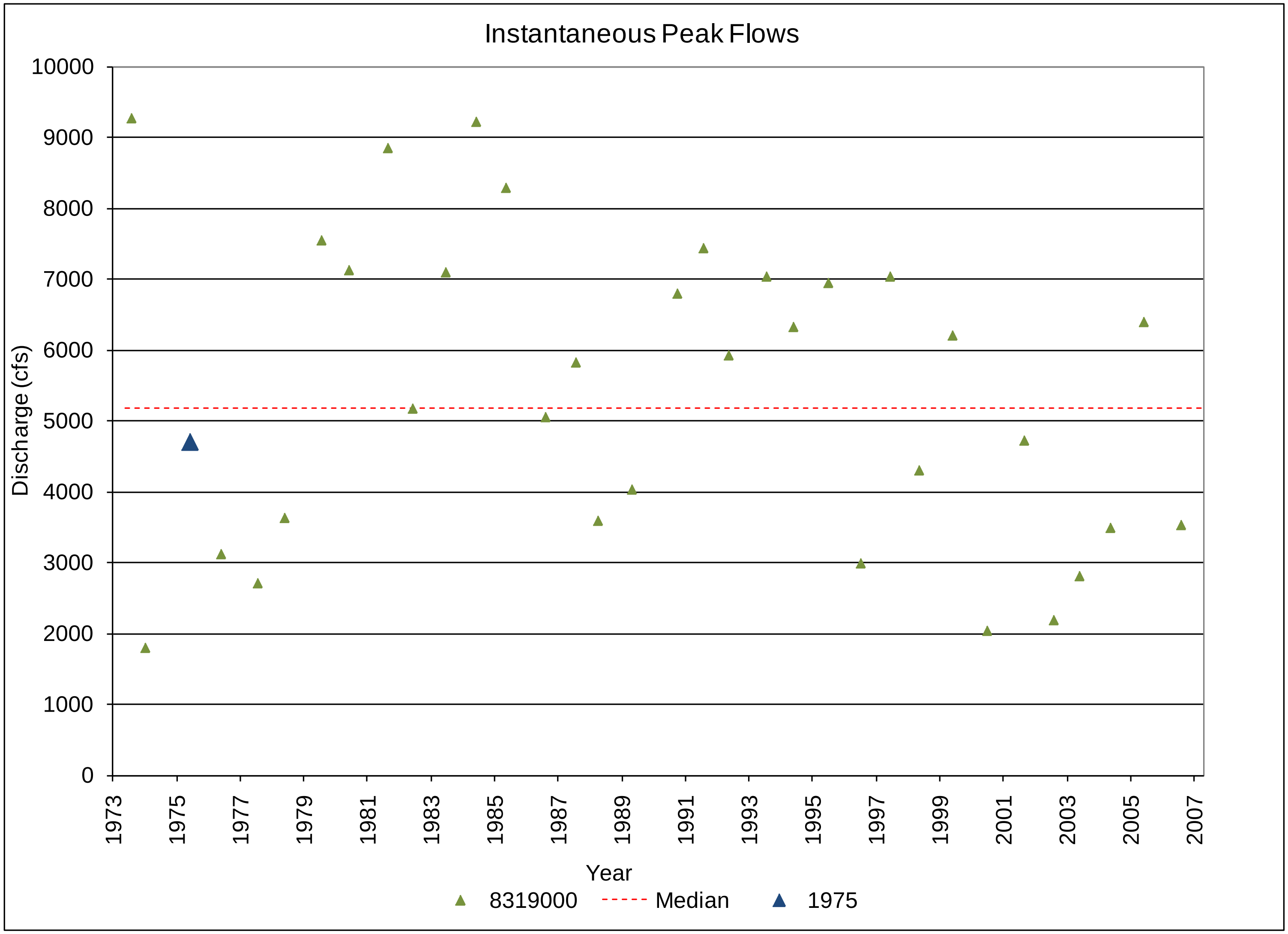


Figure B2.3. Instantaneous peaks at San Felipe gauge (USGS 08319000).

Figure B2.2 demonstrates the advantage of using flows from a specific year and not an average year. An average year will, by nature, have lower peak storm events. The sediment transport relationship with discharge is not linear, so using an average year would underestimate the sediment load calculated during sediment routing. This 1-year duration gauge record was repeated for a 60-year duration to achieve a convergent solution. Similar comparisons and relative relationships were verified for the other gauge records along the Middle Rio Grande, validating that 1975 was appropriate for the entire solution domain.

2.2 Geometry Development

A consistent set of cross-section locations has been identified along the Middle Rio Grande to compare geometry through time. This set of cross sections was developed to monitor changes in bed elevation over time and are called aggradation/degradation (agg/deg) lines. Aerial photographs coupled with ground control surveys and aerial triangulation (photogrammetry) has been used to develop the geometry at these agg/deg lines since 1962 at approximately 10-year intervals. Agg/deg lines have a typical spacing of 500 feet. The most recent set of photogrammetry and associated agg/deg geometry is from 2002.

2.2.1 Representative Cross Sections

As the goal of modeling is to consider nearly 200 miles of river in a mobile-bed 1D model, using all of the agg/deg lines with a 500-foot nominal spacing would yield excessive computation time. Therefore, the cross sections were filtered so that the main river features could be represented with fewer cross sections. A total of 105 cross sections was used to represent the roughly 200 miles from Cochiti Dam to the Narrows of Elephant Butte Reservoir.

In order to validate the cross-section spacing, a comparison is made between the water surface elevation (WSE), channel hydraulic depth, and channel velocity resulting from using all of the cross sections from the 2002 geometry file and the WSE resulting from using the representative 105 cross sections.

Figure B2.4 presents the difference in WSE resulting from the two geometry datasets for three different discharges:

- PF 1 = 1,500 cubic feet per second (cfs)
- PF 2 = 3,000 cfs
- PF 3 = 4,500 cfs

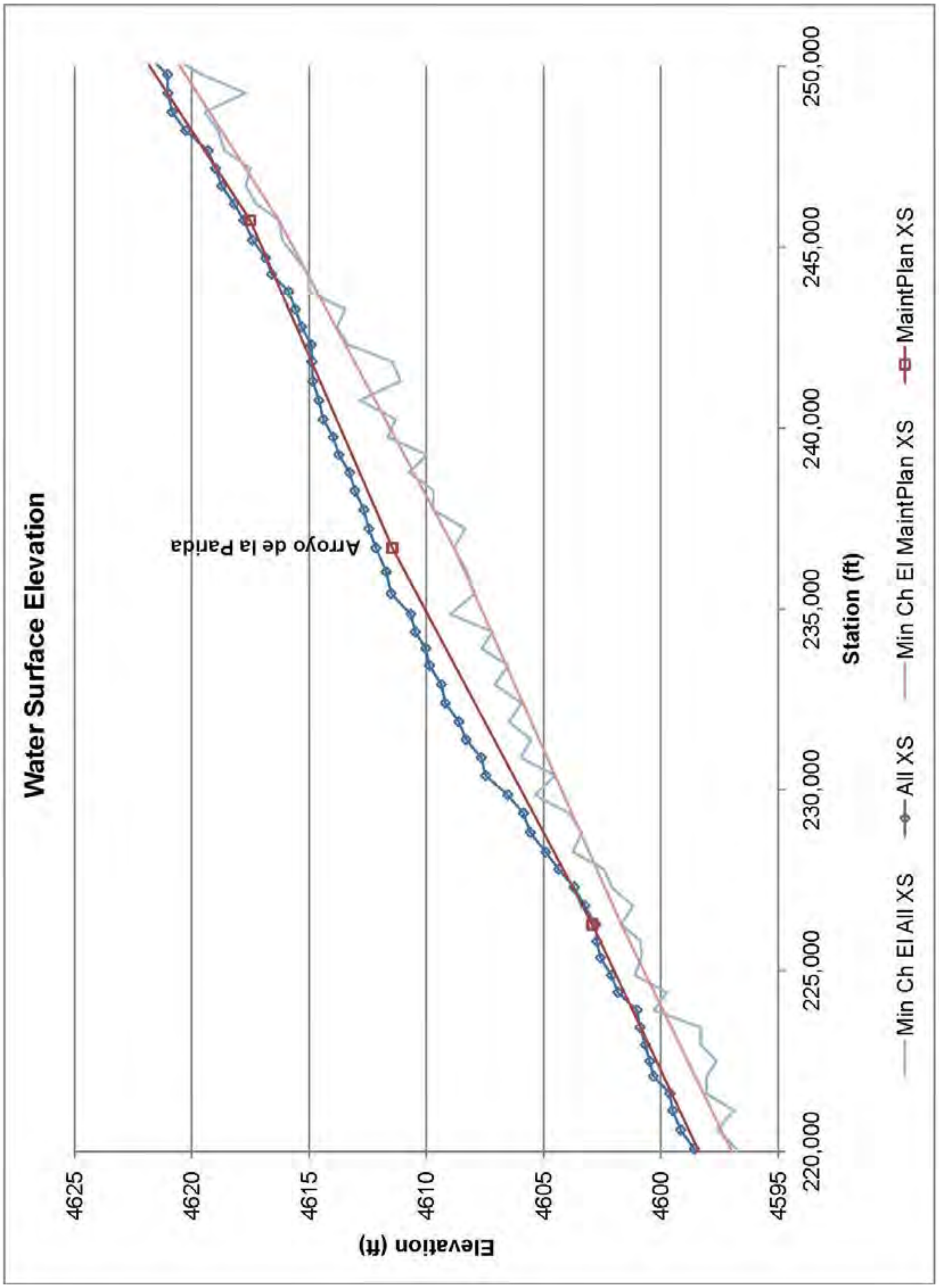


Figure B2.4. Difference in water surface elevations at model cross sections based on using all cross sections and using representative cross sections.

The agreement in the WSE is good for most of the model extent, except for the following locations (from downstream to upstream):

- Near Arroyo de la Parida
- Near San Acacia Diversion Dam
- Arroyo Tonque to Angostura Diversion Dam

Figures B2.5– B2.7 present longitudinal profiles (for the 4,500 cfs case) at the locations listed in the above bulleted list. As can be seen, the discrepancy in WSE is a result of not capturing the locally steep slopes at these hydraulic controls. It was deemed acceptable to lose this resolution in geometry during the modeling from the beginning of this effort as model instabilities can result in SRH-1D when the cross-section spacing varies dramatically (fine spacing to coarse spacing and vice versa).

The development of the 2002 geometry and associated errors are instructive when looking at the above figures. The following discussion summarizes documentation of the 2002 geometry development as documented in Holmquist-Johnson et al. (2006).

The 2002 geometry was initially developed from photogrammetry in which the vertical quality control standard for the cross sections was:

> Horizontal cross sectional coordinate requirements were as follows: horizontal distances were not to exceed 1.0 foot from true locations. Vertical cross section requirements were as follows: 90% of all points shown on each cross section line had to be within plus or minus 0.50 foot of the true elevation and no point could be more than 1.0 foot from true elevation. Where the view of the ground was severely obscured by trees, brush or ground shadows, not more than 10% of the elevations measured in such areas could be in error by more than 1 foot and no point could be in error by more than 2 feet.

In addition, an underwater prism was developed to represent the channel because photogrammetry represents the water surface and not the channel bottom. A trapezoidal section was developed to represent the portion of the channel that was below water during the photogrammetric data collection. The bottom elevation of the prism was adjusted such that Hydrologic Engineering Centers River Analysis System (HEC-RAS) modeled water surface elevation of the resulting geometry "matched the measured water surface elevation within a tolerance of 0.5 ft."

Considering the quality control standards set forth for the photogrammetric data collection, along with the development of the underwater prism, any given cross-section point for any of the 2002 cross sections could have an elevation error of 1 foot (ft), with a potential maximum error of 2.5 ft.

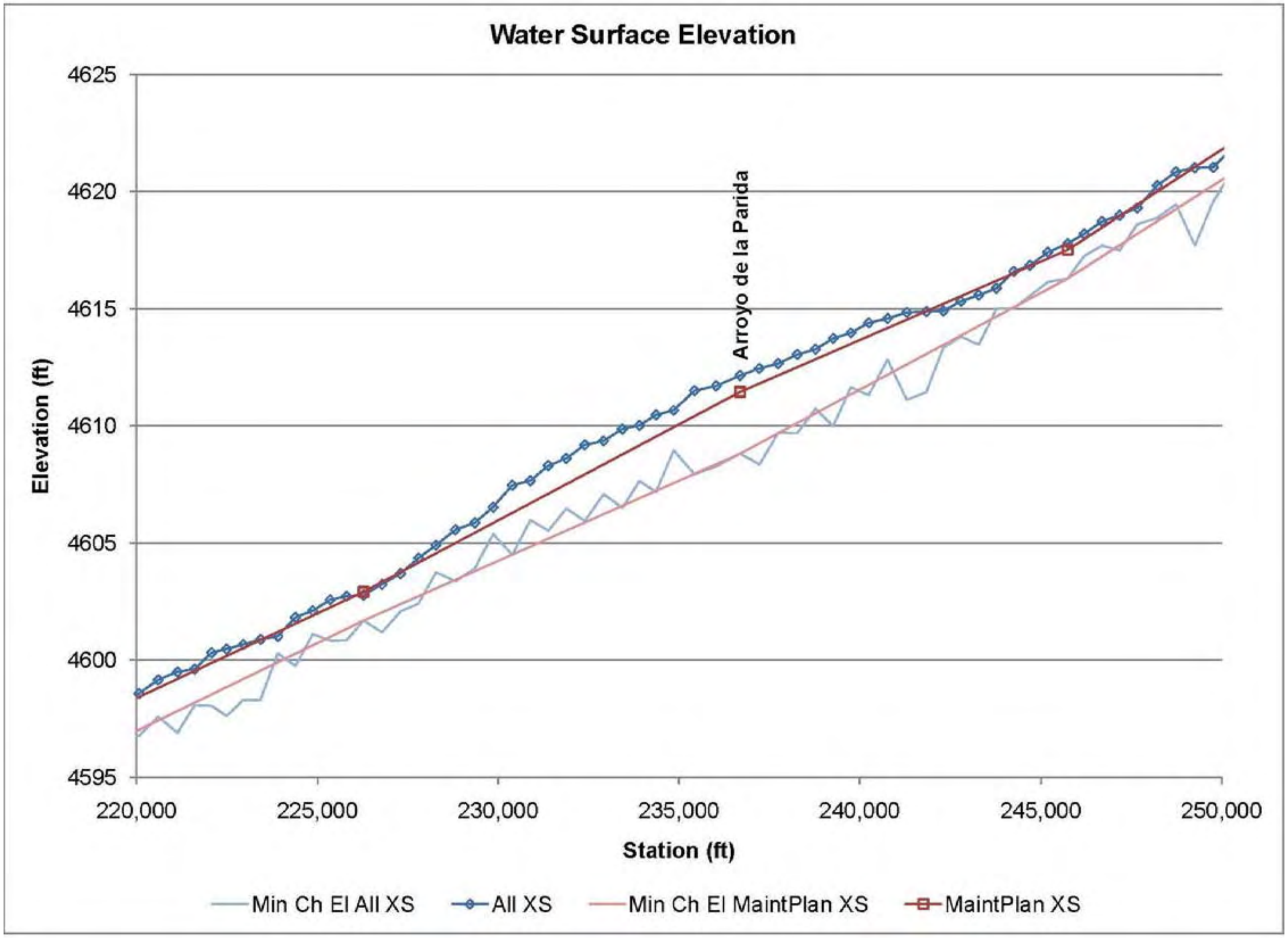


Figure B2.5. Longitudinal profile near Arroyo de la Parida.

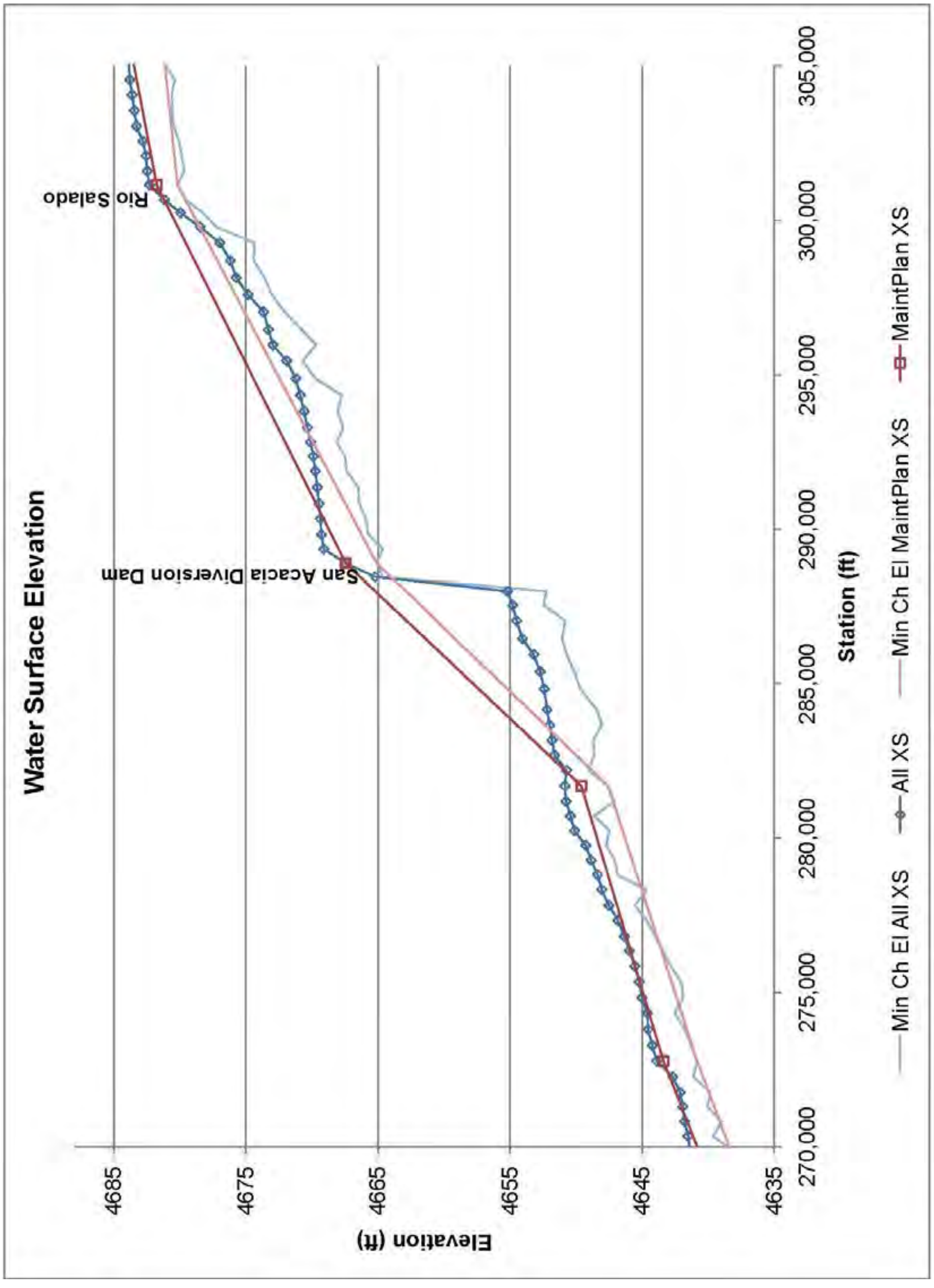


Figure B2.6. Longitudinal profile near San Acacia Diversion Dam and Rio Salado.

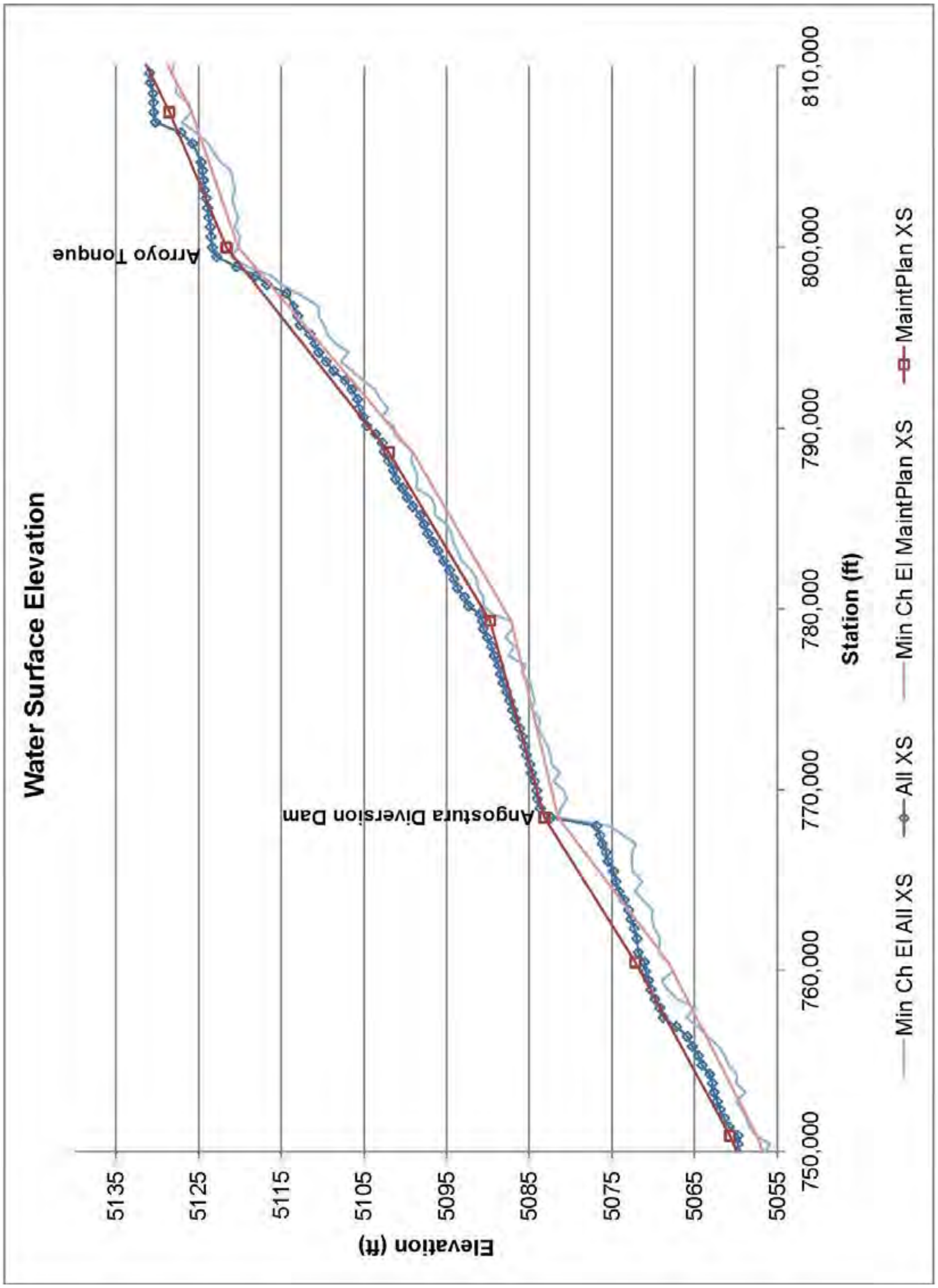


Figure B2.7. Longitudinal profile near Angostura Diversion Dam and Arroyo Tonque.

There are 98 cross sections considered in this comparison of WSE developed from all of the 2002 cross sections and from the representative cross sections. The differences in WSE as presented in figure B2.4 are summarized by range in table B2.2.

Table B2.2. Difference in Water Surface Elevation by Range and by Discharge

Difference (ft)	1,500 cfs	3,000 cfs	4,500 cfs
±0.5	74%	73%	69%
±1.0	95%	94%	92%
±1.5	98%	98%	97%
±2.0	100%	100%	100%

Figure B2.8 presents a plot of reach-averaged hydraulic depth based on the 2002 geometry for three discharges along with the difference in depth based on using the representative cross sections. The difference in reach-averaged hydraulic depth for the three discharges is ±0.25 ft for all reaches except Rio Puerco to San Acacia, where the difference is within ±0.5 ft, which is insignificant compared to the accuracy of the survey data.

Figure B2.9 likewise presents a plot of reach-averaged velocity based on the 2002 geometry for three discharges along with the difference in velocity based on using the representative cross sections. The difference in reach-averaged channel velocities between the two geometry datasets is ±0.5 foot per second (ft/s) for all reaches and all profiles except in Reach 4 (Rio Puerco to San Acacia Diversion Dam) and the Reach 6 (Arroyo de las Cañas to San Antonio Bridge). The difference in channel velocity is between -1 and 0 ft/s for these two reaches. These differences are reasonable based on the accuracy of the survey data.

2.2.2 Adjustments to Width and Thalweg Elevation

The active channel planform was digitized from aerial photographs flown in 2006. This quantified the on-ground observations of channel narrowing that occurred between 2002 and 2006 (figure B2.10). The 105 cross sections selected to represent the Middle Rio Grande were adjusted in terms of width to better represent the current river geometry. Similarly, a longitudinal river profile was surveyed in 2007, and the results of the longitudinal survey were incorporated into the geometry by adjusting cross-section elevations to better match current channel conditions (figure B2.11).

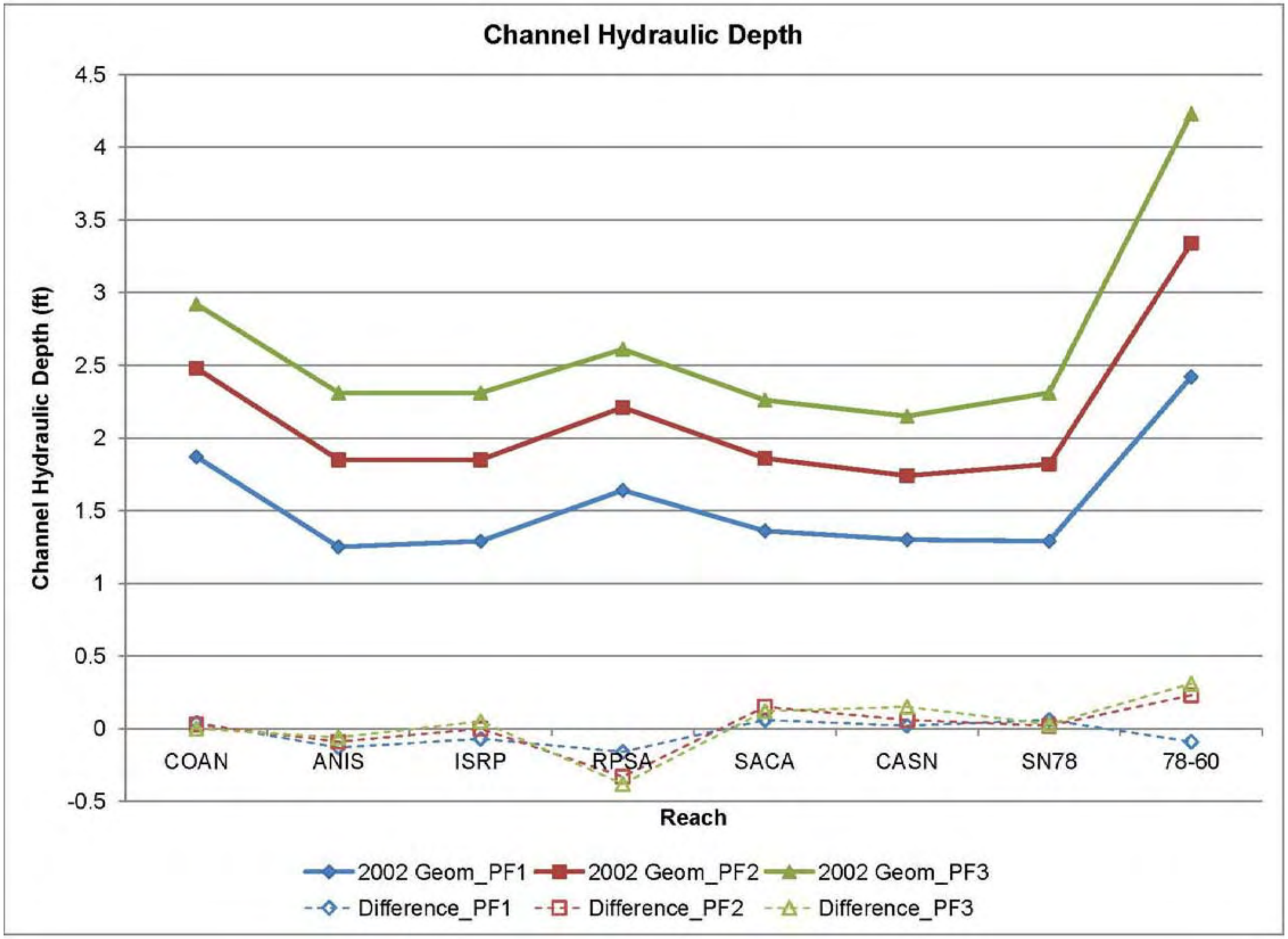


Figure B2.8. Reach average hydraulic depth based on using 2002 geometry and the difference in depth based on the using the representative cross sections.

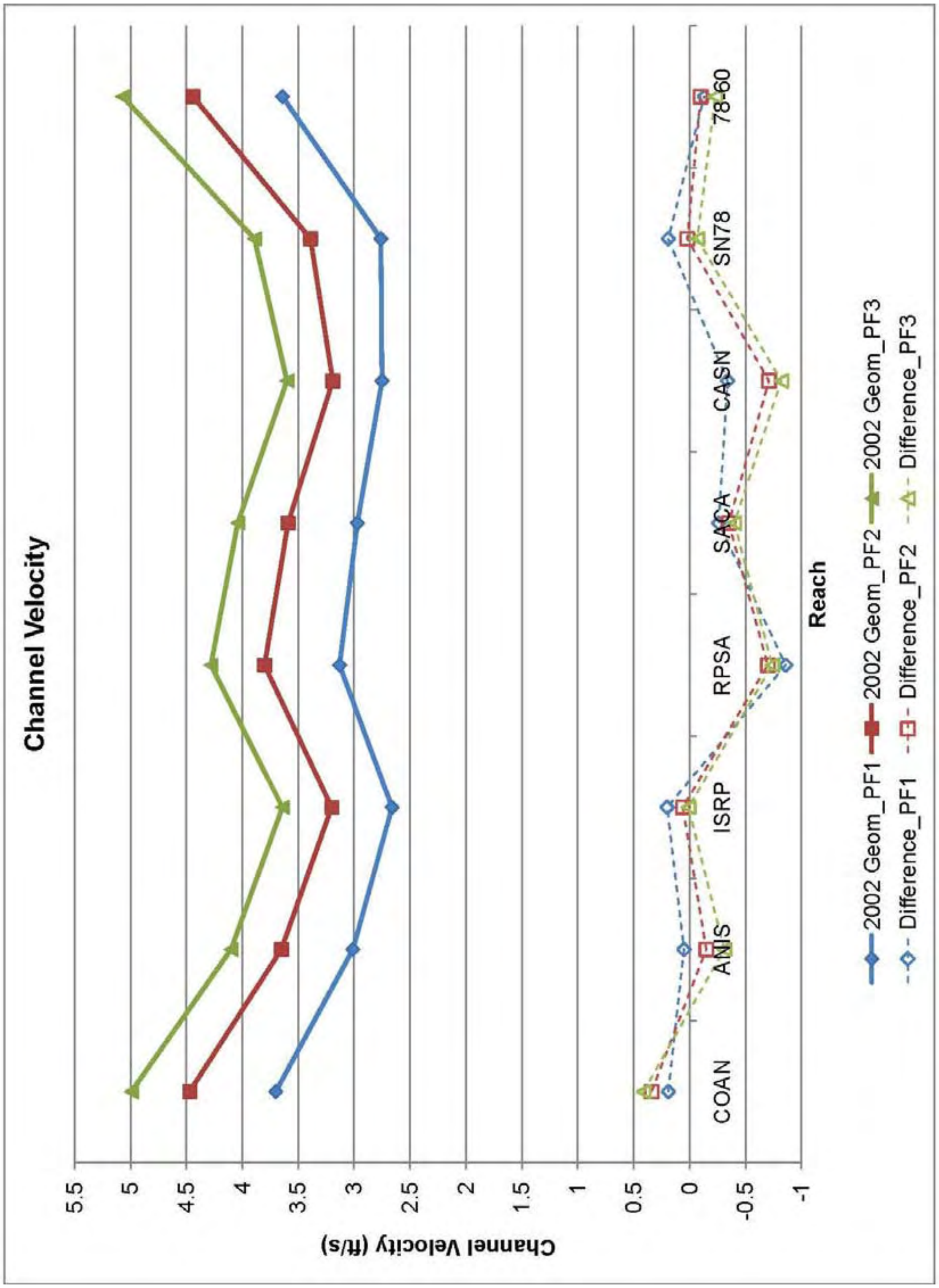


Figure B2.9. Reach average velocity based on using 2002 geometry and the difference in velocity based on the using the representative cross sections.

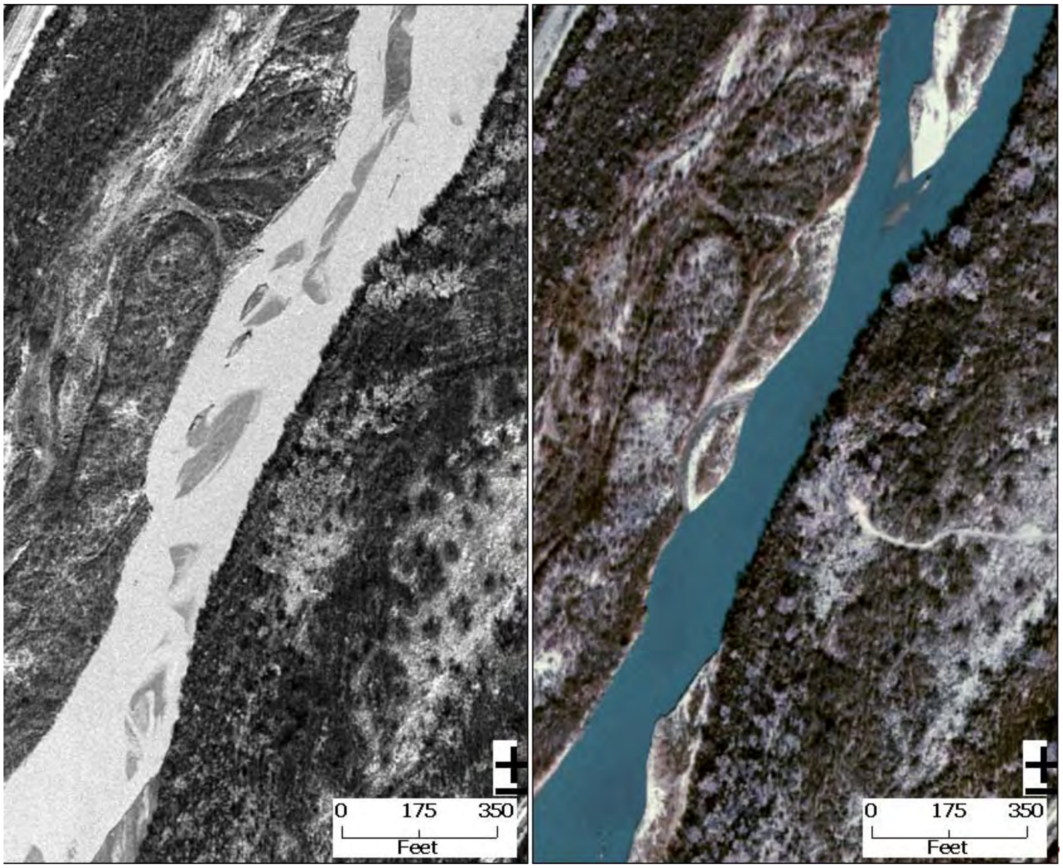


Figure B2.10. Width change from 2002 (left) to 2006 (right), approximately 1 mile upstream of Arroyo de Los Alamos near RM 125.

Using the 105 cross sections in HEC-RAS (Brunner 2008) and running a variety of flows produced model instabilities in this fixed-bed model, which would also yield instabilities in a mobile-bed model such as SRH-1D. The instability occurring in HEC-RAS of most concern was when the energy equation could not be solved and the program defaulted to critical depth at that cross section. These instabilities were mitigated by interpolating cross sections, which are not meant to represent the geometry of the river, but are used solely for numerical stability.

2.2.3 Baseline Geometry

More agg/deg lines could be included in the model, but this would not necessarily increase numerical stability. Interpolating cross sections so that the maximum spacing between cross sections (original or interpolated) did not exceed 5,280 feet led to model stability. The only exception to this was between the cross sections just upstream and just downstream from San Acacia Diversion Dam, where the maximum cross-section spacing was limited to 2,640 feet. This yielded a total of 129 interpolated cross sections, making the number of cross sections (interpolated and original) sum to 234.

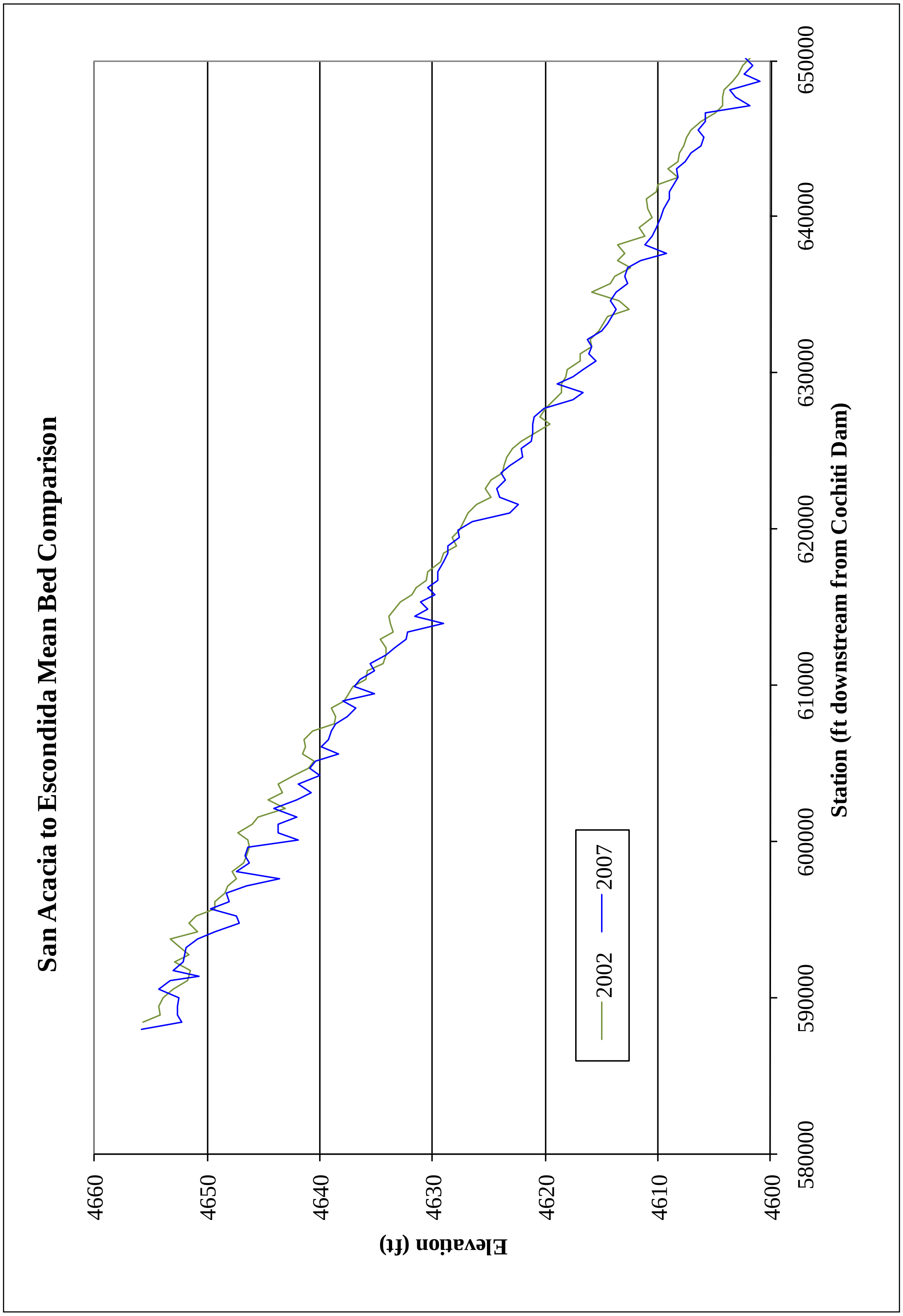


Figure B2.11. Bed elevation change from 2002 to 2007, San Acacia Diversion Dam to Escondida.

In summary, the baseline geometry for this modeling effort is comprised of 105 agg/deg lines from 2002 photogrammetry, which were then adjusted for width changes and elevation changes as well as an additional 129 interpolated cross sections for numerical stability purposes. The average cross-section spacing from Cochiti Dam to Elephant Butte Reservoir, including interpolated cross sections, is about 4,450 feet.

2.3 Bed Sediment Size

There is a fairly well distributed collection of sediment gradations on the river spatially (figure B2.12) and temporally (figure B2.13) from the various projects conducted on the Middle Rio Grande. The date and location of the bed material samples collected highly depends on the project and the purpose within that project. A total of 78 grain size distributions based on existing sediment samples was applied to 78 of the original 105 cross sections (see section 2.2) based on the spatial location of the sample, with the result being a collection of bed material gradations along the Middle Rio Grande. Figure B2.14 presents a summary of the reach lengths, number of sediment samples per reach, and the resulting average sediment sample spacing per reach.

These 78 grain size distributions were redefined to have a consistent set of 13 grain size bins, as needed by the model, and these 13 phi-class size bins (American Society of Civil Engineers [ASCE] 2008) ranged from coarse silts to large cobble. Although the Middle Rio Grande is historically a sand-dominated system, more gravel has been observed in recent years, and large gravel and cobble deposits exist at the mouths of some tributaries. This modeling effort attempts to consider the full range of grain sizes present on the river by location. SRH-1D has an interpolation scheme that uses upstream and downstream data to develop grain size distributions for cross sections without a specified gradation. This was used for the 27 of the original 105 cross sections that did not have grain size distributions assigned to them as well as for all 129 cross sections that were interpolated in HEC-RAS for numerical stability.

2.4 Sediment Transport Relationship

With the hydrology, geometry, and bed sediment size data preprocessed, the next step was to determine the relationship between water discharge and sediment discharge (transport equation) that was most appropriate for the Middle Rio Grande. This process was expedited by use of an in-house program, Sedimentation and River Hydraulics Capacity Model (SRH-Capacity) (Huang et al. 2009). This program is essentially a stripped down version of SRH-1D, in which hydraulic parameters are coupled with grain size distributions

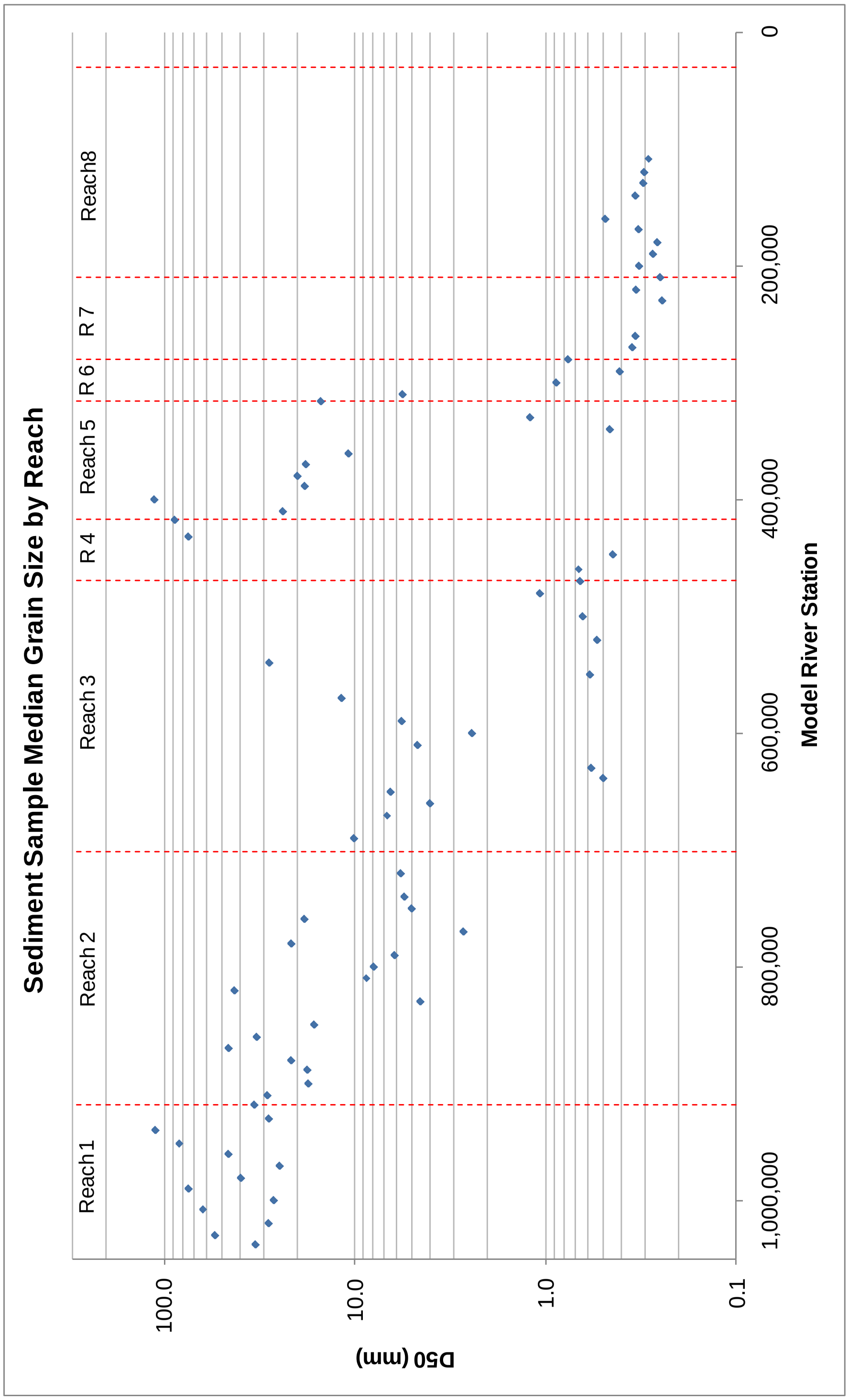


Figure B2.12. Median grain size (D50) for the sediment samples used in the SRH-1D model by reach.

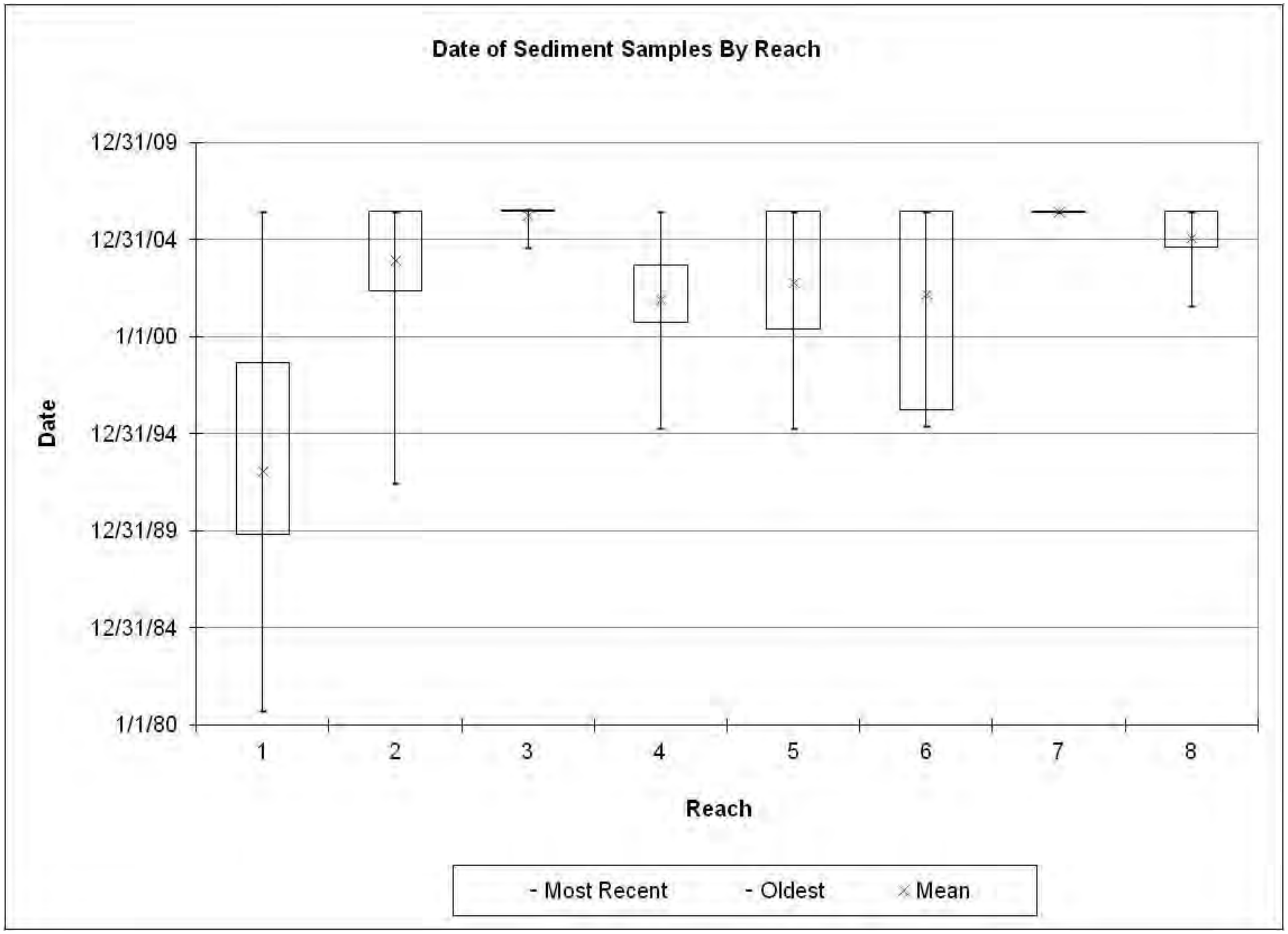


Figure B2.13. Temporal distribution of sediment samples by reach.

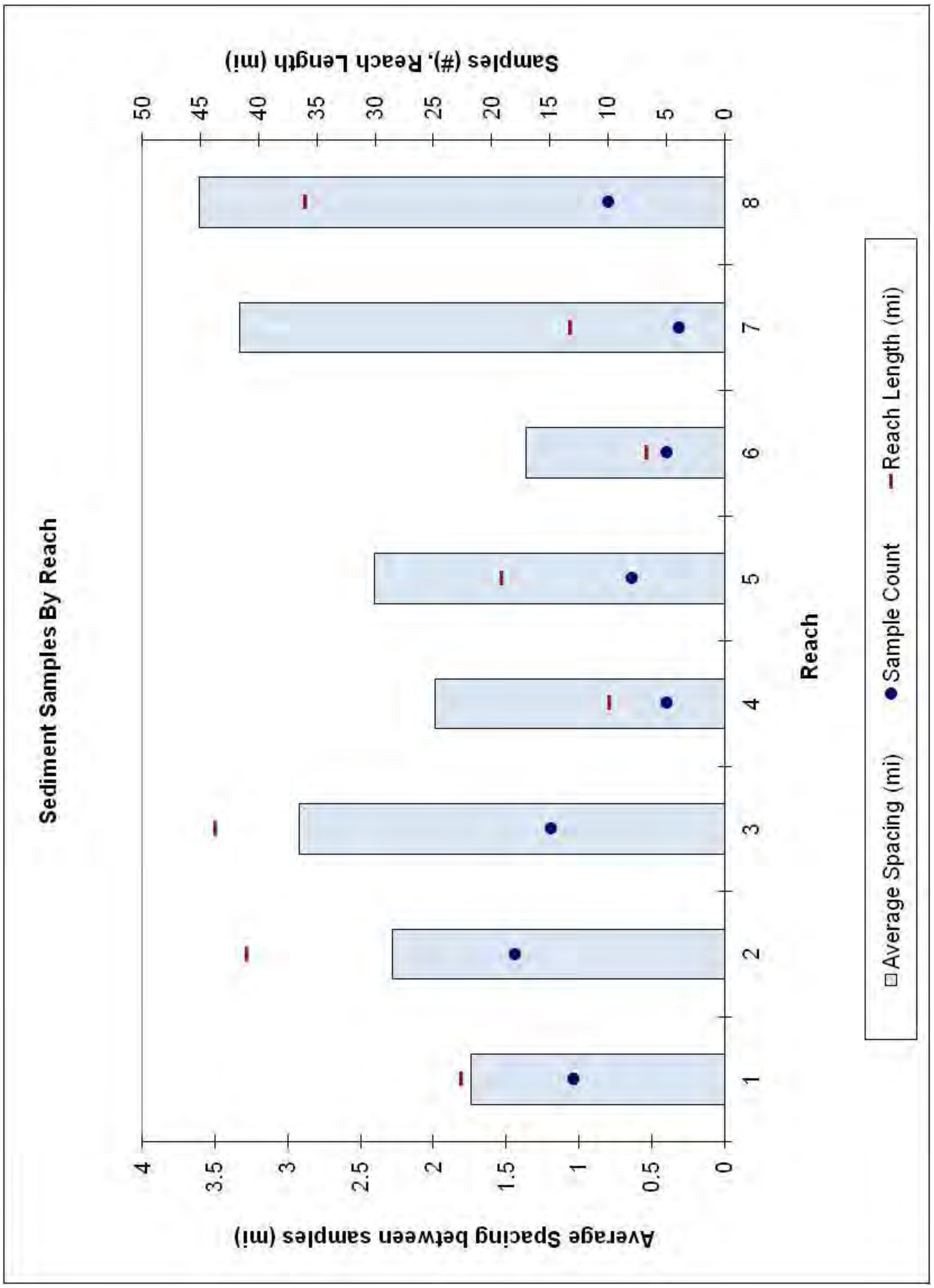


Figure B2.14. Sediment sample count, reach length, and resulting average sample spacing.

and a sediment transport equation to yield a relationship between flow discharge and sediment transport capacity, but where sediment is not routed from one cross section to the next.

Suspended sediment concentration, velocity, and hydraulic geometry are used in conjunction with the Bureau of Reclamation Automated Modified Einstein Procedure (BORAMEP) (Holmquist-Johnson et al. 2009) to estimate the total load at three gauges on the Middle Rio Grande:

- Albuquerque (08330000)
- San Acacia (08354900)
- San Marcial (08358400)

Total sediment discharge (tons/day) was then plotted as a function of flow discharge (cfs) for each gauging station. This relationship between sediment discharge and flow discharge is used to assess the appropriateness of the transport equation. The range of discharges run through SRH-Capacity is reflective of the water year 1975, so the discharges do not span the domain of discharges associated with the stream gauge measurements.

A variety of transport equations were run on the reach-averaged hydraulics for a variety of discharges in SRH-Capacity along with a reach-averaged grain size distribution. The transport equations considered were Engelund-Hansen (EH), Wilcock and Crowe (2003), Parker (1990), Wu (2000), and Yang’s 1979 sand and 1984 gravel. Two additional transport equations were also run: one that coupled EH with Parker and one that coupled EH with Wilcock and Crowe. These coupled equations were developed and implemented in the SRH-Capacity program (as well as in SRH-1D). The program decides which equation to use based on a combination of grain size and applied shear stress. The program chooses either the EH or Parker (or Wilcock and Crowe 2003) equation to calculate the sediment transport capacity (Huang et al. 2007). Parker coupled with EH (Parker-EH) showed the most agreement with the BORAMEP data.

The last step was to determine the most appropriate transport coefficients: specifically, the reference shear stress and hiding factor (Parker 1990). The default values, which were developed based on a dataset for a gravel bed river, are approximately 0.04 and 0.9 for the reference shear stress and hiding factor, respectively. The transport coefficients were calibrated to the BORAMEP data to better reflect the finer grain sizes present in the Middle Rio Grande relative to the dataset for which the default parameters were developed.

Figures B2.15–B2.17 show plots of the BORAMEP data along with results from SRH-Capacity for a variety of combinations of reference shear stress and hiding factor at the three measurement gauges listed above. The reference shear stress varied from 0.02 to 0.05, and the hiding factor varied from 0.2 to 0.95. For the

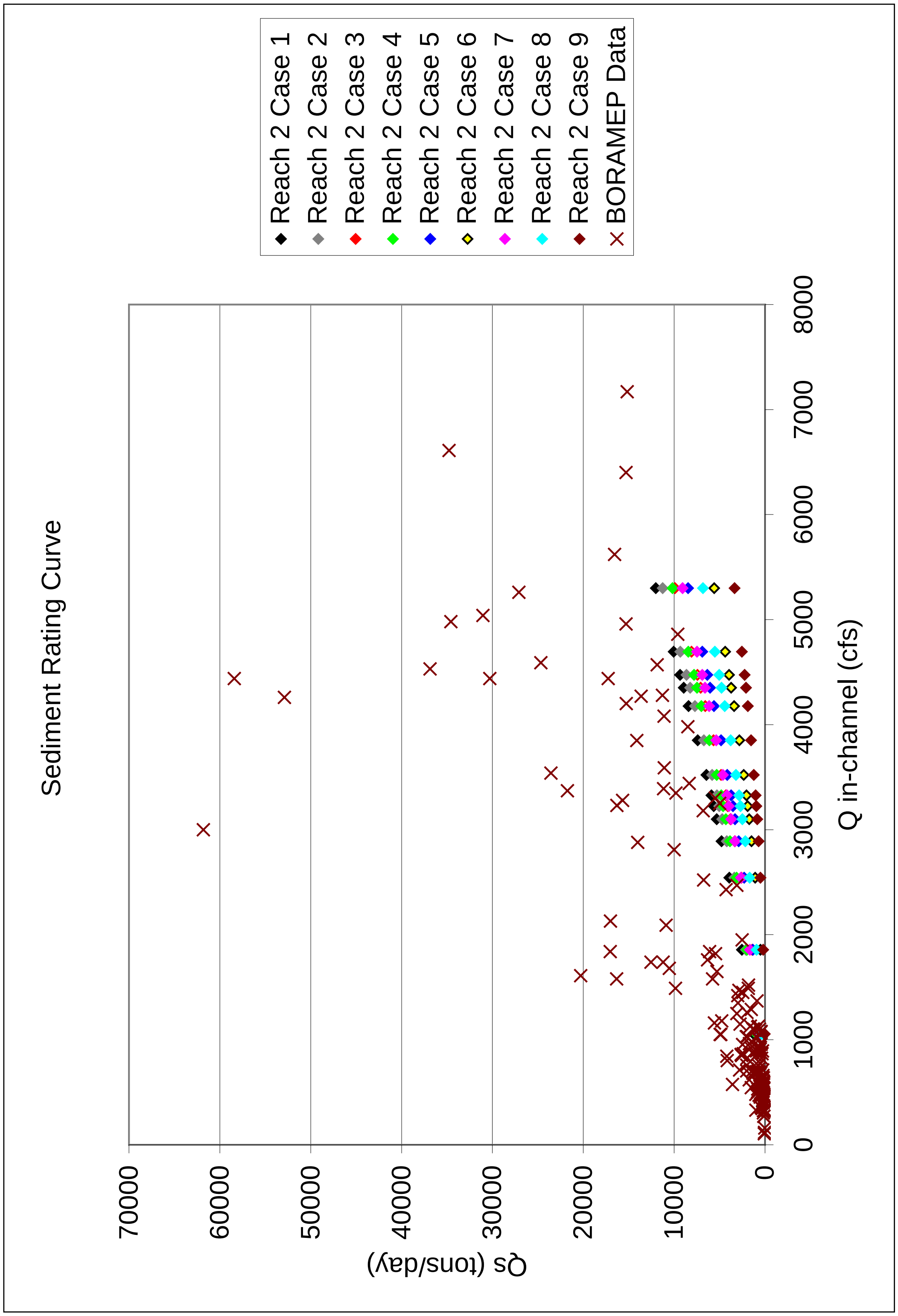


Figure B2.15. Albuquerque gauge BORAMEP data with Parker-EH.

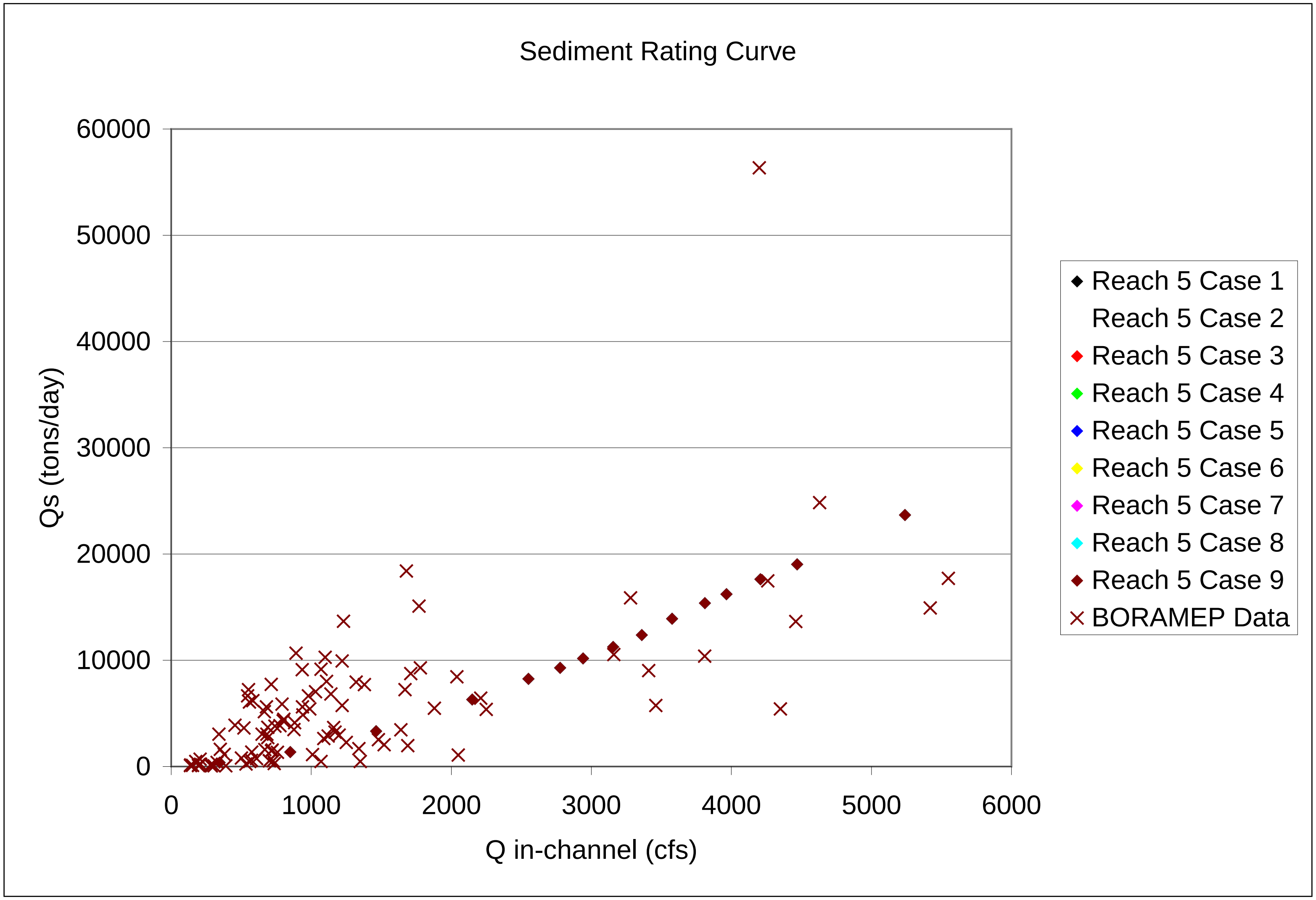


Figure B2.16. San Acacia gauge BORAMEP data with Parker-EH.

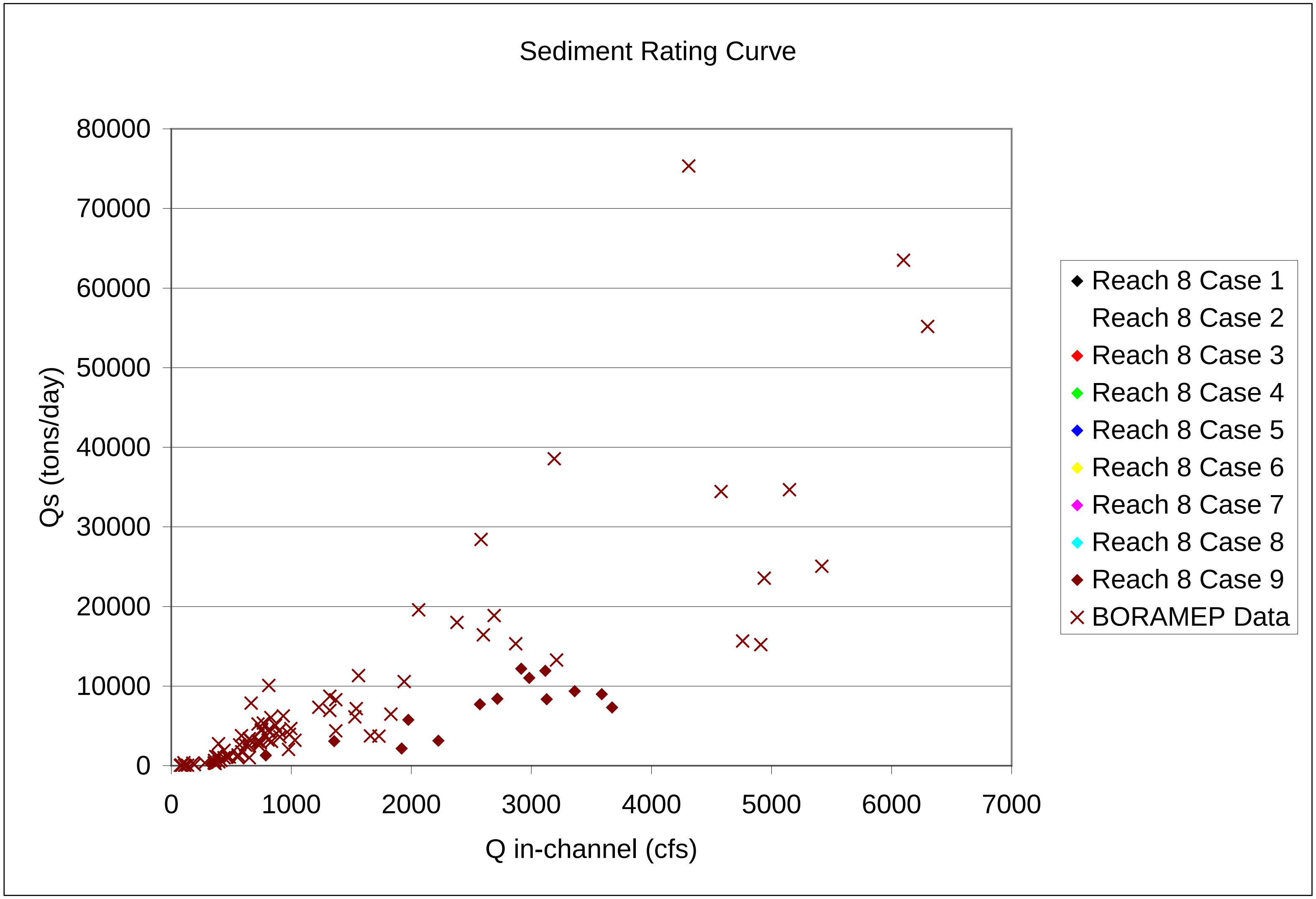


Figure B2.17. San Marcial gauge BORAMEP data with Parker-EH.

Albuquerque gauge, which is in Reach 2 (Angostura Diversion Dam to Isleta Diversion Dam), figure B2.15 shows that "Case 1," which is a reference shear stress of 0.02 and a hiding factor of 0.2, has the best agreement with the BORAMEP data. Figure B2.15 shows that "Case 1" fails to represent the central tendency of the BORAMEP data. As BORAMEP is a prediction of total load and Parker is a bed load estimate, the underprediction is to be expected. For both the San Acacia gauge (Reach 5) (figure B2.16) and the San Marcial gauge (Reach 8) (figure B2.17), the Parker-EH equation defaulted to the EH equation (due to grain size and applied shear stress), which is why the different cases fall atop each other, as they are not dependent on the Parker equation's transport coefficients. The EH equation is a bed material load equation and appears to match the BORAMEP data fairly well above about 2,000 cfs, but underpredicts the BORAMEP data below 2,000 cfs. It is likely that the discrepancy is due to the fact that at low flows a significant portion of the total load is wash load, which would not be captured by a bed material load such as EH. At higher flows, the wash load is not a significant portion of the total load, and the bed material load is well predicted by EH. Thus, the transport equation used in SRH-1D is Parker-EH, with a reference shear stress of 0.02 and a hiding factor of 0.2.

3 SRH-1D Modeling

The preprocessing outlined above covers the majority of data inputs for the SRH-1D model, which are summarized below.

The mean daily values for water year 1975 are a quasi-steady state representation of the gauge record data for the Middle Rio Grande. Using a year-long hydrograph provides flow variability (unlike using a single representative discharge), and repeating that single year hydrograph increases the likelihood of reaching a dynamic equilibrium bed slope and elevation in the model (section 2.1).

The geometry data of 234 cross sections is based on 105 representative sections and 129 interpolated cross sections incorporated to increase numerical stability. The 105 representative cross sections were developed from 2002 photogrammetric cross sections, which were adjusted in terms of channel width digitized from 2006 aerial photographs and adjusted in terms of elevation based on a 2007 longitudinal profile (section 2.2).

The 78 bed material grain size distributions were applied to 78 of the 105 representative cross sections, and the grain size distributions for the rest of the cross sections were populated by an interpolation scheme within SRH-1D (section 2.3).

The Parker transport equation coupled with the EH transport equation (Parker-EH) as implemented within SRH-1D with a reference shear stress of 0.02 and a hiding factor of 0.2, was found to show the best fit to the sediment discharge BORAMEP data. This coupled equation allows for a consistent transport equation to be used continuously across the entire solution domain from Cochiti Dam to Elephant Butte Reservoir. Additional model inputs need to be specified to run SRH-1D, which are discussed below.

3.1 Additional Inputs and Model Assumptions

A specified time step is needed to dictate how frequently the model adjusts the cross-sectional geometry (erosion/deposition) and re-calculates hydraulics at each cross section. Short time steps yield long simulation times while longer time steps potentially yield an unstable model. The time step was decreased incrementally until the model results were stable such that the largest time step was used which produced model stability. The optimum time step was found to be one-tenth of a second.

Fine material (smaller than 0.063 millimeter [mm]) was included in this modeling effort, as fine materials in large part dictate the properties in the downstream portion of the Middle Rio Grande, particularly those areas influenced by Elephant Butte Reservoir. Fine material sediment routing cannot be estimated by transport equations as the electrochemical forces dominate the gravitational forces experienced by the particle. To model fine sediment routing, it is necessary to specify some additional parameters that deal with the erosion and depositional rates, the associated shear stresses, fall velocities, dry bulk densities, and consolidation rates. Vermeyen (1995) performed a series of tests on samples taken from Elephant Butte Reservoir, and the erosion and depositional properties were derived based on the results of this report. These fine sediment parameters were applied to the reaches from Arroyo de las Cañas to Elephant Butte Reservoir, and the upstream parameters were set so that there was no deposition of fine sediment, as field observations indicate fines generally act as wash load in the upstream reaches.

Exner sediment routing (see Huang et al. 2007) was used, which ignores changes in suspended sediment concentration over time. Assuming that changes to the volume of sediment in suspension are much smaller than the changes to the volume of sediment in the bed is "generally true for long-term simulations where steady flow is being simulated" (Huang et al. 2007).

The downstream boundary condition for the model was a fixed water surface elevation, representing the pool elevation of Elephant Butte Reservoir. Although this elevation will vary in time, the number of possible sequences of wet and dry years (and associated water surface elevations) for the next 60 years represents a number of simulations that are outside the scope of this study. It was decided to use the average water surface elevation from 2008 and assume that this represents the water surface elevation for the entire simulation period. Statistically, 51 percent of the years since the closing of Elephant Butte in 1916 have had higher average water surface elevation than the average water surface elevation for 2008. Since the closing of Cochiti in 1973, 66 percent of the years have had higher average water surface elevations than the water surface elevation for 2008.

There is a large number of tributary rivers and arroyos along the Middle Rio Grande. Previous Bureau of Reclamation (Reclamation) studies (Bauer et al. 2006; Holmquist-Johnson 2004; and Huang et al. 2005) identified 20 tributaries that have historically supplied significant flow to the Middle Rio Grande. Only the North Albuquerque Metropolitan Arroyo Flood Control Authority floodway tributary does not contribute sediment because a sediment exclusion feature exists on this tributary before the flow enters the Rio Grande. Five of the 20 tributaries have flow gauges on them, and the remaining 15 tributaries are ungauged. Flow and sediment volumes from the 15 ungauged tributaries were based on drainage area and the Modified Universal Soil Loss Equation. These initial estimates were then adjusted as part of the calibration effort of the previous studies.

Additionally, part of the previous modeling calibration included creating a hydrograph ranging from 3 to 8 days long to represent the yearly flow volume and sediment load for each ungauged tributary (Bauer et al. 2006, Holmquist-Johnson 2004, Huang et al. 2005). Figure B3.1 shows the yearly flow volume (acre-ft) supplied by the tributaries (upstream to downstream) to the Middle Rio Grande.

In addition, estimated diversions at Angostura Diversion Dam and Isleta Diversion Dam were simulated to reflect the reduction of in-channel flows due to irrigation practices in the Rio Grande Valley. Figure B3.2 shows the tributaries and the associated yearly volumes of sediment supplied to the Middle Rio Grande. Figure B3.3 shows the yearly sediment supply volumes by size class, excluding fines (material smaller than 0.0625 mm).

3.2 Modeling Results

Eight of the 11 reaches for the Middle Rio Grande (between Cochiti Dam and Elephant Butte Reservoir) as described in section 2 were modeled. For the remainder of this document, the reaches as outlined in table B3.1 will be referred to by this model numbering scheme. Due to the cross-section spacing, the approximate reach lengths listed in table B3.1 may be a mile or two off from the listed RM denotations in section 2.

Table B3.1. Reach Definitions for the Numerical Modeling of the Middle Rio Grande

Model Reach Number	Descriptive Name	Approximate Length (RM)
1	Cochiti Dam to Angostura Diversion Dam	22.7
2	Angostura Diversion Dam to Isleta Diversion Dam	41.0
3	Isleta Diversion Dam to Rio Puerco	43.8
4	Rio Puerco to San Acacia Diversion Dam	9.9
5	San Acacia Diversion Dam to Arroyo de las Cañas	19.2
6	Arroyo de las Cañas to San Antonio Bridge	6.8
7	San Antonio Bridge to River Mile 78	13.3
8	River Mile 78 to Elephant Butte Reservoir	36.1

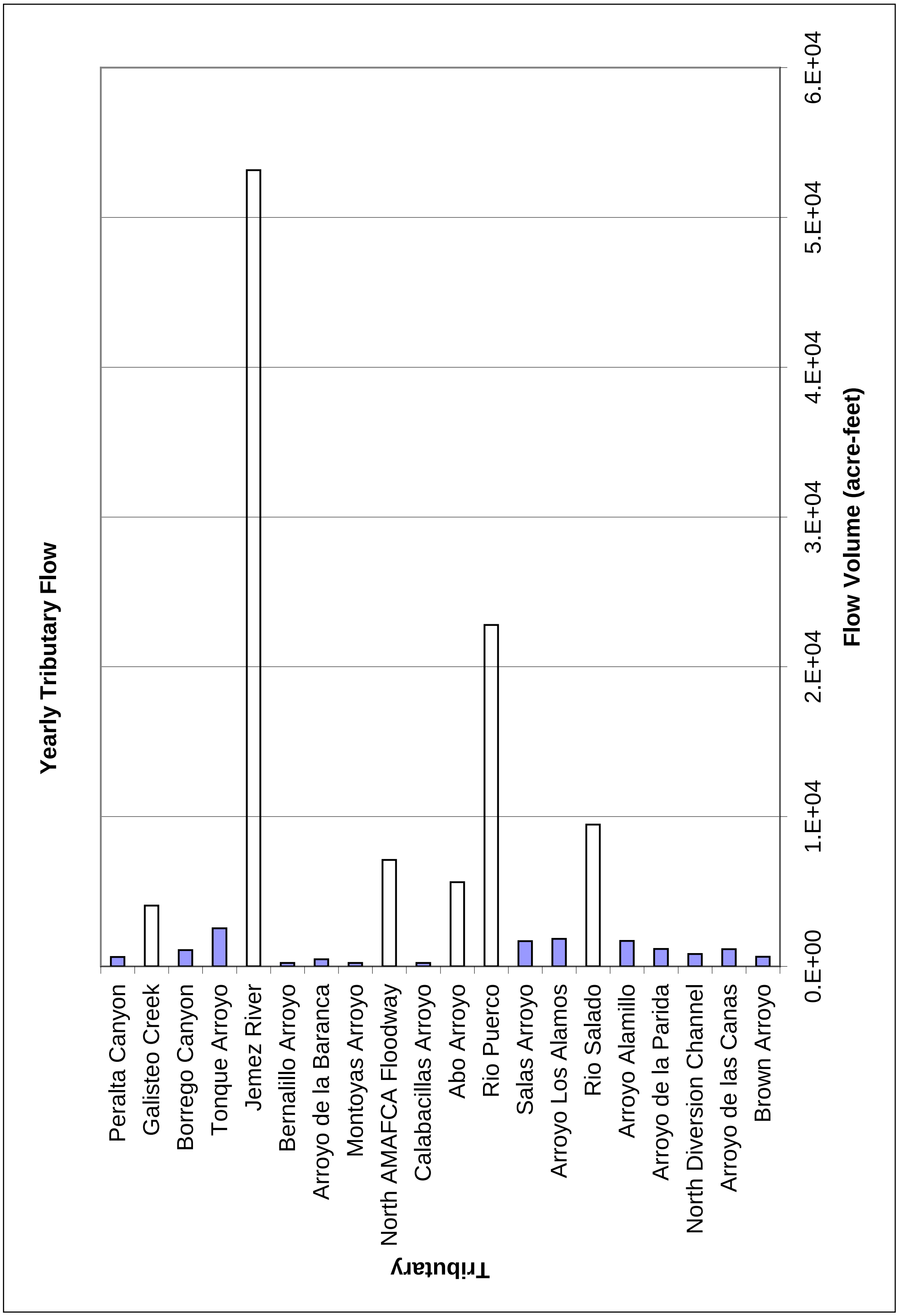


Figure B3.1. Cumulative yearly volume of water supplied by tributaries.

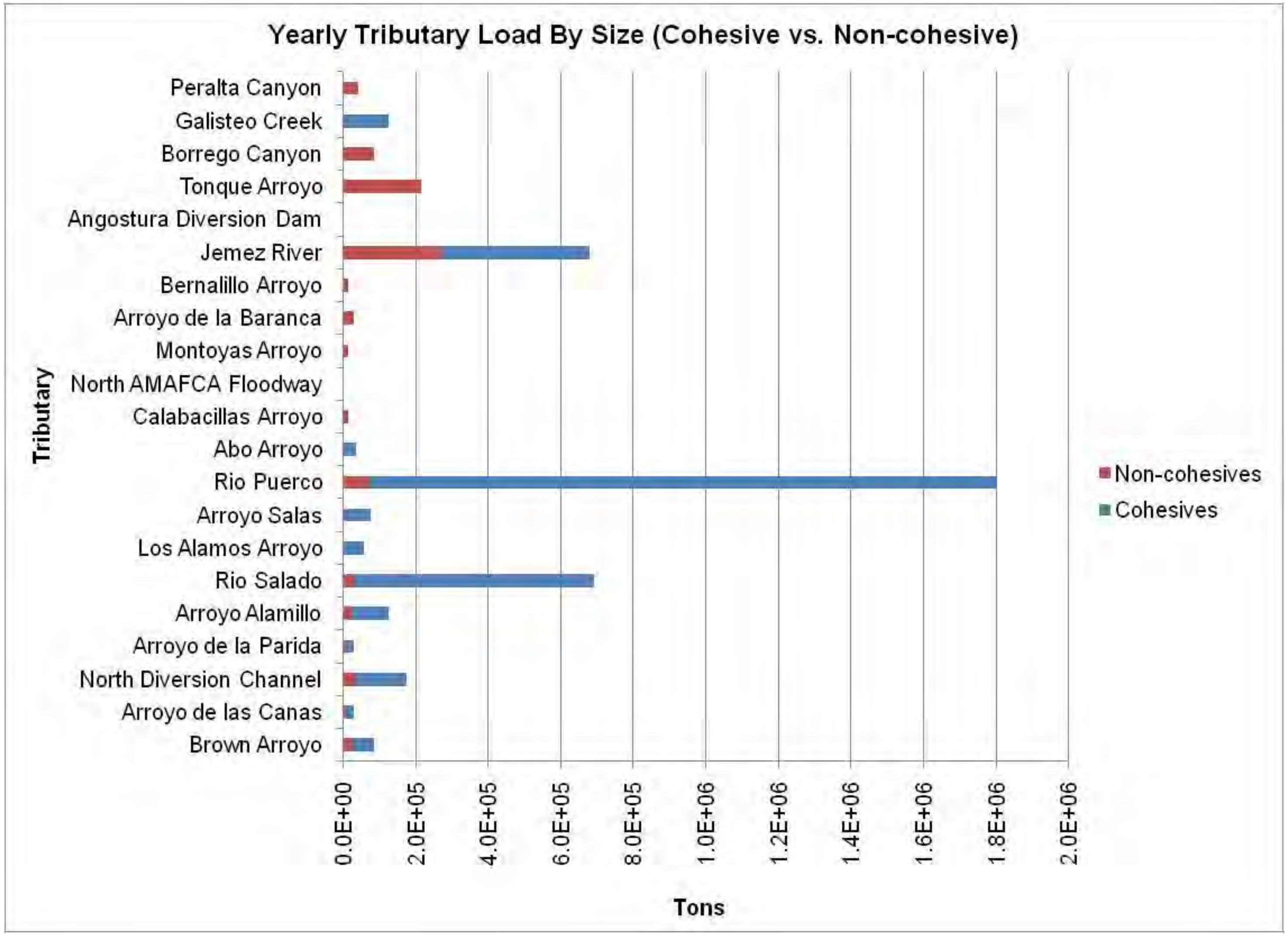


Figure B3.2. Yearly sediment supplied to the Middle Rio Grande by tributaries.

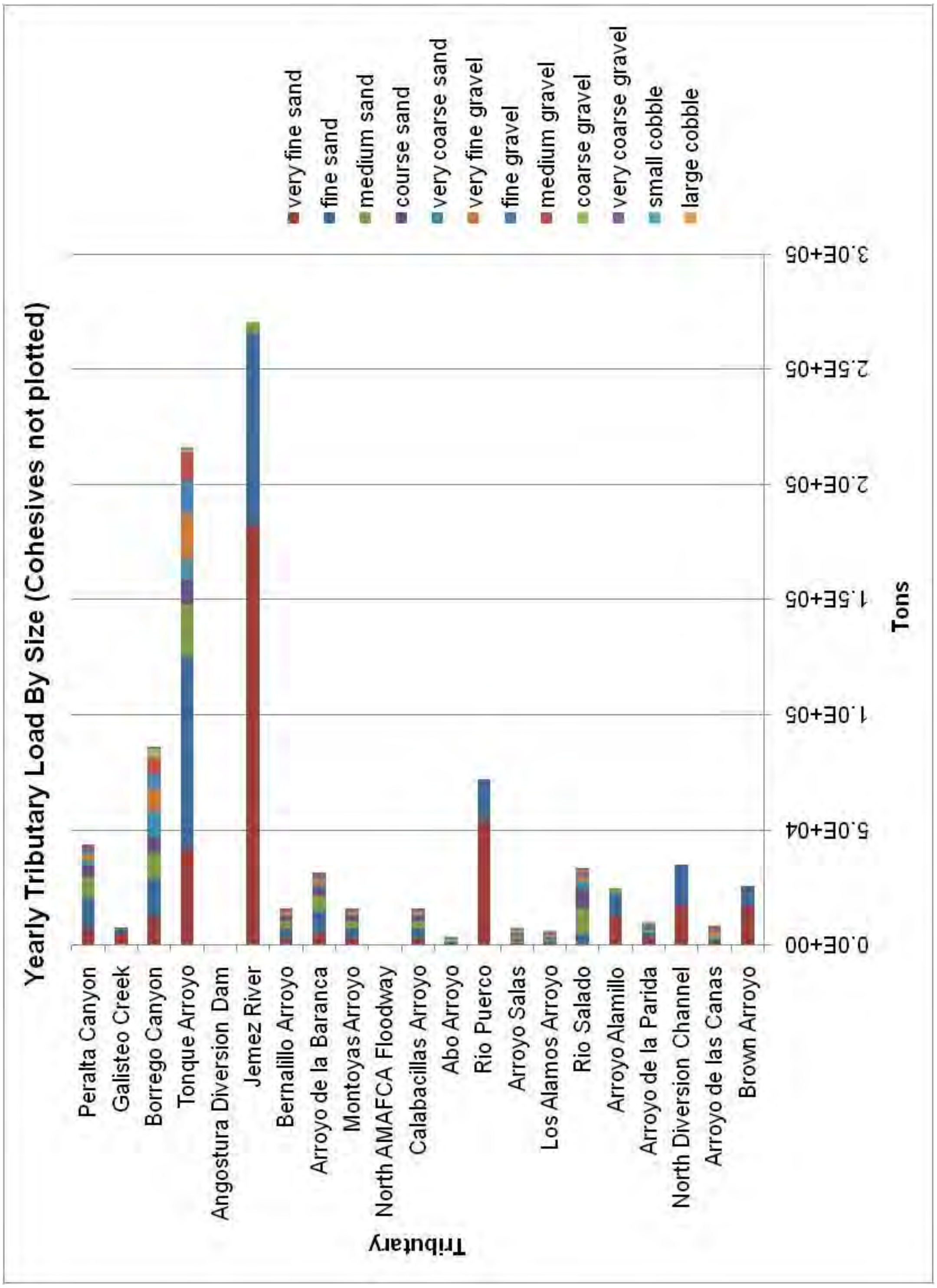


Figure B3.3. Yearly sediment supply from tributaries without fines plotted for clarity.

The SRH-1D model converged in a simulation period of approximately 60 years. Two parameters were used to determine model convergence: (1) volume of material deposited in a reach and (2) reach-averaged slope. For both parameters, the values at a given year (i) were compared to the values at the previous year (i-1). Figures B3.4 and B3.5 show the convergence plots (by reach) for depositional volume and for slope, respectively.

In general, the model results show minimal change in bed elevation for the Middle Rio Grande from Cochiti Dam down to about the North Diversion Channel, RM 102.5 (figures B3.6–B3.8). The Middle Rio Grande from about the North Diversion Channel downstream to about RM 78 is depositional (figure B3.9), and from RM 78 downstream to Elephant Butte Reservoir, the results show some degradation upstream, which gets deposited downstream. Reach 8 (River Mile 78 to Elephant Butte Reservoir) is defined in large part on the influence of Elephant Butte Reservoir. Recall that the assumed fixed water surface at Elephant Butte Reservoir is a relatively low pool elevation.

The resulting reach-averaged slopes and depositional volumes are presented in table B3.2. Erosion is represented as a negative depositional volume.

Table B3.2. Reach-Averaged Equilibrium Slope and Depositional Volume from the SRH-1D Model

Reach	Description	Slope (ft/ft)	Depositional Volume (tons/year/mile)
1	Cochiti Dam to Angostura Diversion Dam	0.00118	1,414
2	Angostura Diversion Dam to Isleta Diversion Dam	0.00088	-409
3	Isleta Diversion Dam to Rio Puerco	0.00077	-1,404
4	Rio Puerco to San Acacia Diversion Dam	0.00076	2,768
5	San Acacia Diversion Dam to Arroyo de las Cañas	0.00078	3,973
6	Arroyo de las Cañas to San Antonio Bridge	0.00084	48,001
7	San Antonio Bridge to River Mile 78	0.00071	19,970
8	River Mile 78 to Elephant Butte Reservoir	0.00051	-2,270

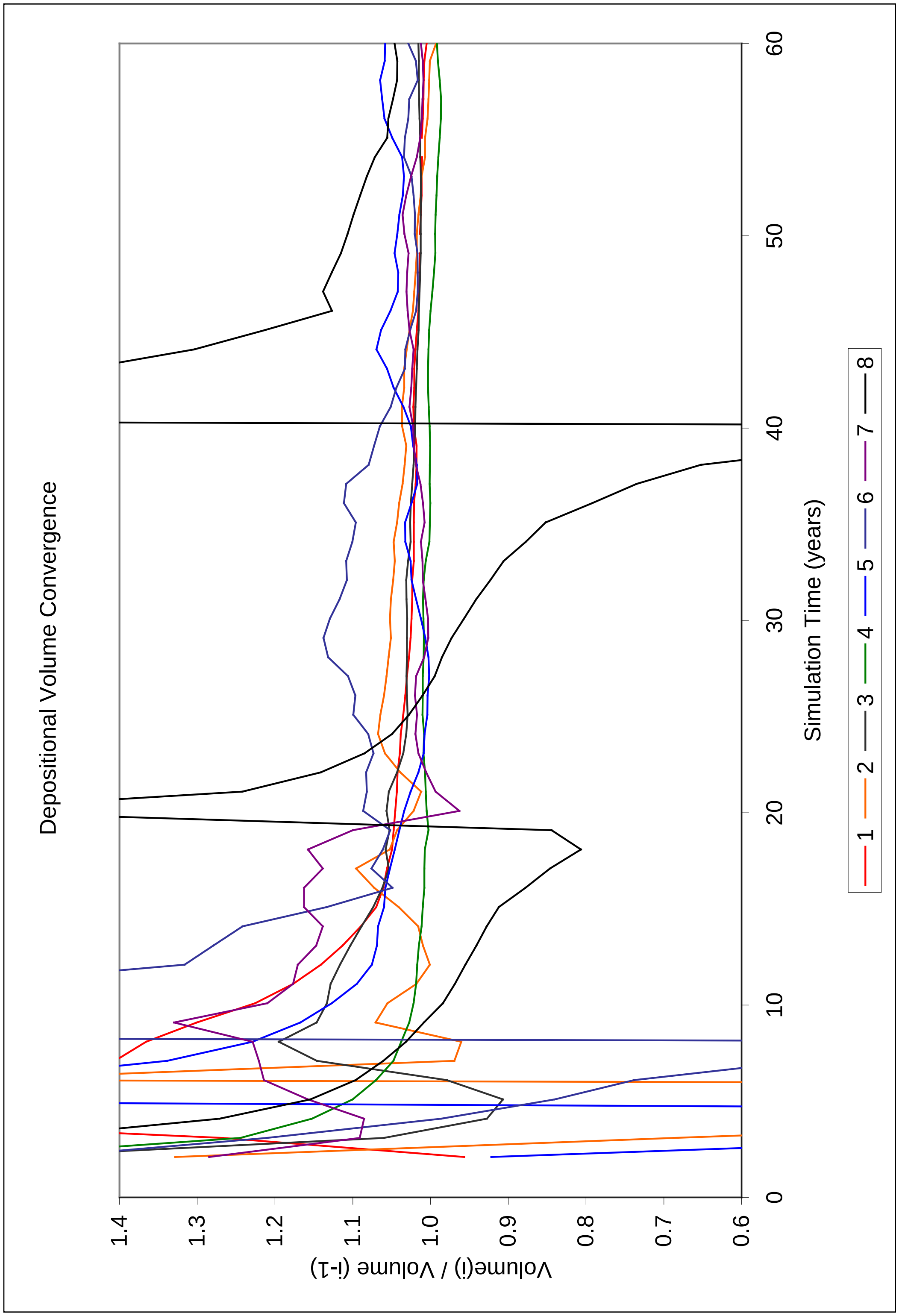


Figure B3.4. Convergence plot for depositional volume.

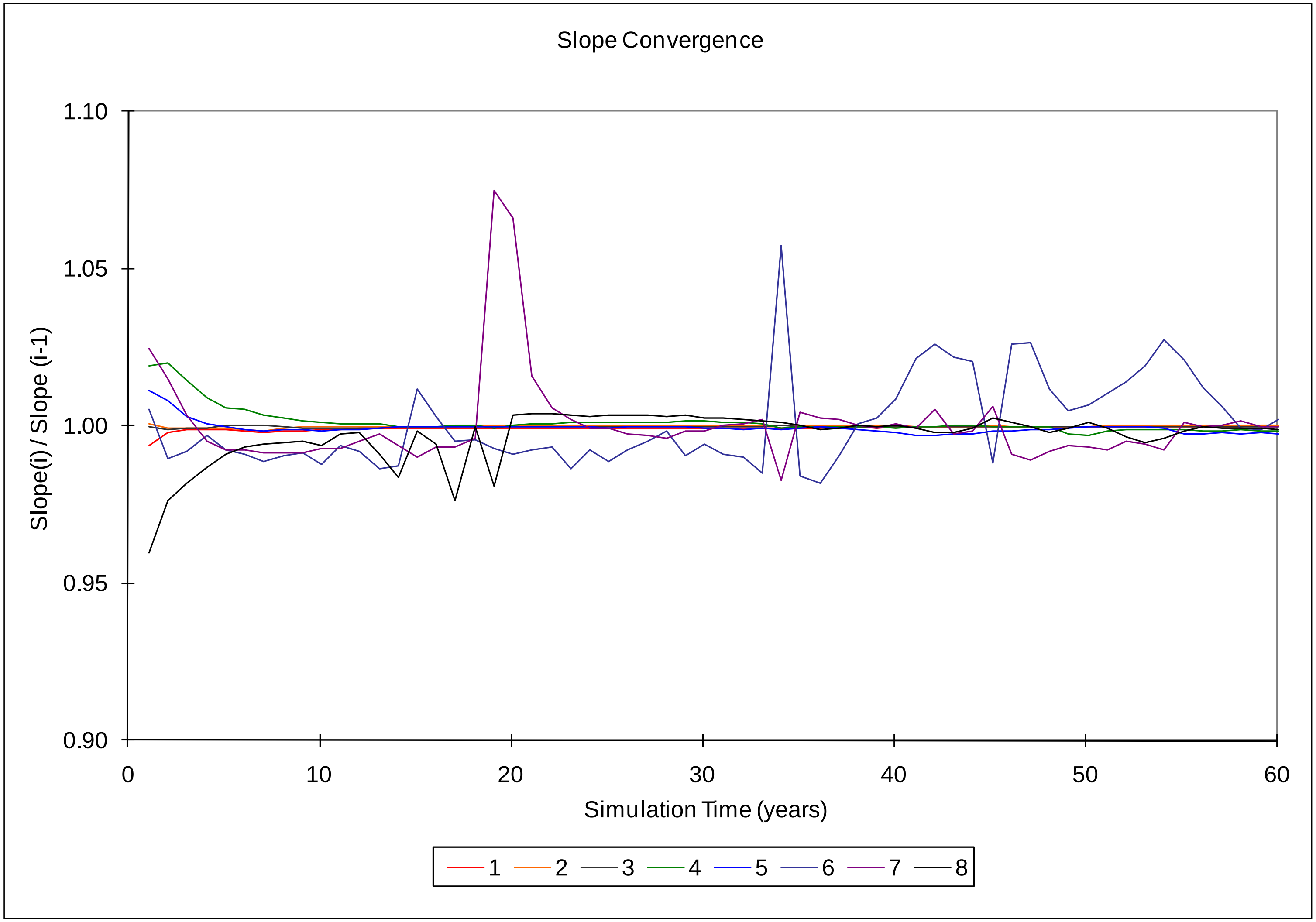


Figure B3.5. Convergence plot for reach slope.

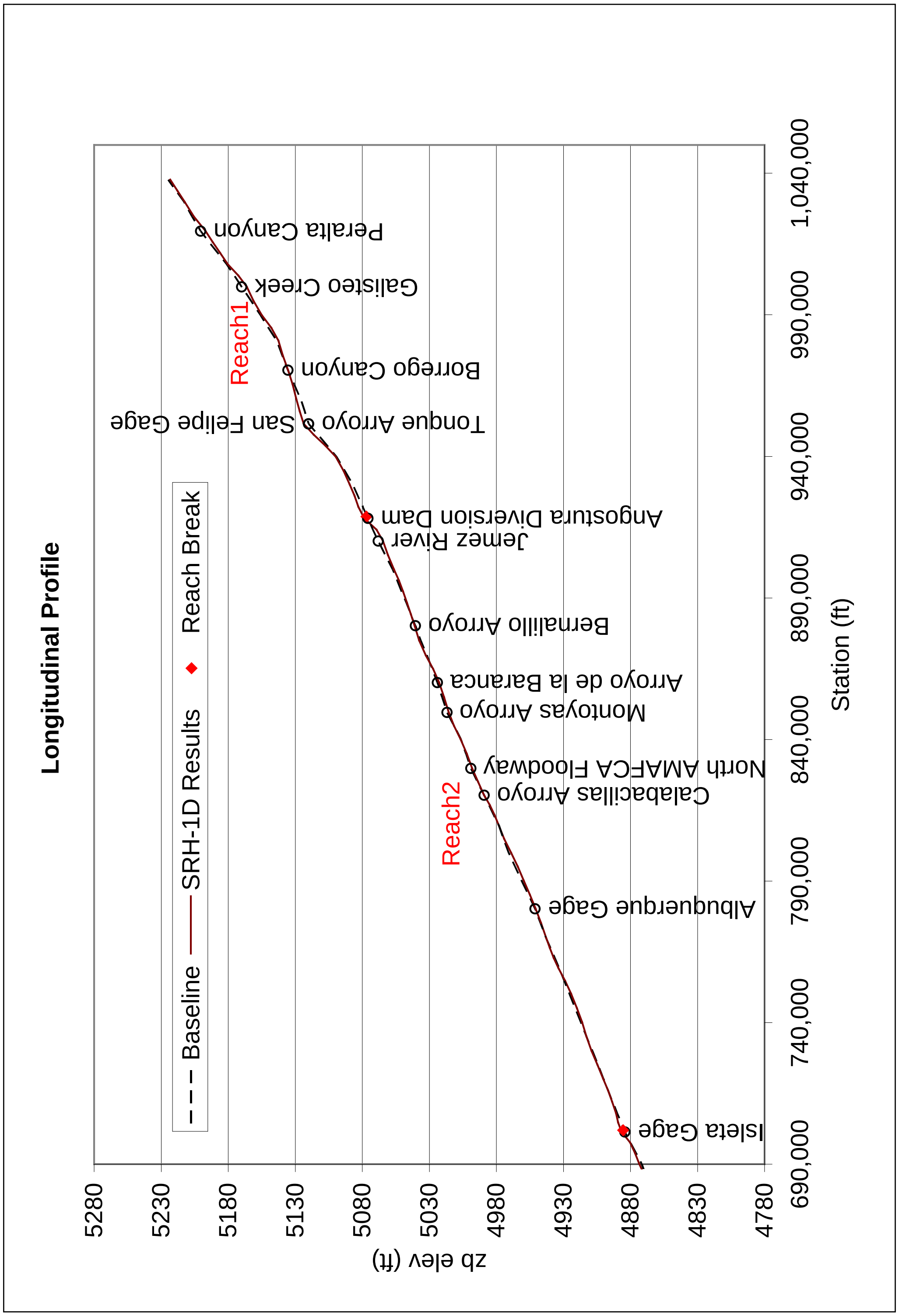


Figure B3.6. Longitudinal profile with tributaries and landmarks: Reaches 1 (Cochiti Dam to Angostura Diversion Dam) and 2 (Angostura Diversion Dam to Isleta Diversion Dam).

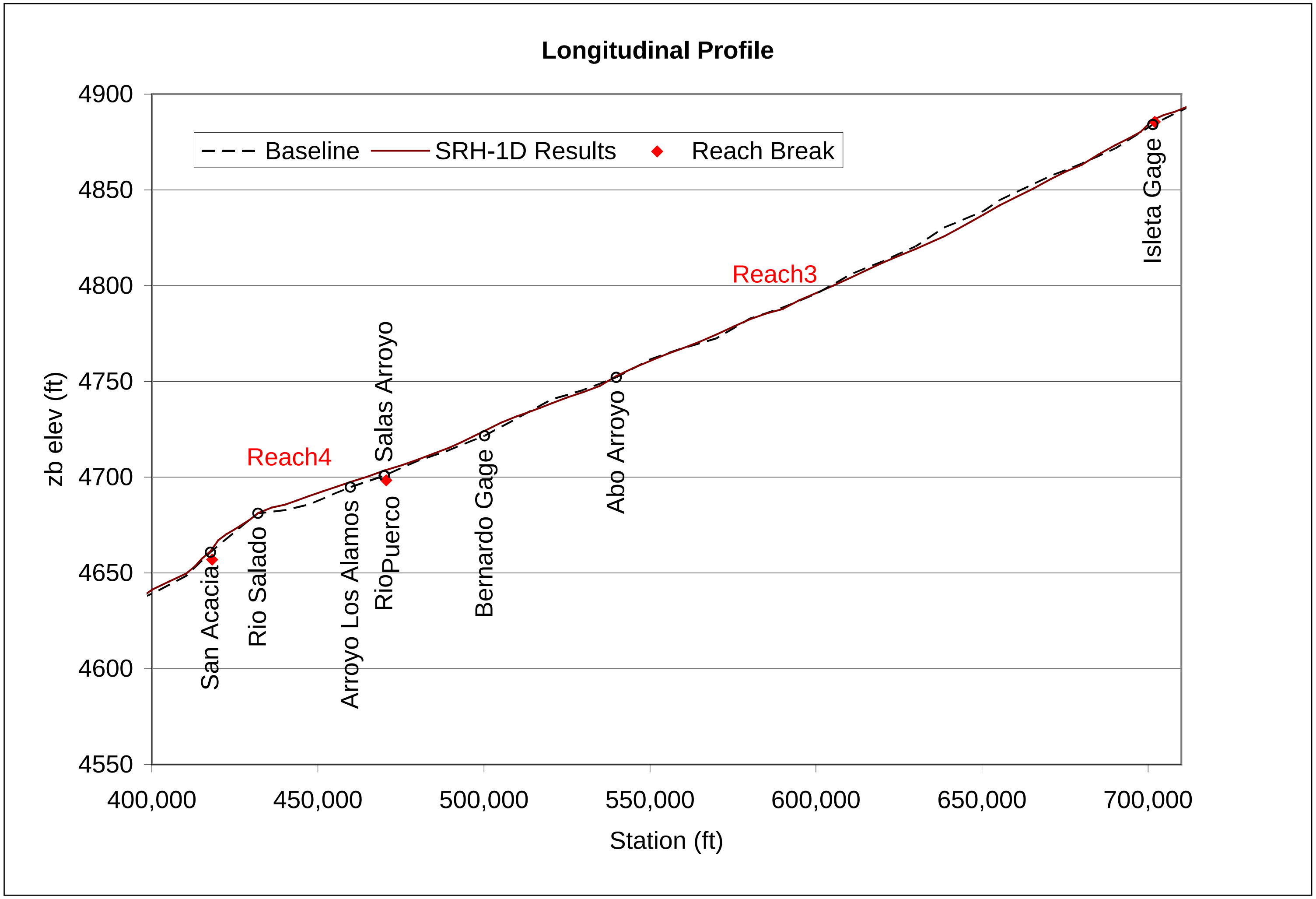


Figure B3.7. Longitudinal profile with tributaries and landmarks: Reaches 3 (Isleta Diversion Dam to Rio Puerco) and 4 (Rio Puerco to San Acacia Diversion Dam).

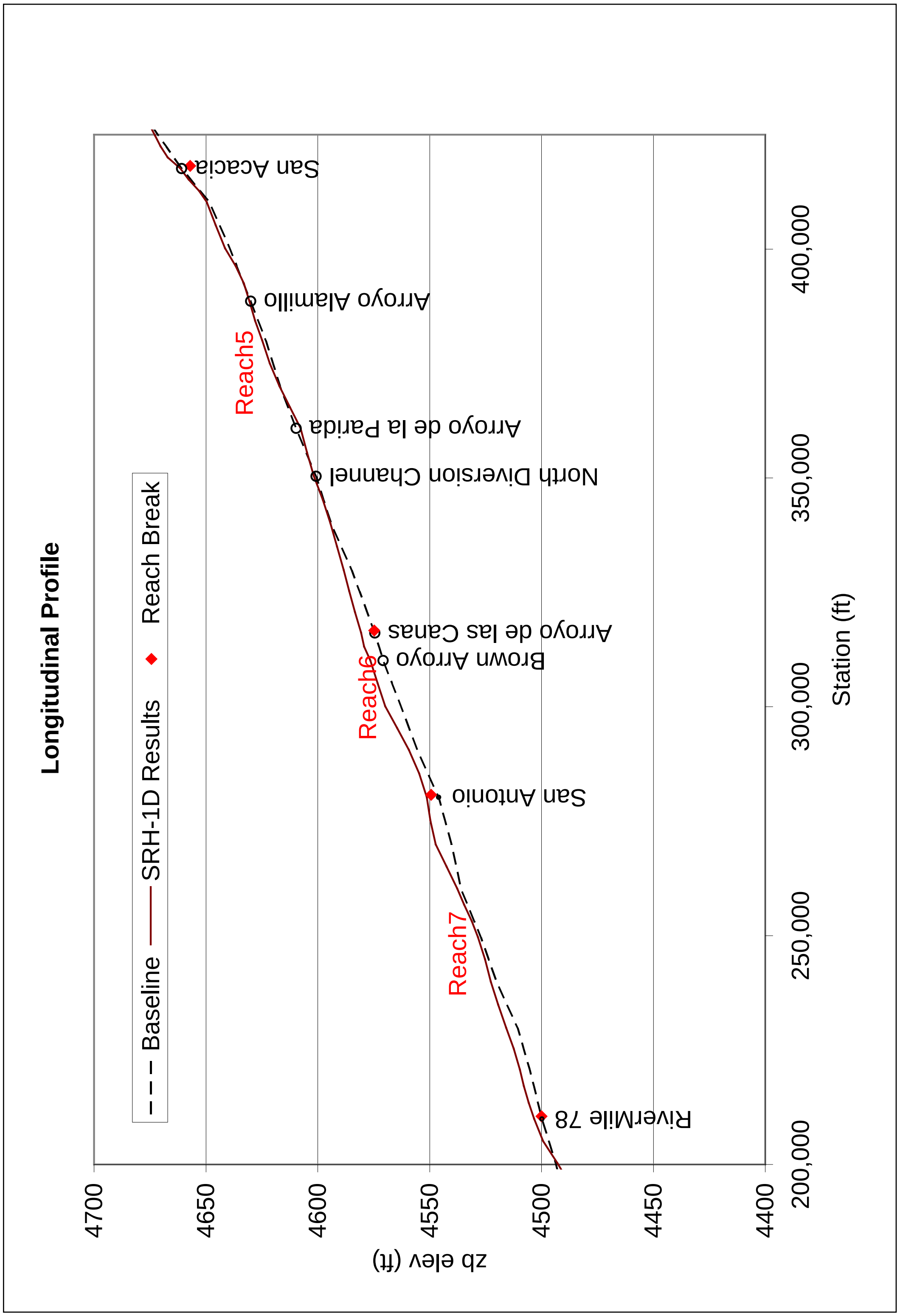


Figure B3.8. Longitudinal profile with tributaries and landmarks: Reaches 5 (San Acacia Diversion Dam to Arroyo de las Cañas), 6 (Arroyo de las Cañas to San Antonio Bridge), and 7 (San Antonio Bridge to River Mile 78).

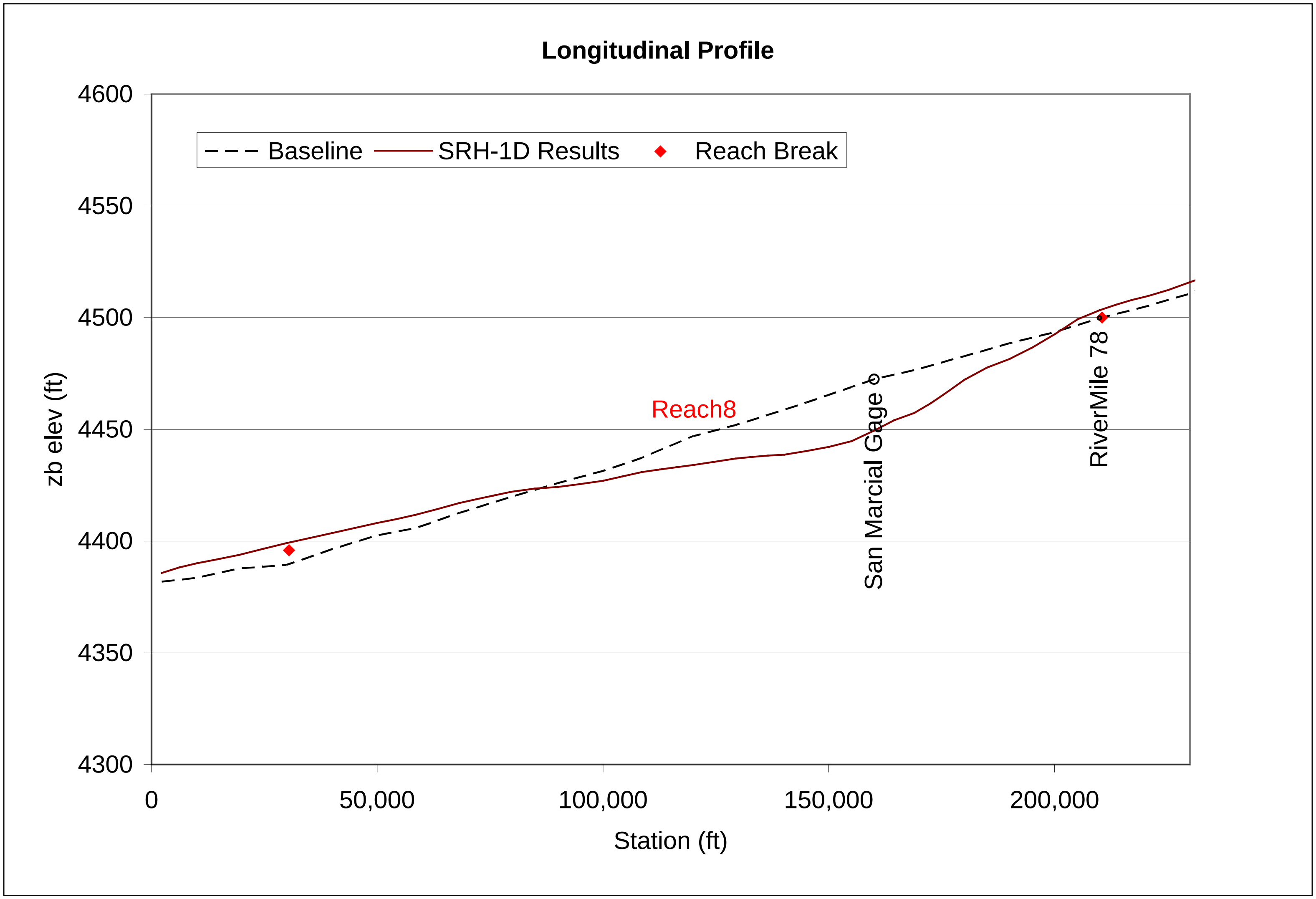


Figure B3.9. Longitudinal profile with tributaries and landmarks: Model Reach 8 (River Mile 78 to Elephant Butte Reservoir).

3.3 Sensitivity Analyses

Sensitivity analyses were performed to assess the modeling results. A typical parameter to perform sensitivity analysis on is resistance to flow (Manning roughness coefficient, Chezy C, etc.). However, this was not done in this modeling effort, as the roughness values for the Middle Rio Grande have already been calibrated in the previous Reclamation modeling efforts (Bauer et al. 2006, Holmquist-Johnson 2004, and Huang et al. 2005). Instead, three primary sensitivity analyses were performed: (1) the treatment of the diversion dams, (2) the downstream boundary condition, and (3) the sediment loads supplied by the tributaries. In addition, three sensitivity analyses were performed on hydrology in which the incoming water volumes were scaled to 80 and 120 percent relative to the incoming water volumes for the Final scenario.

3.3.1 Sensitivity Analyses on Diversion Dams, Downstream Boundary Condition, and Lateral Sediment Volumes

The first sensitivity analysis considered diversion dams. Representing a diversion dam in a 1D model typically involves a set of descriptive parameters (e.g., crest height, crest width, number of radial gates, size of radial gates, etc.) along with a set of closely spaced cross sections just upstream and downstream from the structure. A 1D mobile-bed sediment routing model, such as SRH-1D, could become unstable with order-of-magnitude changes in cross-section spacing. The average cross-section spacing, including interpolated cross sections, is about 4,450 feet. Including detailed geometry data at the diversion dams, as well as allowing for the large spatial extents being considered (~200 miles), would demand a gradual transition in cross-section spacing in the vicinity of the structures, which would increase the number of cross sections and the associated computational time. Since the focus of the modeling was not on the diversion dams themselves, an alternate method of treatment was assumed, and a sensitivity analysis on this alternate treatment was made.

SRH-1D allows limits on the amount of erosion or deposition at any number of specific cross sections. Because the cross sections near the diversion dams (Angostura Diversion Dam, Isleta Diversion Dam, and San Acacia Diversion Dam) represent a length of river on the order of almost a mile, it was unreasonable to fix the elevation of the cross section (i.e., to allow no erosion or deposition). However, the dams do limit the amount of deposition and/or erosion that can occur locally. Therefore, two runs were conducted: one in which the cross sections nearest the diversion dams were allowed to freely adjust vertically and one in which the cross section nearest each diversion dam was limited in terms of erosion to the base of the dam and limited in terms of deposition to the crest of the dam.

The second sensitivity analysis considered the effect of the downstream boundary condition – namely the assumed fixed pool elevation of Elephant Butte Reservoir.

This sensitivity analysis assumes a full pool elevation of the reservoir. The elevation of the top of the storage pool of Elephant Butte Reservoir was set as the downstream boundary condition, as opposed to the average water surface elevation for Elephant Butte Reservoir in 2008 as the boundary condition.

The third sensitivity analysis considered the incoming sediment load from the tributaries. As stated above, the tributary inputs were taken from previous Reclamation studies (Bauer et al. 2006, Holmquist-Johnson 2004, Huang et al. 2005). In addition, a 1994 study by Resource Technology, Inc. (RTI) (RTI 1994), prepared for the U.S. Army Corps of Engineers, estimated different incoming sediment loads for the tributaries of the Middle Rio Grande. Figure B3.10 presents a plot comparing the incoming sediment load at each tributary between the Reclamation values and the RTI values. The total annual sediment load based on the RTI values for all 19 tributaries contributing significant sediment to the Middle Rio Grande is 1.50 times greater than the annual sediment load as estimated by Reclamation. The average ratio of RTI tributary load to Reclamation tributary load is 1.78. The largest relative tributary load is 4.85, and the smallest relative tributary load is 0.39. Additional tributary contributions are included in the RTI report, which were not incorporated in the sensitivity analysis.

Notably, the RTI (1994) study estimates sediment loads coming from numerous unnamed tributaries/arroyos that would likely lessen the amount of degradation occurring around RM 78 if they were connected to the river channel. This SRH-1D modeling effort has no incoming tributary sediment loads downstream from Brown Arroyo in Reach 7 (San Antonio Bridge to River Mile 78) (about RM 93). These unnamed tributaries providing sediment to the valley downstream from Brown Arroyo were excluded from the model due to the fact that irrigation infrastructure in most cases disconnects these tributaries from the Rio Grande.

Table B3.3 provides a summary of the three sensitivity analyses run, as compared to the final simulation, which:

- Use the Reclamation sediment input volumes
- Assume a 2008 average Elephant Butte water surface elevation as the downstream boundary condition
- Limit vertical adjustments occurring at the cross sections, which represent the Angostura, Isleta, and San Acacia Diversion Dam locations

Figure B3.11 presents the slopes resulting from the three simulations outlined in table B3.3 along with the baseline (input geometry) slope for the sake of comparison. Figure B3.12 presents the average depositional volume for the entire modeled section of the Middle Rio Grande. Figure B3.13 presents the same average depositional volume by reach. Erosion is represented as a negative depositional volume.

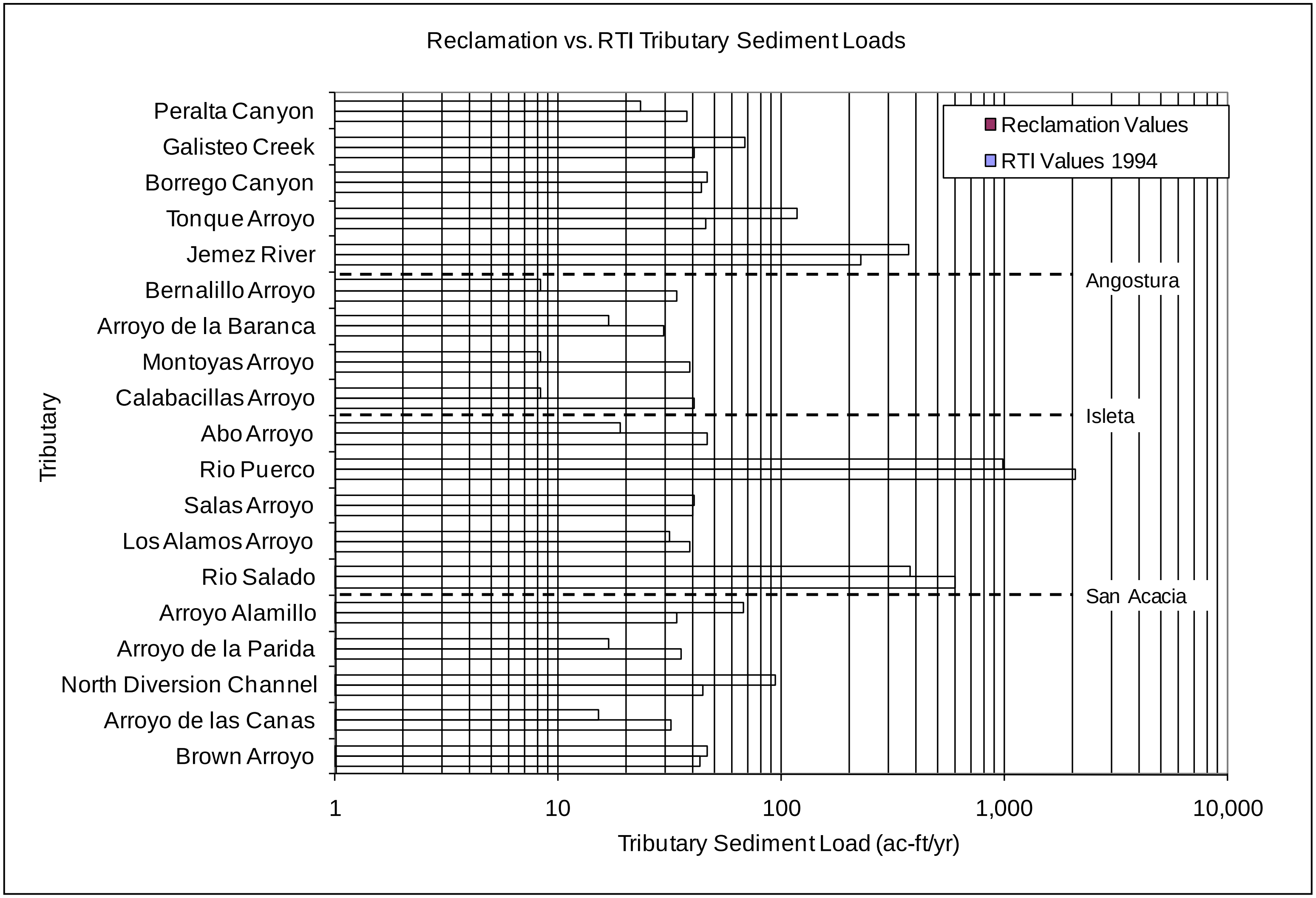


Figure B3.10. Comparison of estimated incoming sediment loads from tributaries.

Table B3.3. Summary of Sensitivity Runs Performed and the Color Code for Figures B3.11–B3.13

Simulation ID	Diversion Dam Treatment	Elephant Butte Elevation	Tributary Sediment Estimate	Color Code
Final	Limited Vertical Change	2008 Average	Reclamation	Black
Free	*Unlimited Vertical Change*[1]	2008 Average	Reclamation	Red
Full Pool	Limited Vertical Change	*Full Pool*[1]	Reclamation	Orange
RTI	Limited Vertical Change	2008 Average	*RTI*[1]	Green

[1] Italicized entries are changes made for sensitivity analyses.

The Full Pool simulation shows no change (both in terms of resulting slope and in terms of depositional volume) upstream of San Acacia Diversion Dam relative to the Final simulation. The most significant changes relative to the Final simulation downstream from San Acacia Diversion Dam occur in model reaches 6 (Arroyo de las Cañas to San Antonio Bridge) and 8 (River Mile 78 to Elephant Butte Reservoir). The Full Pool simulation shows how sensitive the lower model reaches are to the elevation in Elephant Butte Reservoir and indicate the difficulty of applying a single strategy to meet changing conditions in these reaches. A varying downstream boundary condition would complicate the results and limit the likelihood of the simulations reaching a dynamic equilibrium condition. The deposition that occurs during high pool conditions at Elephant Butte Reservoir leads to the management practice of excavating a temporary channel to create a surface connection between the river and the reservoir after the pool recedes to a lower elevation. The Full Pool simulation is a unique sensitivity analysis and is excluded from further consideration as described below. The results of the sensitivity analyses (excluding the Full Pool simulation) generally showed little difference in terms of trends or directions, but mostly a change in the magnitude of those changes.

Notice that for all of the reaches except for model Reach 6 (Arroyo de las Cañas to San Antonio Bridge), the direction of the slope change is the same, and that the magnitude of that change is what differs. Reach 6 (Arroyo de las Cañas to San Antonio Bridge) shows a flattening of the slope for the RTI simulation but a steepening for the Final and Free simulations. This differential is likely due to the alternating relative tributary loads (figure B3.10) for the five tributaries downstream from San Acacia Diversion Dam, and better data on tributary loads should result in better estimates of future channel trends in this reach.

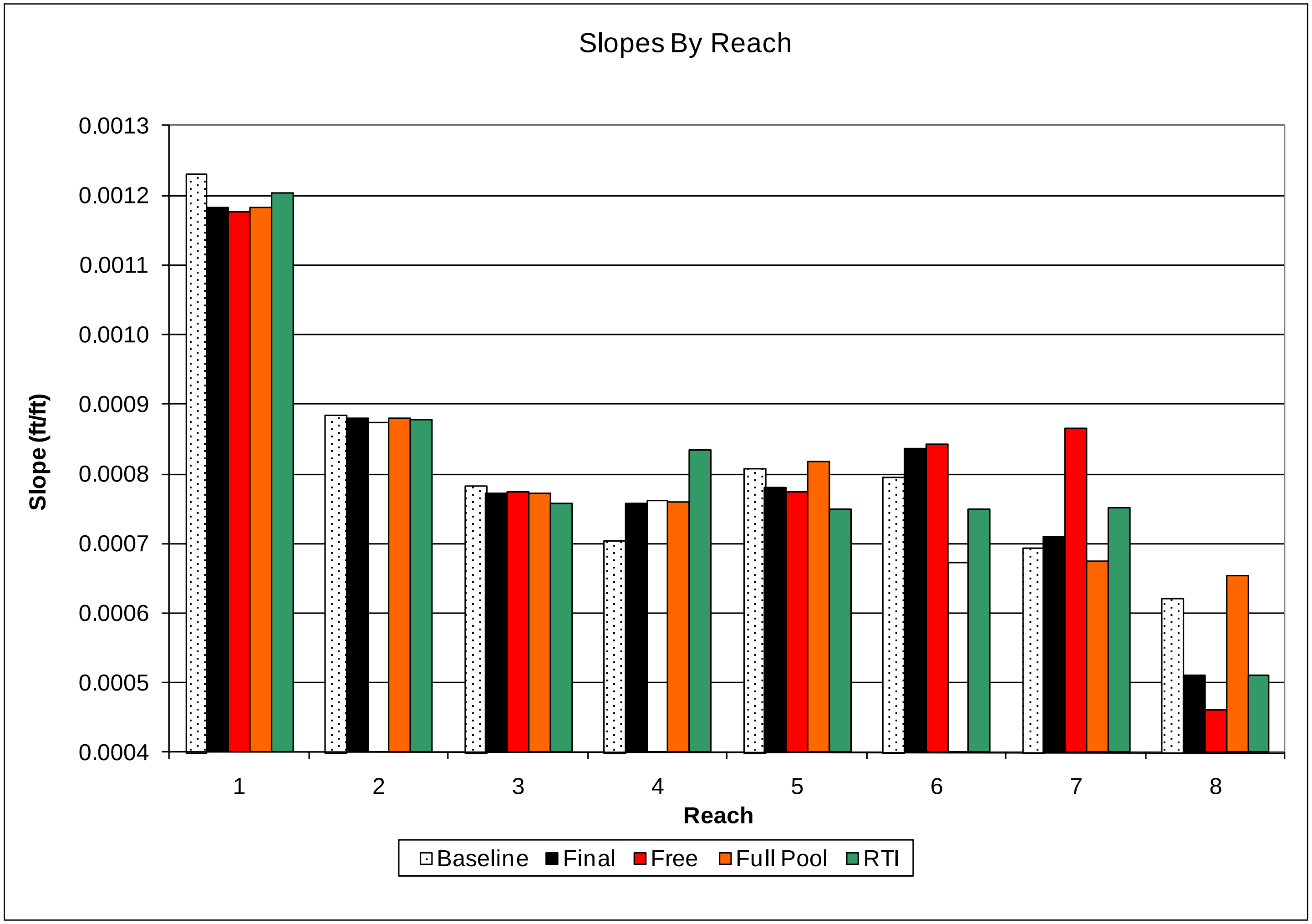


Figure B3.11. Reach-averaged slopes from the four SRH-1D simulations compared to baseline slopes.

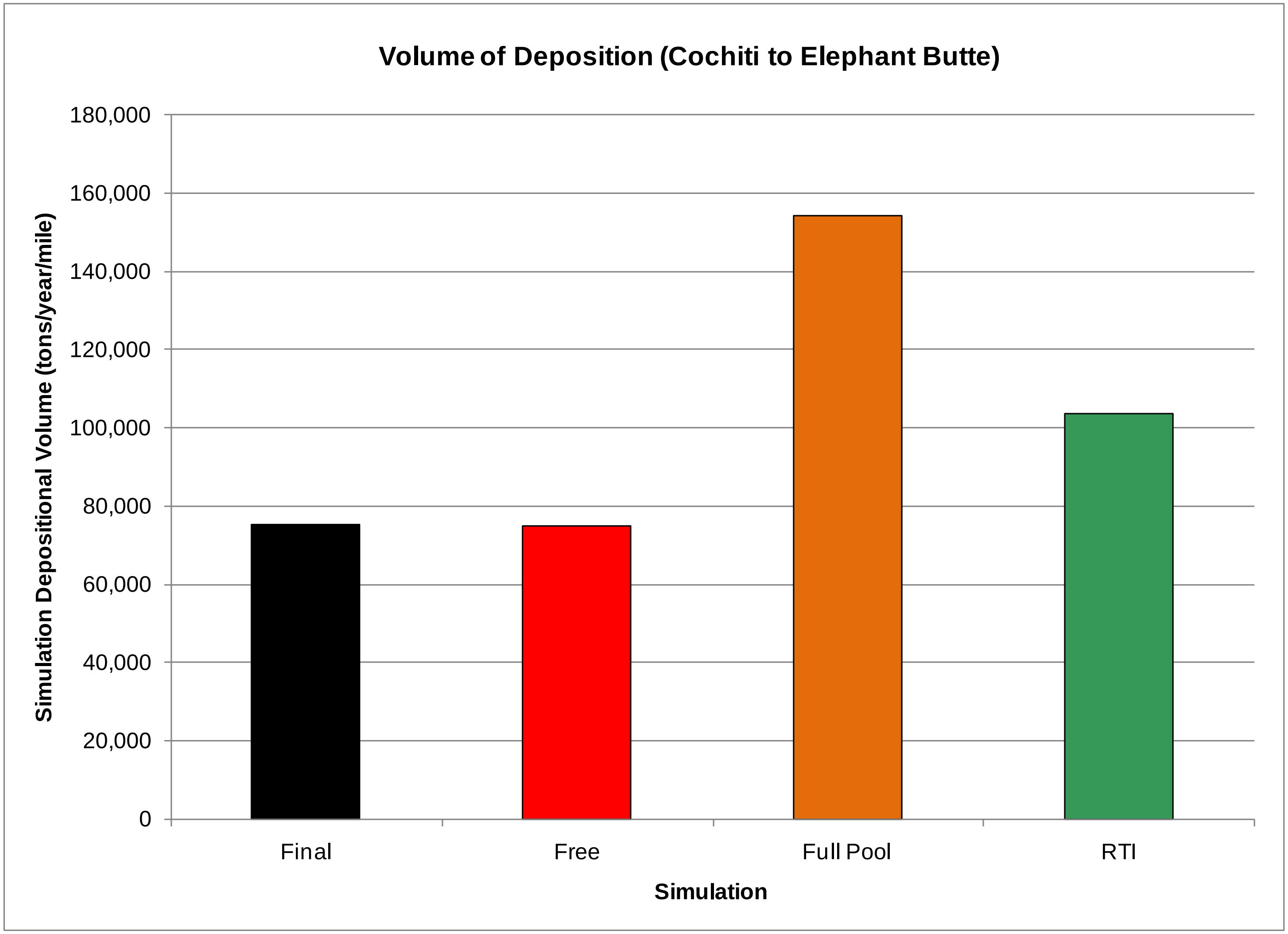


Figure B3.12. Length-averaged deposition volumes from the four SRH-1D simulations.

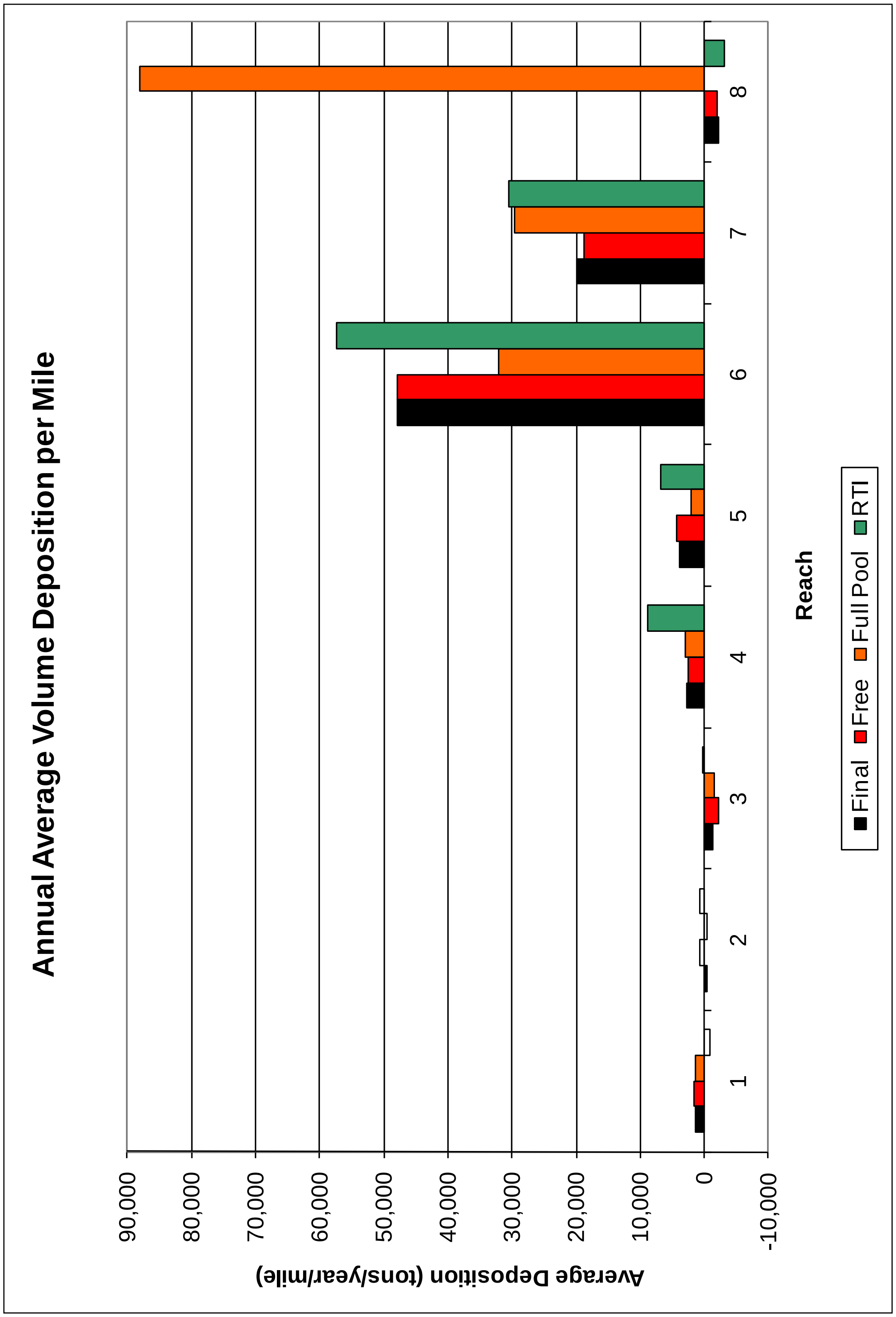


Figure B3.13. Reach-averaged depositional volumes from the four SRH-1D simulations.

Figure B3.12 demonstrates that the amount of deposition for the entire model domain is about 1.4 times greater for the RTI simulation relative to the Final simulation, whereas the tributary loads were 1.5 times greater. This discrepancy is due to the fact that many of the higher sediment loads in the RTI simulation increased the amount of fines entering the system, the majority of which wash downstream and exit the model domain. Although there is some disagreement between the simulations as to whether Reaches 1 (Cochiti Dam to Angostura Diversion Dam), 2 (Angostura Diversion Dam to Isleta Diversion Dam), and 3 (Isleta Diversion Dam to Rio Puerco) will be erosional or depositional (figure B3.13), the magnitudes are so small that there really is little difference between the results for these reaches. Reaches 4 (Rio Puerco to San Acacia Diversion Dam) through 8 (River Mile 78 to Elephant Butte Reservoir) show the same erosional or depositional trends (again, excluding the Full Pool simulation), with the difference between the simulation results lying in the magnitude of the deposition.

3.3.2 Hydrology Sensitivity Analysis

Wet and dry hydrologic years were identified as being at 120 and 80 percent, respectively, relative to a median water year (U.S. Fish and Wildlife Service 2001). In addition the sensitivity analyses described in section 3.3.1, sensitivity to hydrologic input was conducted. These alterations are made with respect to the Final simulation (limited vertical change at the diversion dams, average 2008 pool elevation for Elephant Butte Reservoir, and the Reclamation estimates of sediment loads from the tributaries). The three additional hydrologic model runs are:

- Each daily value of the flow entering at the upstream boundary was reduced to 80 percent of the values used in the Final simulation.
- Each daily value of the flow entering at the upstream boundary was increased to 120 percent of the values used in the Final simulation.
- Each daily value of the flow entering at the upstream boundary was increased to 120 percent of the values used in the Final simulation, and each of the daily values of the flow entering at the tributaries was increased to 120 percent of the Final values.

The model simulations conducted for the Final, Free, Full Pool, and RTI scenarios all converged in a 60-year time period. The model simulations conducted for the three hydrologic inputs listed above did not converge until 120 years. The results of the hydrologic sensitivity runs are compared to the results of the Final values in terms of reach-averaged slope (figure B3.14) and in terms of the depositional volume (figure B3.15)

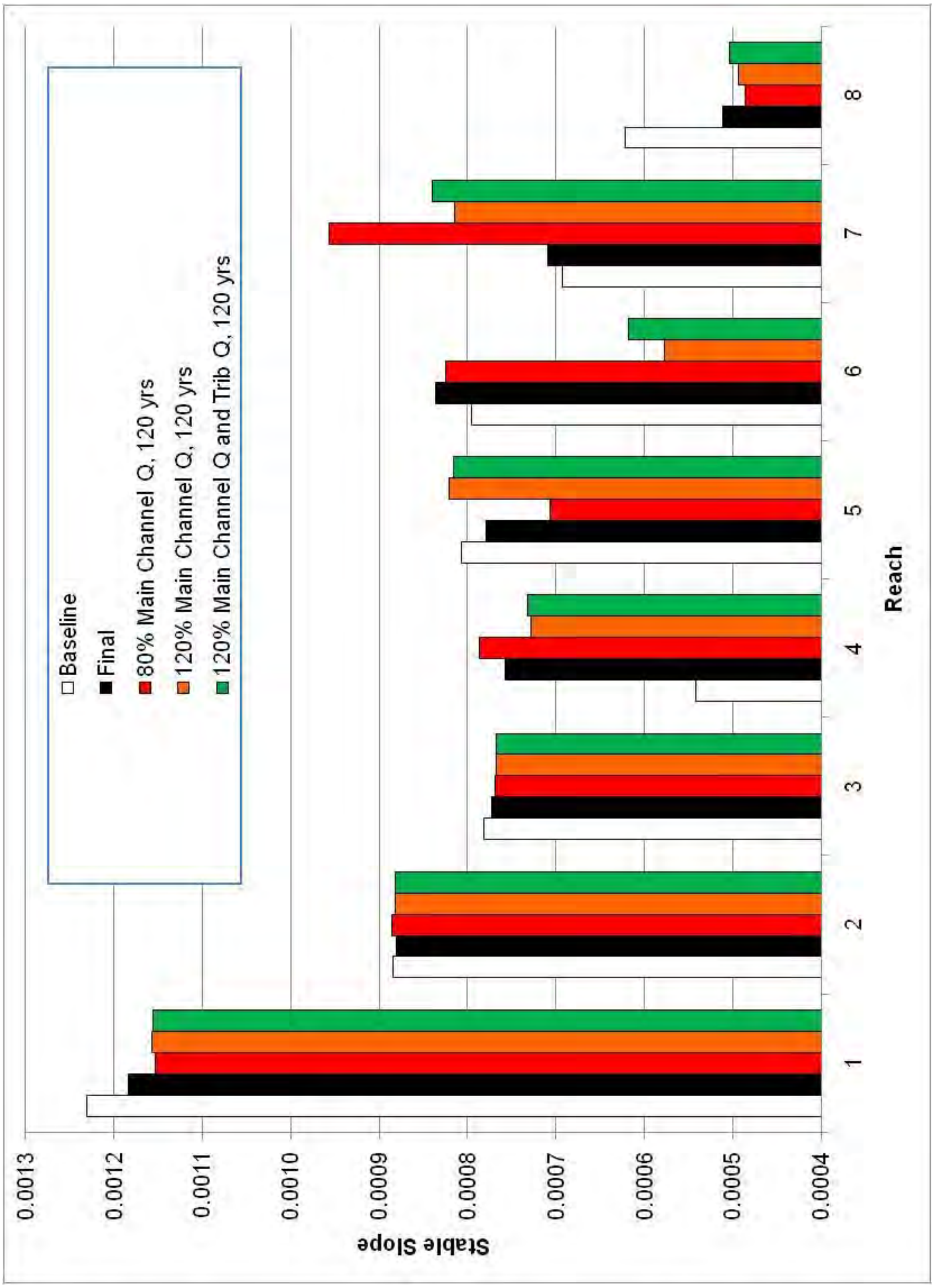


Figure B3.14. Percent difference in reach-averaged slope relative to final simulation for different input hydrology.

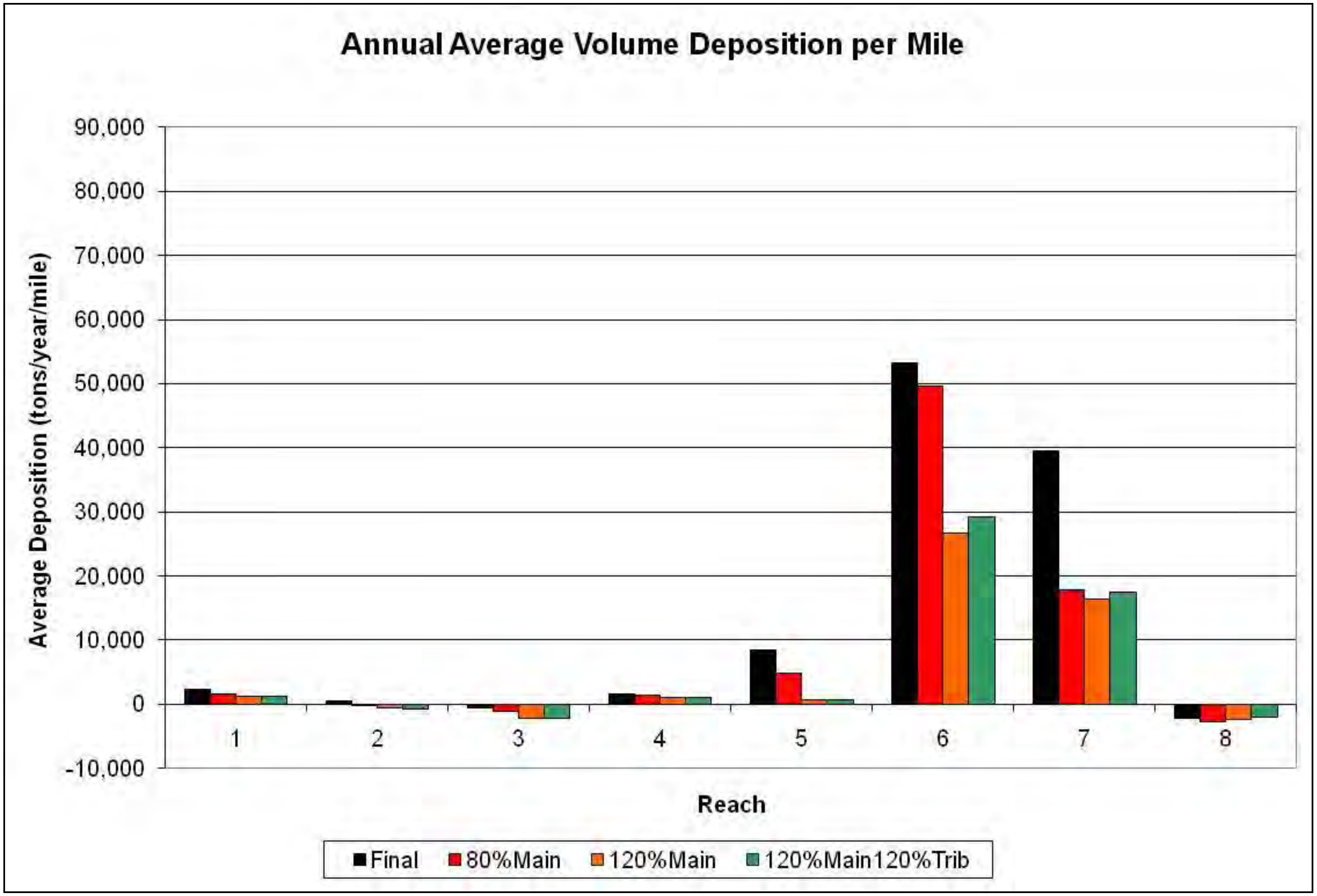


Figure B3.15. Reach-averaged depositional volumes from the hydrology sensitivity analysis.

There is very little difference in the results for Reaches 1–4 (Cochiti Dam to San Acacia Diversion Dam) based on slope (percent difference in slope ±5% relative to Final results) and depositional volume (average deposition ±2500 tons/year/mile).

Downstream from San Acacia Diversion Dam, the same general process occurs among the hydrology sensitivity simulations – only to varying degrees – to get the differences in "stable slope" that we are seeing. The general process is that aggradation begins to occur right around San Antonio due to a width constriction at this location. That aggradation causes a backwater effect that causes aggradation to progress upstream of San Antonio as well as there being continued aggradation downstream from San Antonio. For the lower 80-percent scenario, the upstream progression of aggradation continues upstream of Arroyo de las Cañas (into Reach 5) and this is why the 80-percent scenario has such a low slope for this reach. The higher discharge scenarios (120 percent) limit the upstream progression of aggradation from continuing past Arroyo de las Cañas (more water, more capacity to balance the supply).

The results for Reach 7 (San Antonio Bridge to River Mile 78) are affected by the upstream-moving headcut from Reach 8 (River Mile 78 to Elephant Butte Reservoir). For the 80-percent run, the headcut from Reach 8 has moved upstream of RM 78 whereas it really has not done so for the 120-percent scenarios. The Final scenario has some headcut progressing up Reach 7 about halfway. So, Reach 7 has the combination of (for the 80-percent scenario) more aggradation at the upstream (from the aggradation progressing downstream from San Antonio) and more degradation downstream (from the headcut progressing upstream of Reach 8). This is why the Reach 7 slope is so high for the 80-percent scenario. There is some question as to whether the downstream reaches during the 80-percent scenario did indeed reach equilibrium even after 120 years of simulation. Due to resource limitations the model simulation period was not extended to see if equilibrium ever would be reached. The fact that equilibrium has not been reached after 120 years of simulation would indicate that an equilibrium condition may not be achievable for the lower reaches of the Middle Rio Grande.

3.3.3 Sensitivity Conclusions

The Middle Rio Grande upstream of San Acacia Diversion Dam is relatively insensitive to changes in diversion dam treatment, downstream boundary condition, incoming tributary sediment loads, and hydrology. The exception is the sensitivity of Reach 4 (Rio Puerco to San Acacia Diversion Dam) to incoming sediment loads, which makes sense as the Rio Puerco and the Rio Salado are the most significant point-source contributors of sediment volume (figure B3.10), and the Rio Puerco is the upstream boundary of this reach.

The Middle Rio Grande downstream from San Acacia Diversion Dam is much more sensitive to changes in diversion dam treatment, downstream boundary condition, incoming tributary sediment loads, and hydrology. These reaches are very responsive (both in reality and in these model simulations) to changes in sediment inputs, water inputs, and downstream boundary conditions. All of these modeling scenarios repeat a single year's worth data 60 (or 120) times during the simulations period, and in one scenario (80-percent mainstem water volumes), the model may not have reached equilibrium even after 120 years. In reality, there will be much more variation in sediment and water inputs, as well as the elevation of Elephant Butte Reservoir in a 120-year period. It is reasonable to consider the discussion of equilibrium or of a stable slope for the reaches downstream from San Acacia Diversion Dam as incongruous. Recorded history substantiates the Middle Rio Grande as high sediment load system that fills a channel and leads to overland flow and possibly avulsion (Scurlock 1998; Lagasse 1980; Leopold et al. 1964). Equilibrium and stability are not terms to be used for such a system. Anthropogenic influence is the only driver keeping the river, especially downstream from San Acacia Diversion Dam, in a state that may be considered somewhat "stable." However, this stability is definitely not a self-sustaining stability. The fact that these reaches are inherently unstable largely explains the significant sensitivity they display to model input parameters.

3.4 SRH-1D Modeling Conclusions

This modeling effort identifies which reaches are the furthest away from an equilibrium condition. The magnitude of the slope change and the magnitude of the depositional volumes rank the reaches in the following manner based on the Final simulation:

- Slope change (in order of magnitude):
  - 8 (River Mile 78 to Elephant Butte Reservoir)
  - 4 (Rio Puerco to San Acacia Diversion Dam)
  - 6 (Arroyo de las Cañas to San Antonio Bridge)
  - 1 (Cochiti Dam to Angostura Diversion Dam)
  - 5 (San Acacia Diversion Dam to Arroyo de las Cañas)
  - 7 (San Antonio Bridge to River Mile 78)
  - 2 (Angostura Diversion Dam to Isleta Diversion Dam)
  - 3 (Isleta Diversion Dam to Rio Puerco)

- Deposition volume (in order of magnitude):
  - 6 (Arroyo de las Cañas to San Antonio Bridge)
  - 7 (San Antonio Bridge to River Mile 78)
  - 5 (San Acacia Diversion Dam to Arroyo de las Cañas)
  - 4 (Rio Puerco to San Acacia Diversion Dam)
  - 8 (River Mile 78 to Elephant Butte Reservoir)
  - 1 (Cochiti Dam to Angostura Diversion Dam)
  - 3 (Isleta Diversion Dam to Rio Puerco)
  - 2 (Angostura Diversion Dam to Isleta Diversion Dam)

Reaches 4 (Rio Puerco to San Acacia Diversion Dam) and 6 (Arroyo de las Cañas to San Antonio Bridge) appear in the top four of both rankings, while Reaches 2 (Angostura Diversion Dam to Isleta Diversion Dam) and 3 (Isleta Diversion Dam to Rio Puerco) appear as the last two reaches in each ranking. Reaches 1 (Cochiti Dam to Angostura Diversion Dam), 5 (San Acacia Diversion Dam to Arroyo de las Cañas), 7 (San Antonio Bridge to River Mile 78), and 8 (River Mile 78 to Elephant Butte Reservoir) do not appear in the top four or bottom four of both lists; they will be in the top four of one list and bottom four of the other list or vice versa depending on the reach.

As can be seen in figure B3.9, there is quite a bit of erosion in the upper portion of Reach 8 (River Mile 78 to Elephant Butte Reservoir) and deposition downstream, accounting for the large change in slope while maintaining a small change in net depositional volume. The results for Reach 8 are highly dependent on the downstream boundary condition (Elephant Butte reservoir pool elevation), as shown by the Full Pool simulation. The model results for all simulations do not lead to a single consistent slope for Reach 8, but typically show that Reach 8 could potentially be described by two characteristic slopes—one upstream of the San Marcial Railroad Bridge and another downstream. A linear regression slope for all of Reach 8 (River Mile 78 to Elephant Butte Reservoir) is not representative of the Middle Rio Grande downstream from RM 78.

Reaches 1 (Cochiti Dam to Angostura Diversion Dam), 2 (Angostura Diversion Dam to Isleta Diversion Dam), and 3 (Isleta Diversion Dam to Rio Puerco) show some potential for further slope reduction (figure B3.11) through minor changes in net volume (figure B3.13) regardless of the simulation. It is noteworthy that modeled reaches 1, 2, and 3 are the longest reaches, except for model Reach 8 (River Mile 78 to Elephant Butte Reservoir), which has been shown to be highly dependent on the elevation of Elephant Butte Reservoir. The relatively low slope change and volume change of these modeled reaches is more a function of their location and not their length. These three modeled reaches—which are immediately downstream from Cochiti Dam—have responded to the construction and operation of the dam and the associated reduction in sediment load and decreased peak discharges via channel incision and narrowing. These modeled reaches are relatively long because this portion of the Middle Rio Grande appears to have already adjusted to near dynamic equilibrium so that similar sets of conditions exist for longer sections of river. These three upstream model reaches are also more similar to each other than they are to any of the downstream model reaches.

The Middle Rio Grande downstream from the Rio Puerco and Rio Salado confluences (model reaches 4 [Rio Puerco to San Acacia Diversion Dam] through 8 [River Mile 78 to Elephant Butte Reservoir]) is geologically and geomorphically different than the Middle Rio Grande upstream of the areas near the Rio Puerco and Rio Salado. A break in the geologic drainage basins lies somewhere near the Rio Puerco, Rio Salado, and San Acacia Diversion Dams. The current drainage basin for the Middle Rio Grande used to be a series of individual internally draining basins (i.e., not a river drainage system). Two of these previously internally draining basins adjoin somewhere in this area near the Rio Puerco, Rio Salado, and San Acacia Diversion Dams (Bartolino et al. 2002).

Geomorphically, the Rio Puerco historically contributed a very high volume of sediment to the Middle Rio Grande, and this river has recently been identified as a likely cause of the local convexity on the Middle Rio Grande, supplanting the theory that the Socorro magma body is the cause (Finnegan et al. 2009). The Rio Salado is also a significant contributor of sediment, with substantial portions of that load being sand and fine gravel material, which is relatively coarser than the bed material upstream and downstream from the confluence. In addition, San Acacia Diversion Dam (from installation until the mid 1980s) diverted water from the Rio Grande to the Low Flow Conveyance Channel (which currently acts as a passive drain and irrigation return flow channel for the valley downstream from the dam) and continues to divert flow to the Socorro Main Canal. All of these influences really separate the upstream three modeled reaches of the Middle Rio Grande from the lower modeled reaches of the Middle Rio Grande, with Reach 4 (Rio Puerco to San Acacia Diversion Dam) encompassing much of the transition in terms of geology, geomorphology, and hydraulic structures. Therefore, it is not surprising to see such a different pattern of slope change and net deposition for the downstream reaches relative to the upstream reaches.

Note that the high deposition for the RTI simulation coincides with the RTI sediment load for the Rio Puerco being twice that of the Reclamation sediment load. Reaches 5 (San Acacia Diversion Dam to Arroyo de las Cañas), 6 (Arroyo de las Cañas to San Antonio Bridge), and 7 (San Antonio Bridge to River Mile 78) are sensitive to tributary sediment load inputs and the downstream boundary conditions (elevation of the reservoir pool).

The SRH-1D modeling of the Middle Rio Grande yields the following general conclusions about the eight modeled reaches:

- The three model reaches upstream of the Rio Puerco (Reaches 1 [Cochiti Dam to Angostura Diversion Dam], 2 [Angostura Diversion Dam to Isleta Diversion Dam], and 3 [Isleta Diversion Dam to Rio Puerco]) appear to be in a state of relative equilibrium under current water and sediment loads as indicated by the relatively low slope change and depositional volumes.
- Sensitivity analyses show that the results of the upstream three model reaches 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.
- Model reach 4 (Rio Puerco to San Acacia Diversion Dam) encompasses significant geologic and geomorphic transitions – as well as San Acacia Diversion Dam – which makes model Reach 4 a transitional reach, separating the upstream three model reaches from the downstream four reaches.
- Model Reach 4 (Rio Puerco to San Acacia Diversion Dam) is insensitive to downstream boundary conditions and erosional and depositional limits at the diversion dams, 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 reach.
- Model reaches 4 (Rio Puerco to San Acacia Diversion Dam), 5 (San Acacia Diversion Dam to Arroyo de las Cañas), 6 (Arroyo de las Cañas to San Antonio Bridge), and 7 (San Antonio Bridge to River Mile 78) are reaches that have a high incoming sediment load, which leads them to be zones of deposition.
- Model reaches 5 (San Acacia Diversion Dam to Arroyo de las Cañas), 6 (Arroyo de las Cañas to San Antonio Bridge), and 7 (San Antonio Bridge to River Mile 78) are reaches that are sensitive to hydrologic input (5 less so, 6 and 7 very much so) at the upstream boundary and at the tributaries.
- The results of model reaches 5 (San Acacia Diversion Dam to Arroyo de las Cañas), 6 (Arroyo de las Cañas to San Antonio Bridge), 7 (San Antonio Bridge to River Mile 78) and 8 (River Mile 78 to Elephant Butte Reservoir) are sensitive to tributary sediment inputs and the downstream boundary condition (reservoir pool elevation).
- Model Reach 8 (River Mile 78 to Elephant Butte Reservoir)—the longest and most downstream model reach—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 model Reach 8 (River Mile 78 to Elephant Butte Reservoir) will be greatly reduced due to the likely fluctuation of water surface elevation in Elephant Butte Reservoir. Adaptive management may be an appropriate approach for this model reach.
- The reaches downstream from San Acacia Diversion Dam have been, and continue to be, relatively active, are very sensitive to model inputs, and it may be inappropriate to even discuss these reaches using terms like equilibrium and stability, let alone try to define an equilibrium stable slope.

3.5 No Maintenance Future-Horizontal Modeling

The equilibrium stable slope for current water and sediment loads was determined from the SRH-1D modeling for the vertical portion of the NMF-V modeling. The horizontal portion, 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 valley length would not change for NMF-H (i.e., the reach breaks would not change), but the river would lengthen or shorten, and the result would be a change in sinuosity. Model reaches 1 (Cochiti Dam to Angostura Diversion Dam), 2 (Angostura Diversion Dam to Isleta Diversion Dam), 3 (Isleta Diversion Dam to Rio Puerco), 5 (San Acacia Diversion Dam to Arroyo de las Cañas), and 8 (River Mile 78 to Elephant Butte Reservoir) show a reduction in slope from the SRH-1D modeling (NMF-V), which translates to an increase in channel length for NMF-H (increased spacing between the HEC-RAS cross sections) and an increased sinuosity. Similarly, the increase in reach slope for Reaches 4 (Rio Puerco to San Acacia Diversion Dam), 6 (Arroyo de las Cañas to San Antonio Bridge), and 7 (San Antonio Bridge to River Mile 78) translate to a decrease in channel length (i.e., decreased spacing between cross sections) for NMF-H and an associated decrease in sinuosity. Table B3.4compares the slope and sinuosity between the baseline condition and the NMF-H condition.

Table B3.4. Slope and Sinuosity for Baseline and NMF-H Conditions

Model Reach Number	Baseline		NMF-H	
	Slope	Sinuosity	Slope	Sinuosity
1	0.0012	1.10	0.0012	1.15
2	0.0009	1.04	0.0009	1.05
3	0.0008	1.03	0.0008	1.04
4	0.0007	1.06	0.0008	0.99
5	0.0008	1.06	0.0008	1.09
6	0.0008	1.02	0.0008	0.97
7	0.0007	1.05	0.0007	1.02
8	0.0006	1.09	0.0005	1.31

4 Meander Belt Assessment

The NMF-H meander belt width, the meander belt width associated with a strategy, and baseline condition meander belt width can be compared to existing lateral constraints.

The Middle Rio Grande is a managed system in which most of the valley that would naturally be available to the river is greatly reduced and is dictated by lateral infrastructure constraints. Although levees are the most common infrastructure constraint, there are a few instances in which the constraint is defined by a "zone of protection for infrastructure," where lateral erosion would be controlled through river maintenance actions (e.g., to protect houses). In a few other cases, there are no infrastructure constraints such as the narrow geologic constraints at Sevilleta bend (RM 120). These lateral constraints (levee, geologic, or otherwise) were digitized in ArcGIS[1] using orthorectified imagery (and knowledge of the zones of protection according to the Albuquerque Area Office). A centerline for this constrained valley was also digitized in ArcGIS to develop reach valley lengths. It is important to keep in mind that the digitized centerline was developed based solely on lateral constraints and not according to current channel alignment, the current river alignment, or cross-valley elevation.

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 modeling scenario. The basic characteristics of the sine-generated curve for a given reach are the same because it is assumed that the average channel width remains constant regardless of strategy and that the length of the meander is equal to 10 channel widths (Knighton 1998). The length of the river for a given strategy is based on the representative HEC-RAS geometry, and the sinuosity for a strategy is calculated by comparing the river length to the length of the constrained valley centerline as described above. With an assumed meander length of 10 channel widths and a calculated sinuosity, the maximum departure angle, β, (Knighton 1998) can be solved for iteratively. An Excel spreadsheet was developed to calculate the X, Y coordinates for a sine-generated curve centerline and the associated meander belt width along a neutral axis for each strategy and each reach. The meander belt width is calculated as the meander width plus one channel width, and this sum is multiplied by a factor of 1.5 to account for natural variability in river meanders.

A script was then developed for ArcGIS that would take the points calculated in the spreadsheet and plot the sine-generated curve and associated meander belt

[1] ArcGIS is a suite consisting of a group of geographic information system software products produced by ESRI.

width relative to a non-neutral axis; in our case, the digitized constrained valley centerline. In this way, the sine-generated curve meander belt width for a given strategy and given reach can be compared to the lateral constraints of that reach. Figure B4.1 presents an example sine-generated curve layout along the constrained valley centerline.

A sensitivity analysis was performed on the meander length ratio (MLR), which is the ratio of meander length to channel width. As stated above, the MLR was assumed to be equal to 10. Both 8 and 12 were used as meander length ratios. Table B4.1 summarizes the maximum departure angle (β) and meander belt width determined for the MLR equal to 10 as well as the percent difference in meander belt width (MBW) for assuming an MLR of 8 and an MLR of 12 for the baseline conditions. The magnitude of the percent difference in maximum departure angle for both MLR 8 and MLR 12 was less than 1 percent for all reaches even though the magnitude of percent difference in meander belt width ranged from 10 to 15 percent.

Table B4.1. Sensitivity Analysis Results on MLR

Reach	Channel Width (feet)	MLR = 10		MLR = 8	MLR = 12
		β (degree)	MBW (feet)	MBW (feet)	MBW (feet)
1	259	35.1	1,188	1,029	1,348
2	437	22.6	1,495	1,327	1,663
3	373	19.7	1,181	1,057	1,306
4	242	28.2	951	832	1,067
5	307	26.4	1,158	1,018	1,298
6	396	17.1	1,166	1,055	1,280
7	285	24.5	1,026	907	1,146
8	140	32.8	612	531	692

The MBW was compared to the lateral constraints by model reach. This comparison is quantified by determining the percent of the MBW that is inside and the percent that is outside of the constraint lines (see Indicator H1, section 5.1). This comparison is presented in figures B4.2–B4.17 for the baseline condition. Two figures are presented for each reach—one figure is an overview of the entire reach, and the other figure zooms in to better show portions of the MBW that are in and portions that are out of the current lateral constraints.

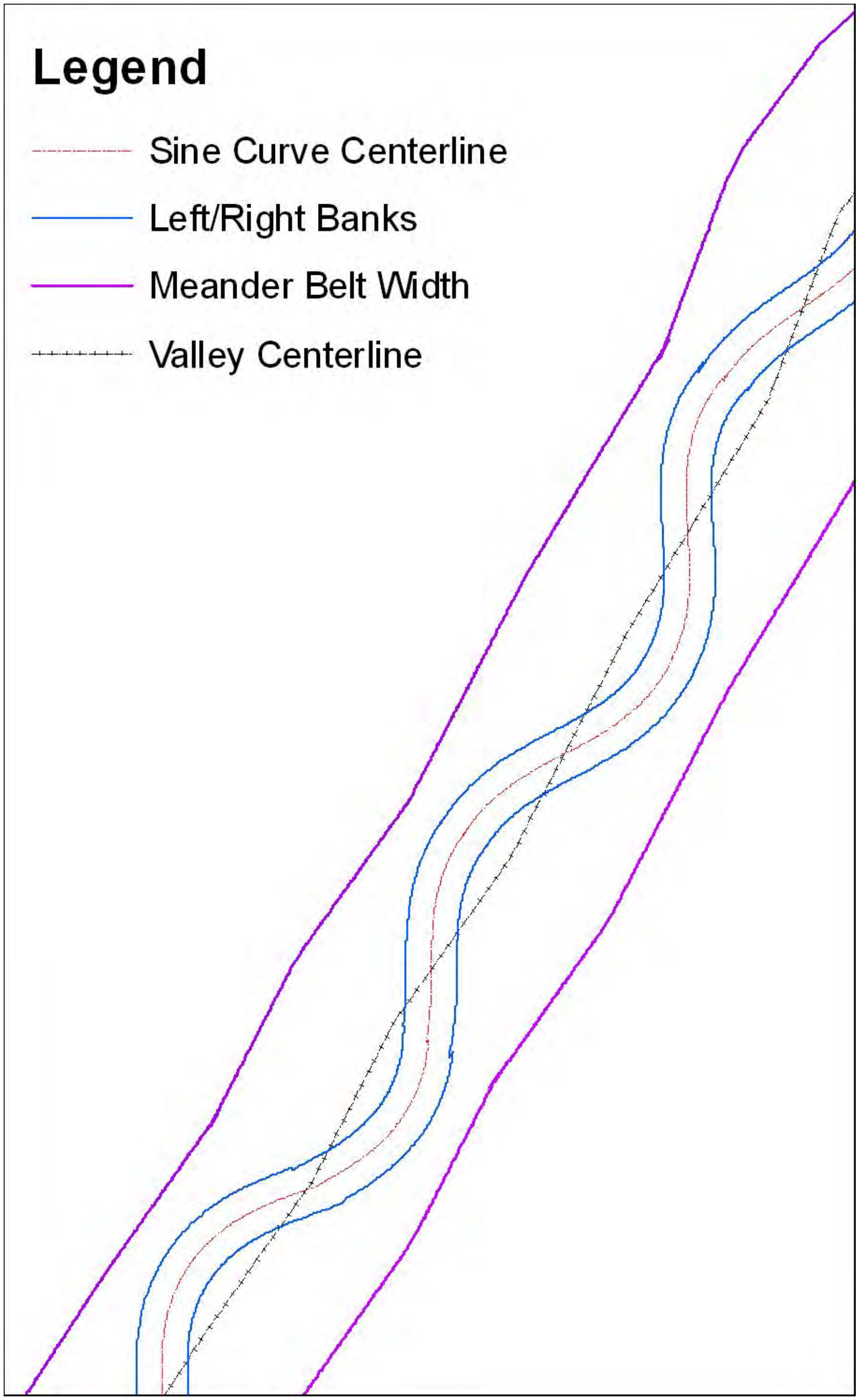


Figure B4.1. Example sine-generated curve and associated MBW.

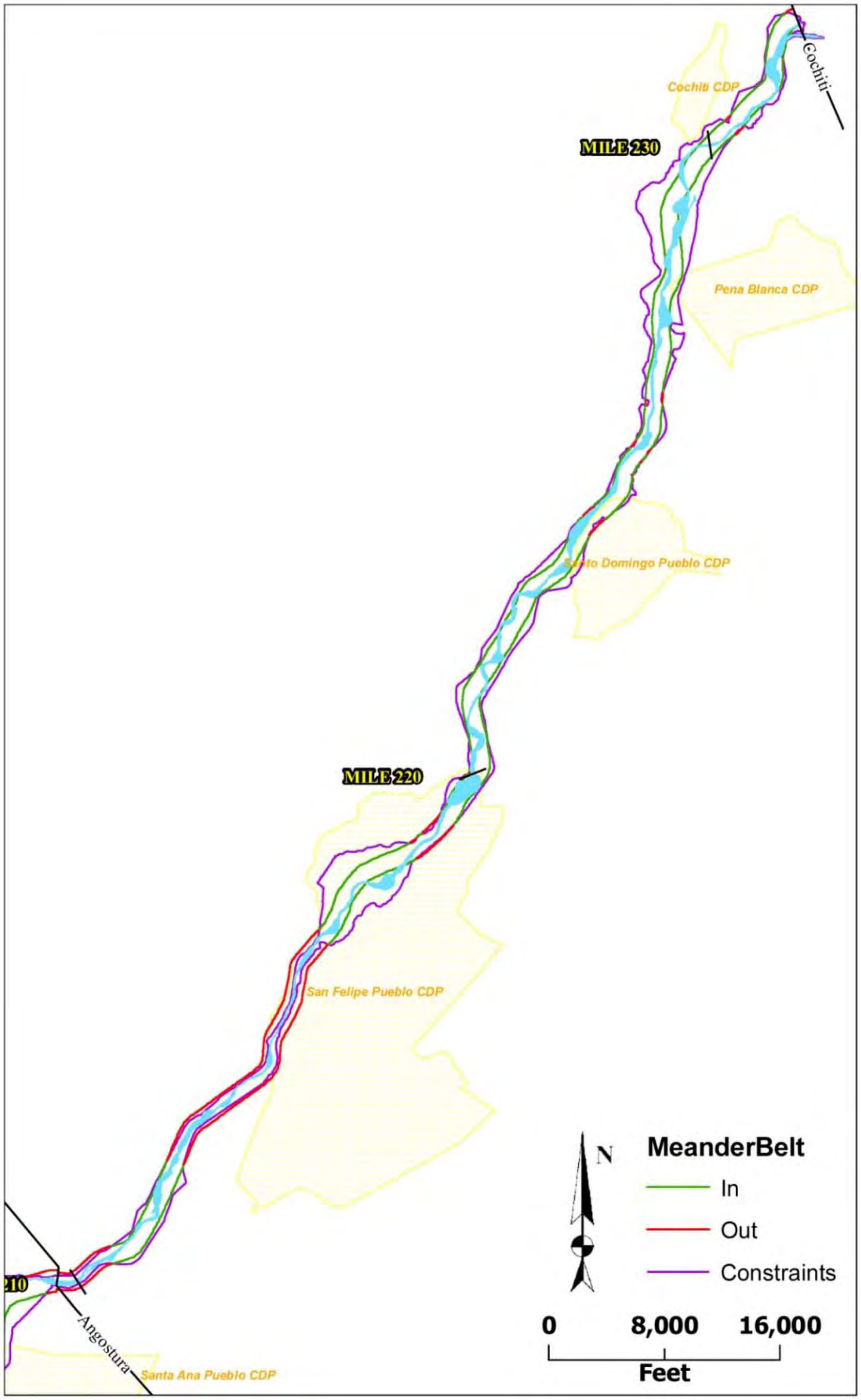


Figure B4.2. Overview mapping of MBW Reach 1 (Cochiti Dam to Angostura Diversion Dam).

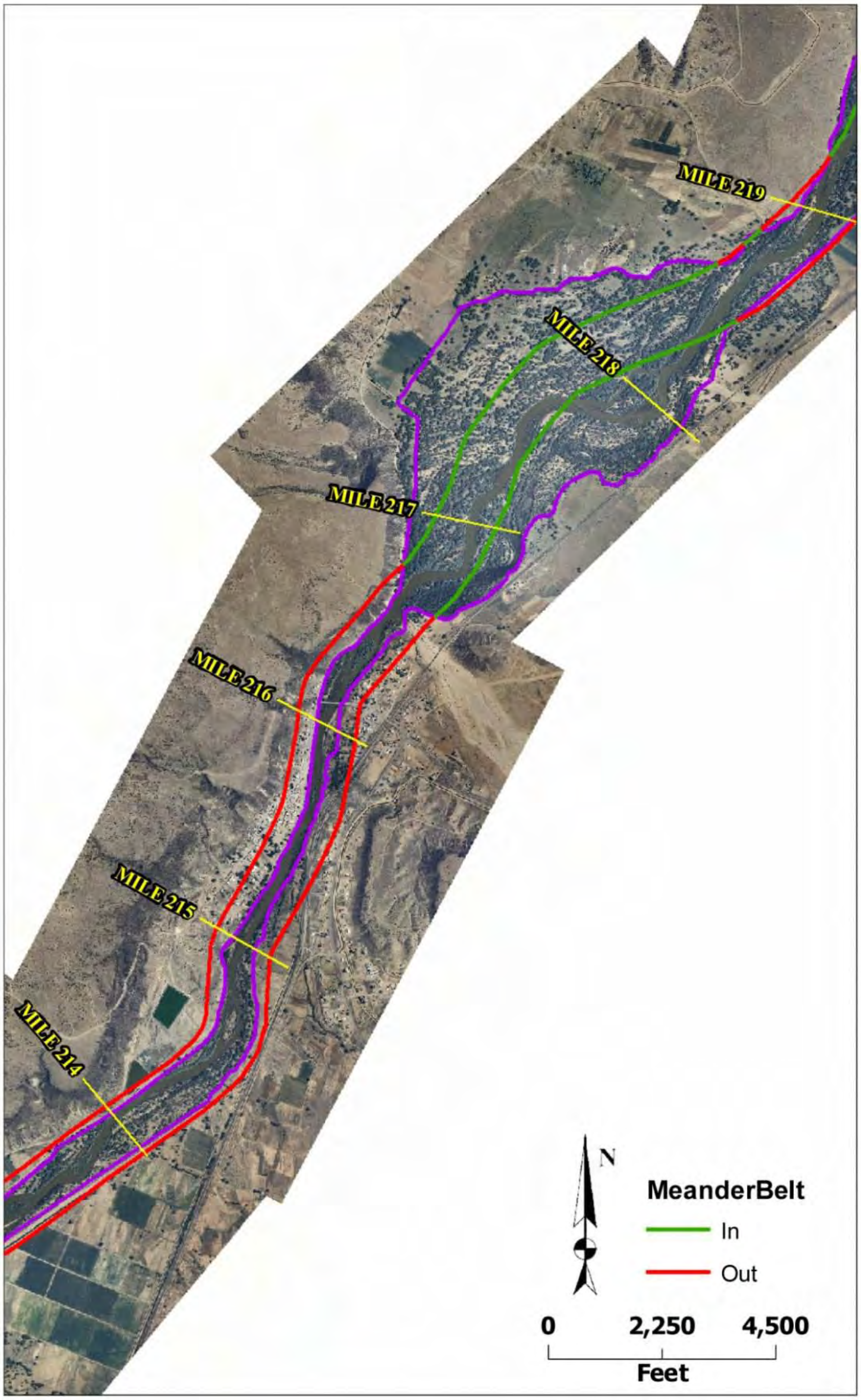


Figure B4.3. Specific location mapping of meander belt width, Reach 1 (Cochiti Dam to Angostura Diversion Dam).

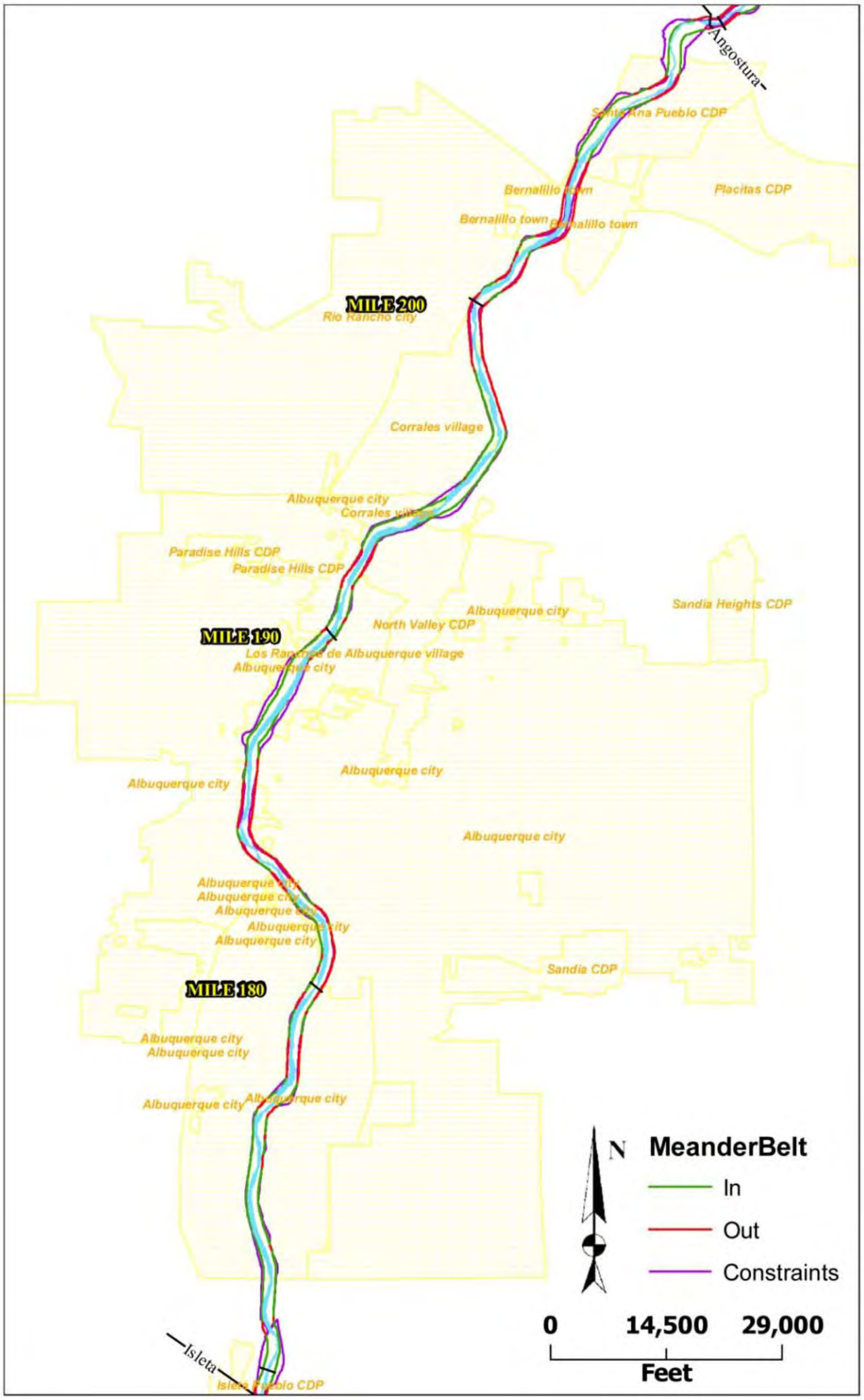


Figure B4.4. Overview mapping of MBW, Reach 2 (Angostura Diversion Dam to Isleta Diversion Dam)

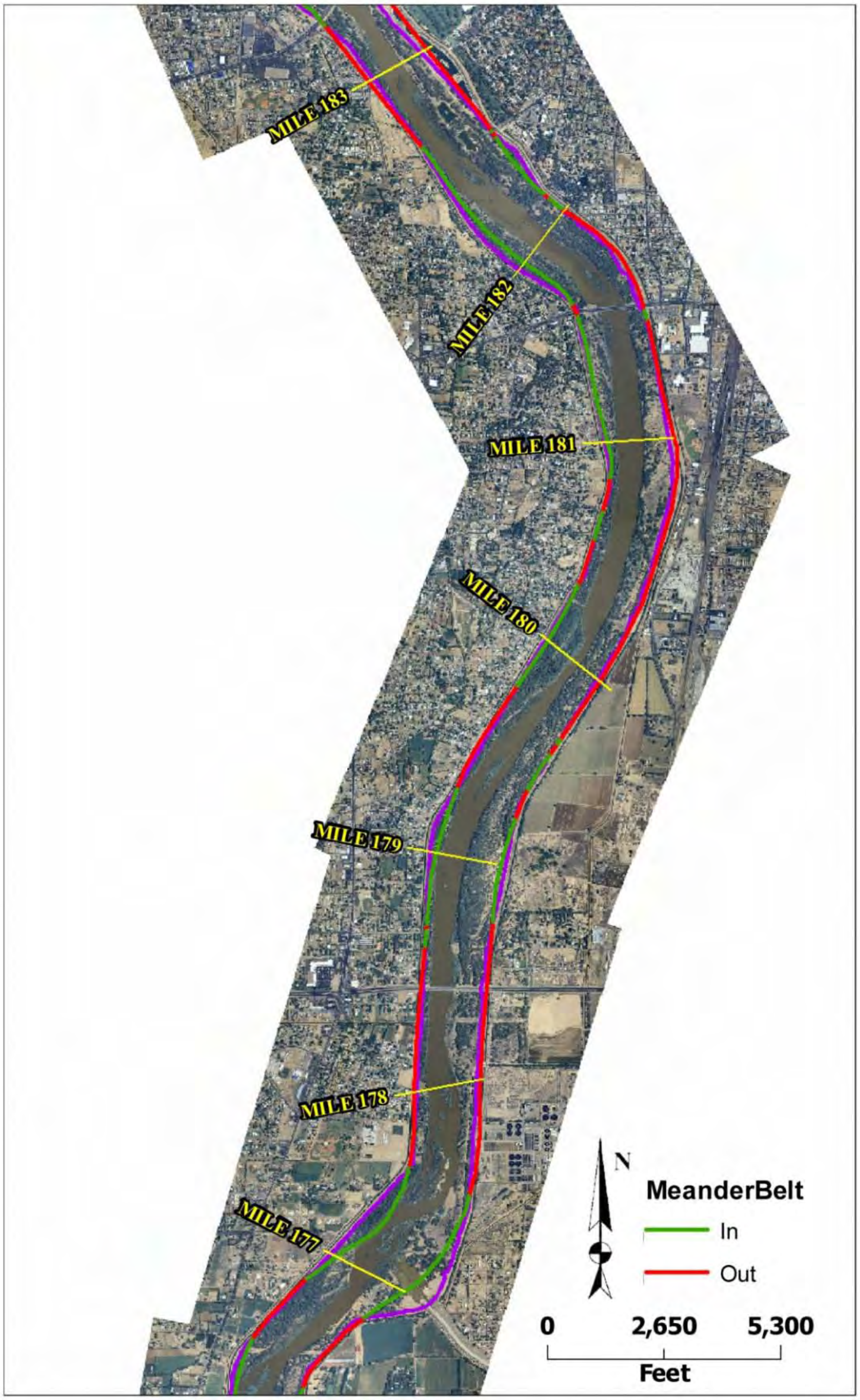


Figure B4.5. Specific location mapping of MBW, Reach 2 (Angostura Diversion Dam to Isleta Diversion Dam).

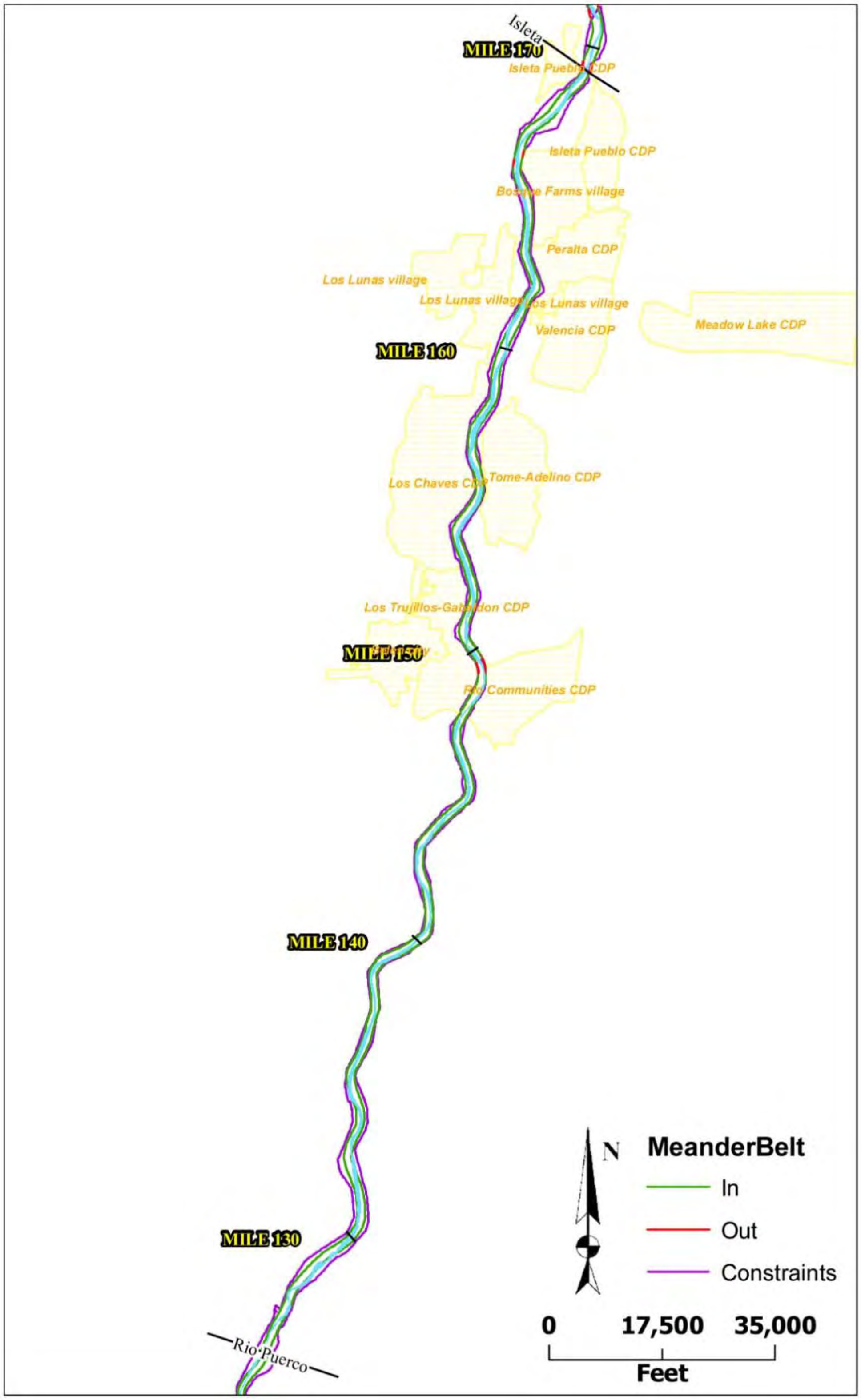


Figure B4.6. Overview mapping of MBW, Reach 3 (Isleta Diversion Dam to Rio Puerco).

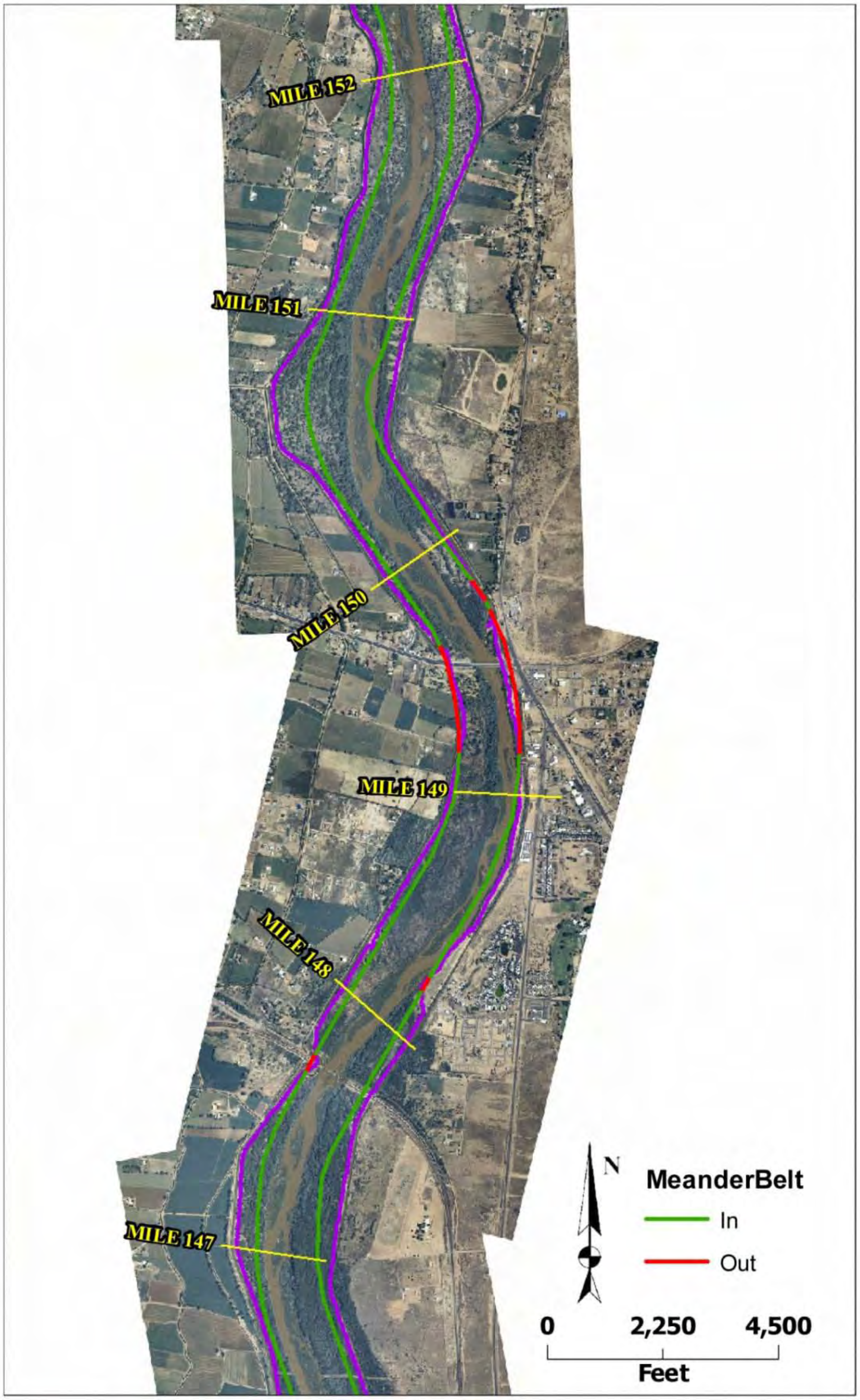


Figure B4.7. Specific location mapping of MBW, Reach 3 (Isleta Diversion Dam to Rio Puerco)

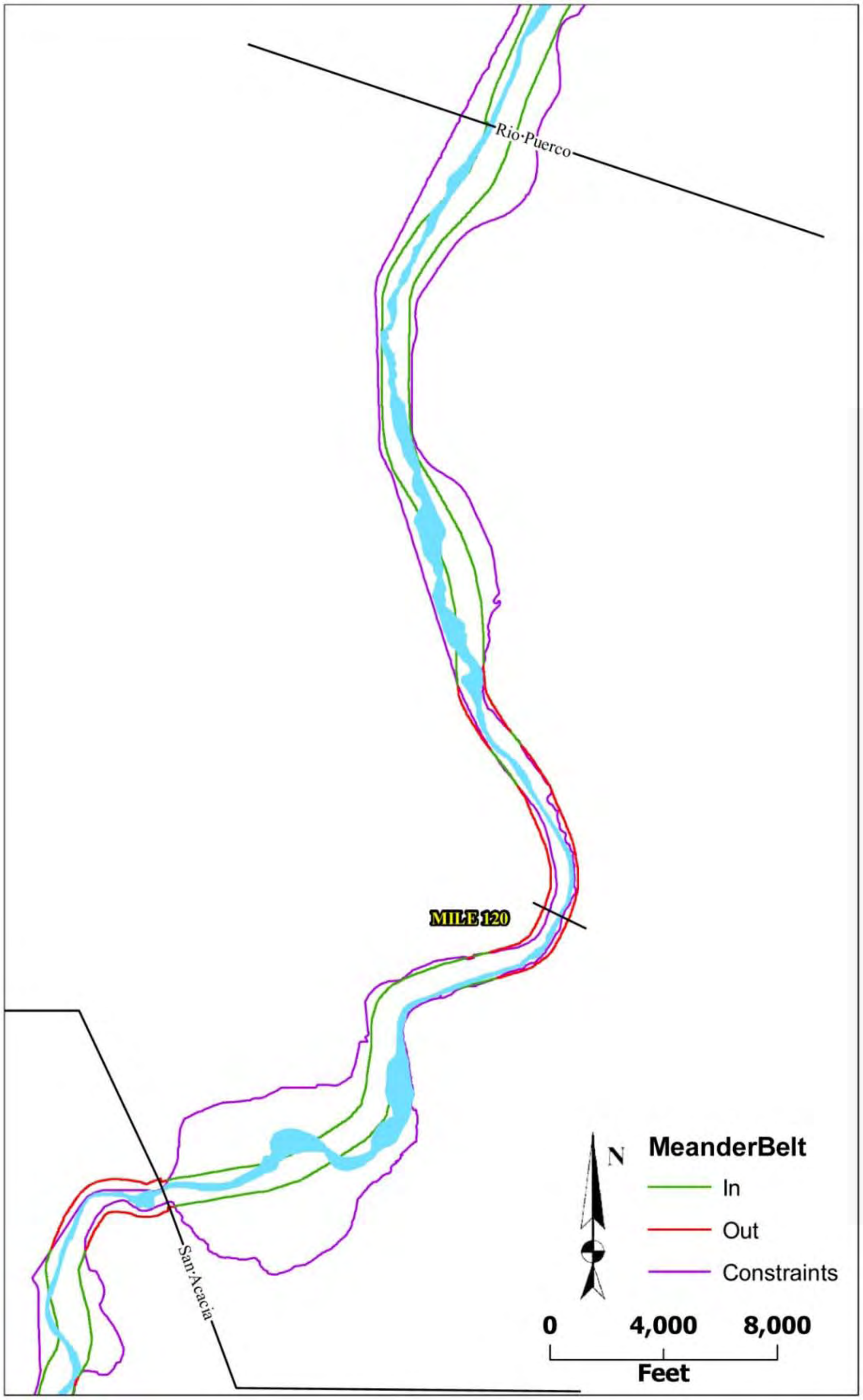


Figure B4.8. Overview mapping of MBW, Reach 4 (Rio Puerco to San Acacia Diversion Dam).

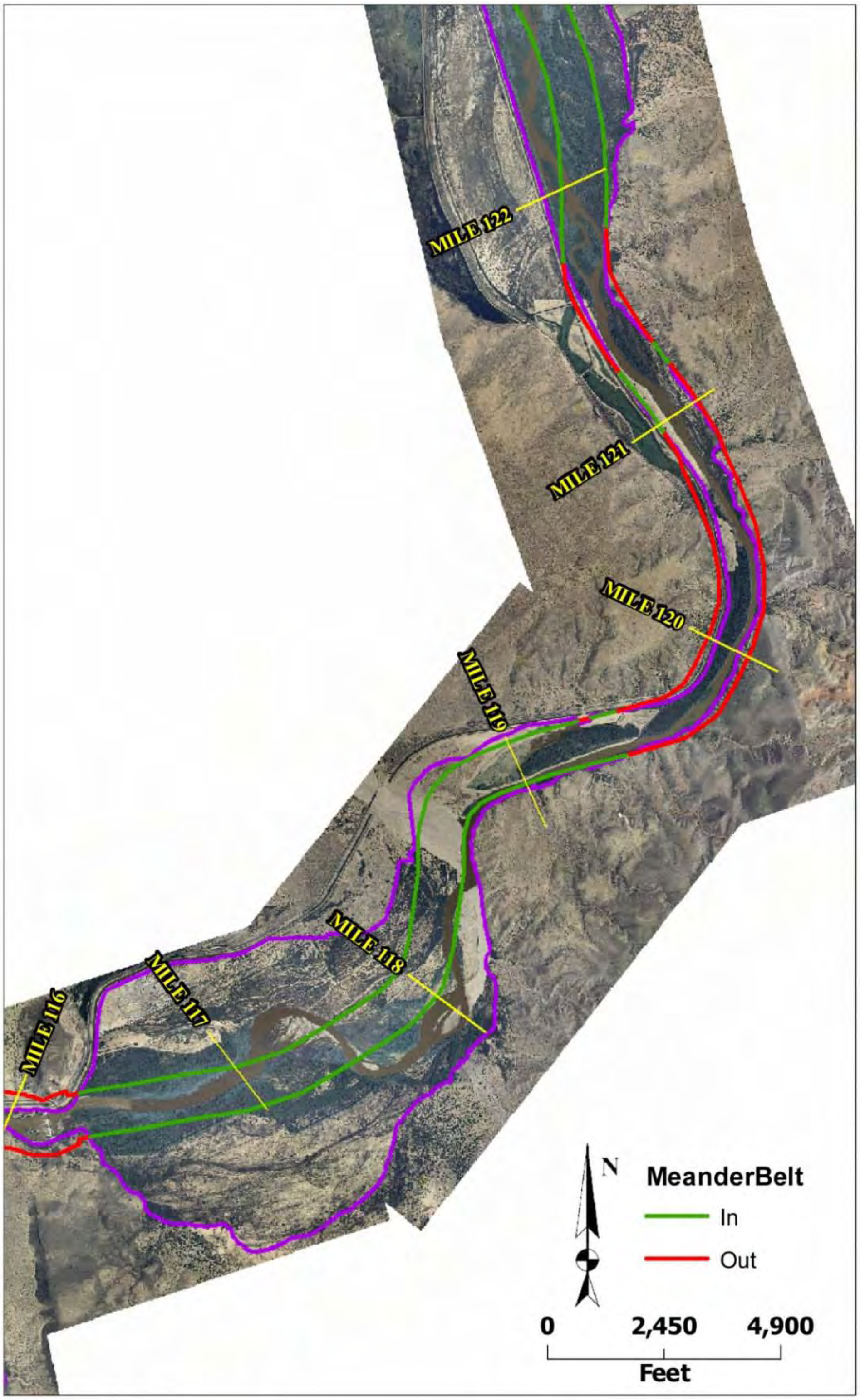


Figure B4.9. Specific location mapping of MBW, Reach 4 (Rio Puerco to San Acacia Diversion Dam).

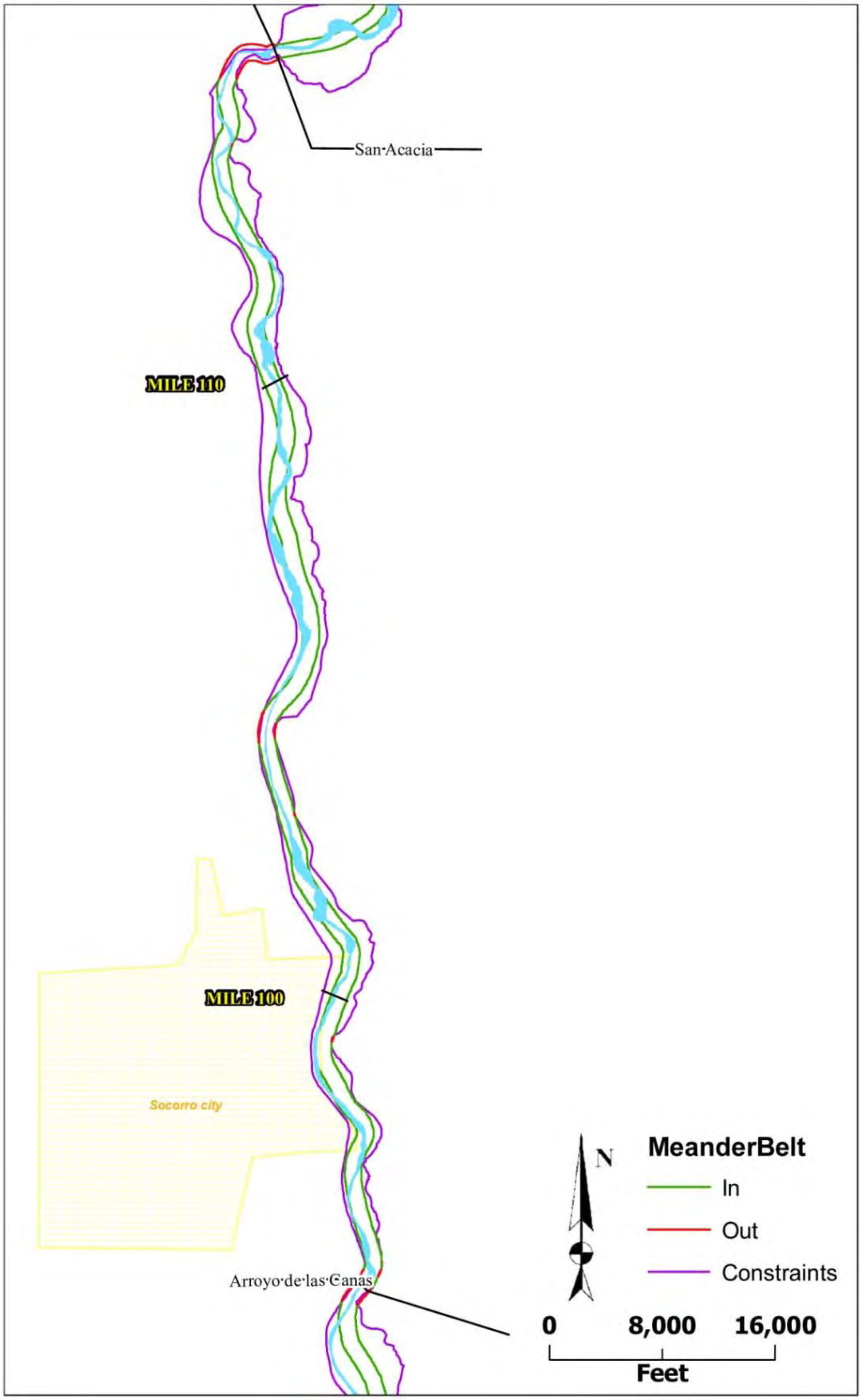


Figure B4.10. Overview mapping of MBW, Reach 5 (San Acacia Diversion Dam to Arroyo de las Cañas).

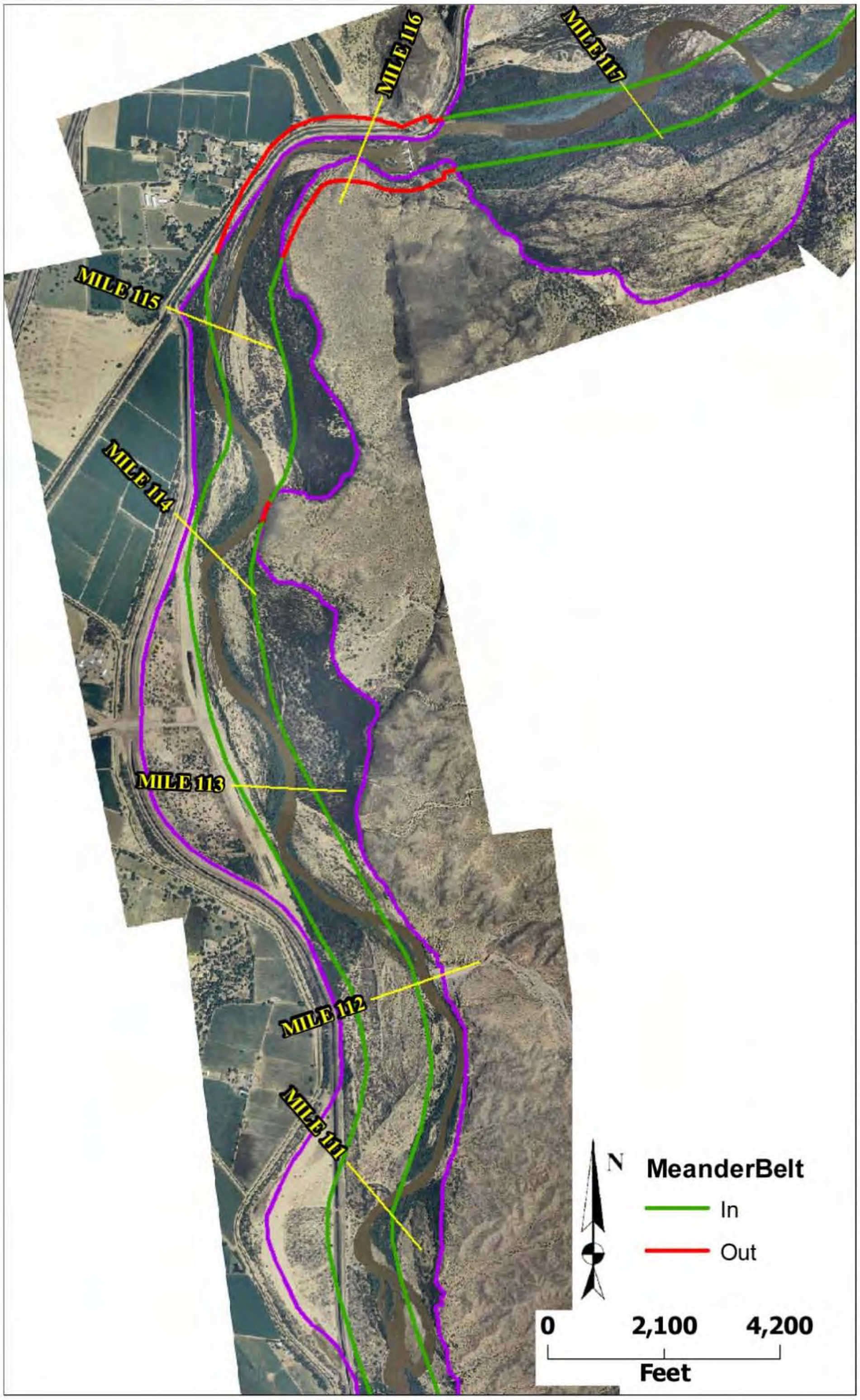


Figure B4.11. Specific location mapping of MBW, Reach 5 (San Acacia Diversion Dam to Arroyo de las Cañas).

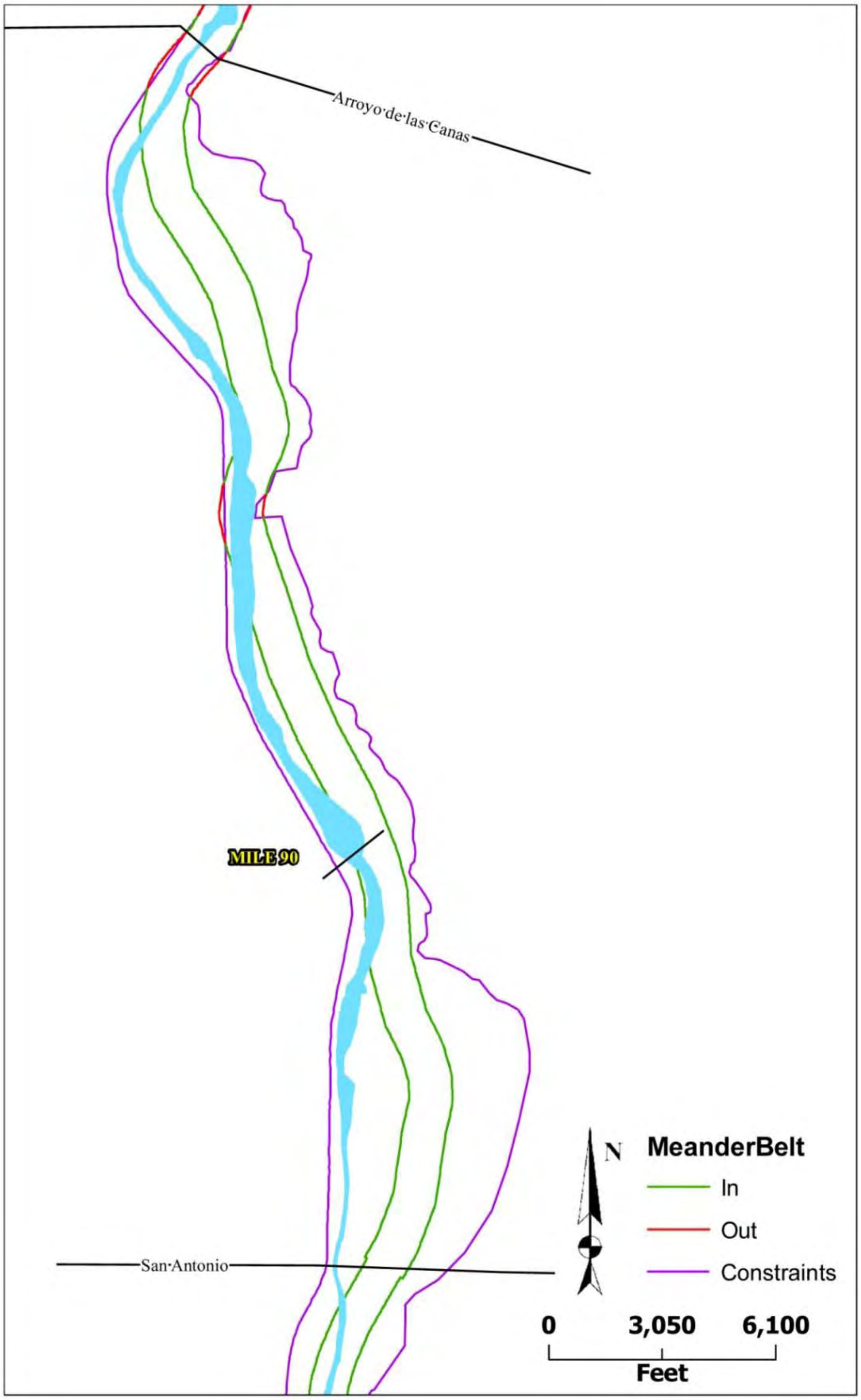


Figure B4.12. Overview mapping of MBW, Reach 6 (Arroyo de las Cañas to San Antonio Bridge).

Figure B4.13. Specific location mapping of MBW, Reach 6 (Arroyo de las Cañas to San Antonio Bridge).

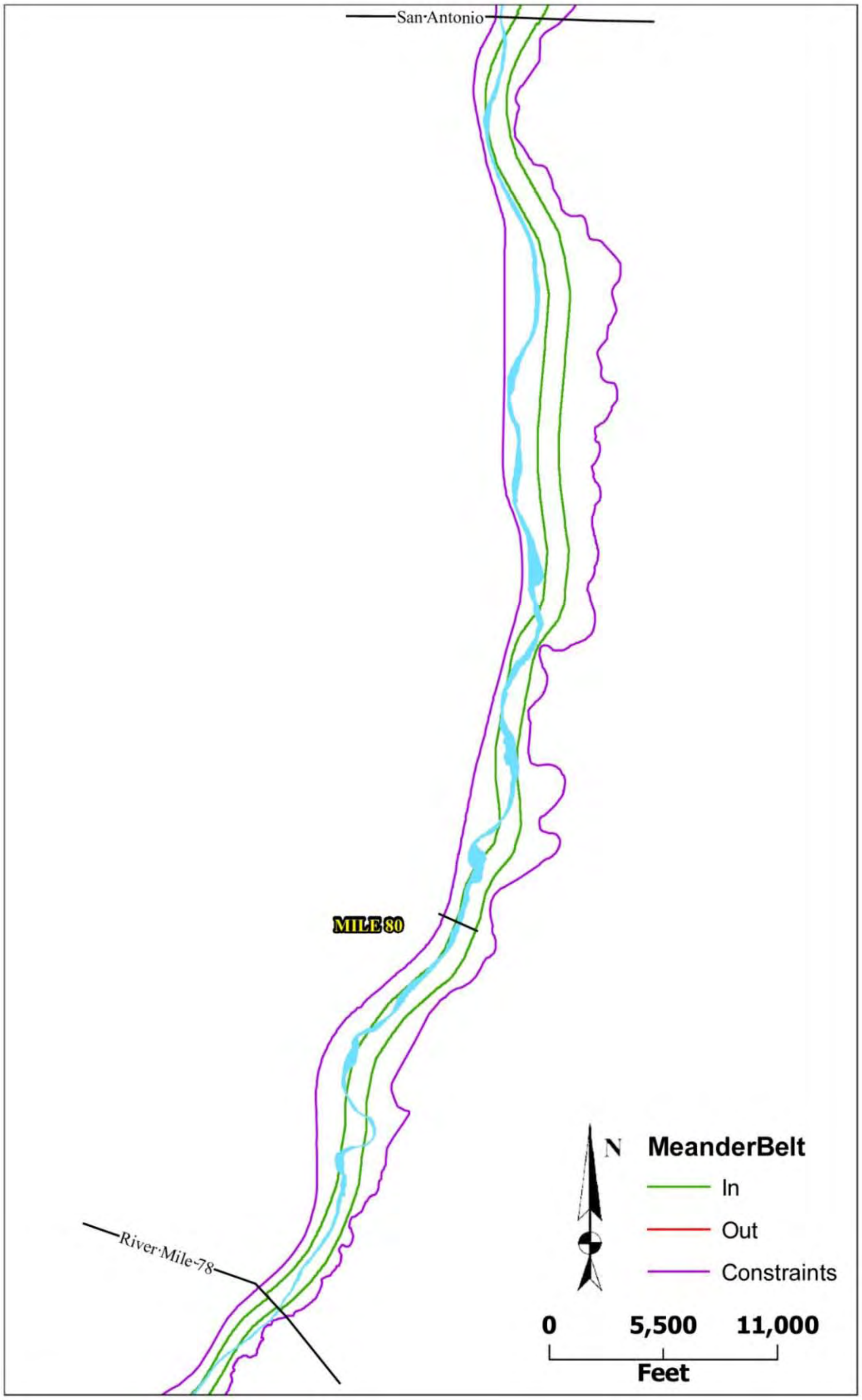


Figure B4.14. Overview mapping of MBW, Reach 7 (San Antonio Bridge to River Mile 78).

Figure B4.15. Specific location mapping of MBW, Reach 7 (San Antonio Bridge to River Mile 78).

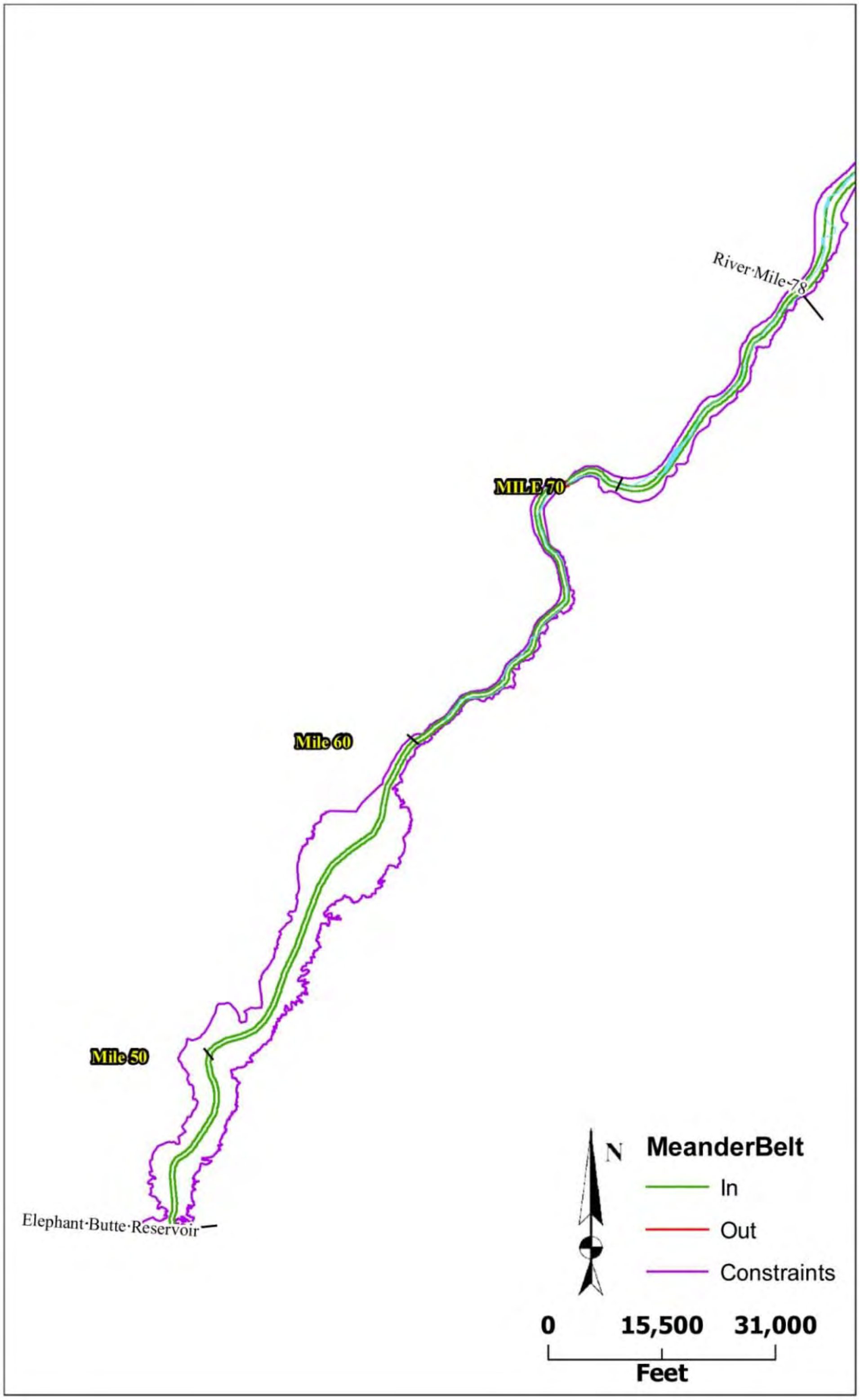


Figure B4.16. Overview mapping of MBW, Reach 8 (River Mile 78 to Elephant Butte Reservoir).

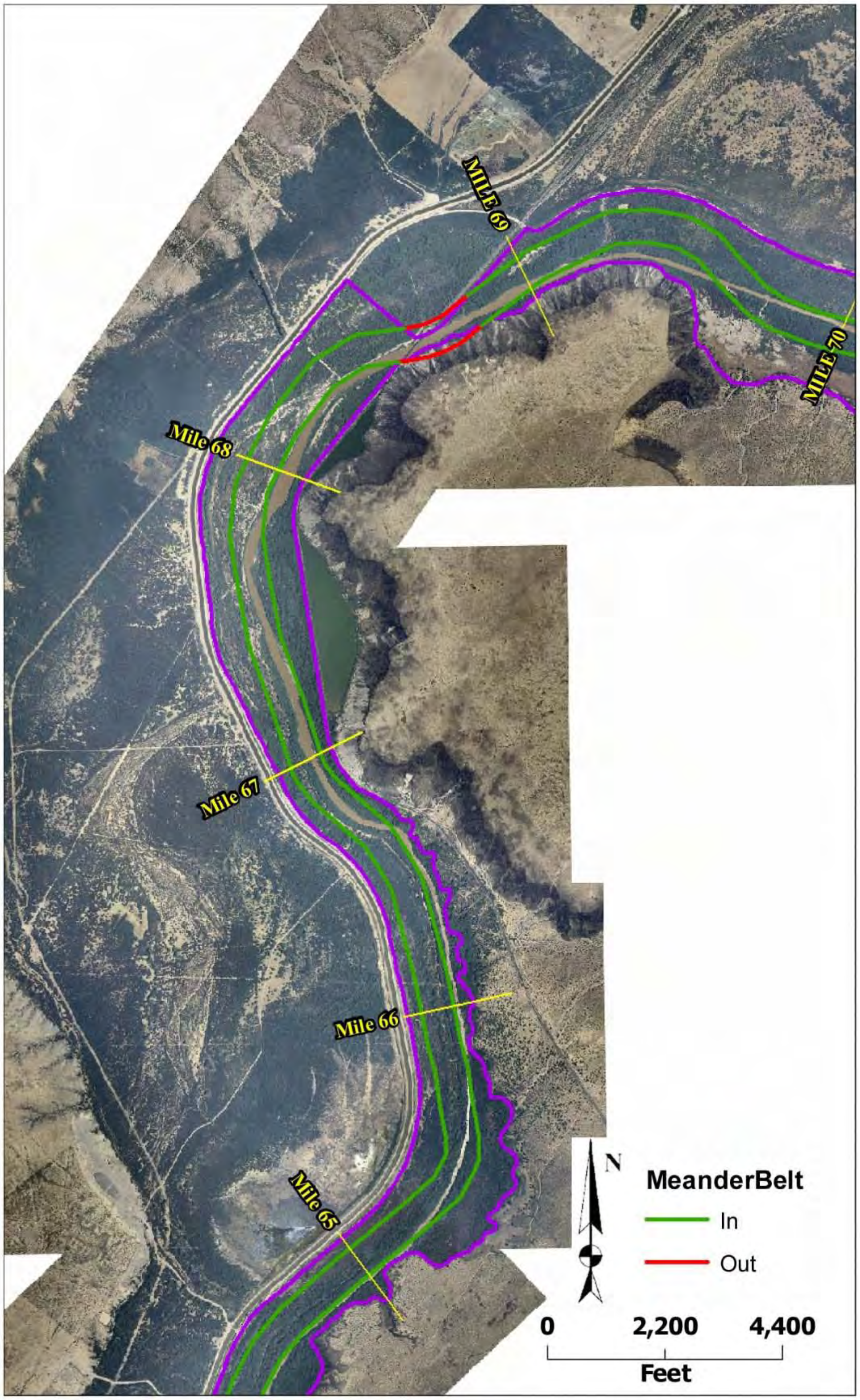


Figure B4.17. Specific location mapping of MBW, Reach 8 (River Mile 78 to Elephant Butte Reservoir).

5 HEC-RAS Strategy Modeling

This section will describe 1D fixed-bed hydraulic modeling of the six strategies as outlined in section 1.1. These geometries were modeled in HEC-RAS at different constant discharges. The HEC-RAS modeling represents implemented strategies and provides information on the expected hydraulic effects of strategy implementation in a reach at representative discharges. Section 5.1 discusses the geometries developed to represent the six strategies, and section 6.1 provides information on the hydraulic modeling of those geometries.

5.1 Strategy Geometry

Four unique geometries are representative of the six strategies considered in this modeling effort. The geometry appropriate for each strategy and the assumptions made are discussed in section 6.2. The four unique geometries are:

- **BASE**. This is the baseline geometry as developed for the SRH-1D model and is described in section 2.2. This geometry represents the current geometry of the Rio Grande.
- **NMF-V**. This is the geometry that is output from the Final SRH-1D simulation. It represents dynamic-equilibrium conditions for current water discharge and sediment discharge characteristics. This geometry assumes that all of the channel adjustment occurs by vertical adjustment in bed elevation.
- **NMF-H**. This geometry is similar to the BASE geometry except that the spacing between the cross sections has been adjusted as described in section 3.5. This geometry assumes that all of the channel adjustment occurs by a change in channel length (channel sinuosity).

  REHAB. This geometry represents Rehabilitate Channel and Floodplain and has three basic assumptions. First, the channel alignment is the same as the baseline condition. Second, the flood plain is set to the water surface elevation corresponding to a discharge of 3,800 cfs at each cross section in the reach. Third, there is a 100-foot buffer from lateral constraints (levee toes or other infrastructure) that would not be altered due to the implementation of this strategy. The development of the geometry involved the following steps:

    - Run a 3,800 cfs discharge through the baseline geometry in HEC-RAS.
    - Do not adjust points that are already below the 3,800 cfs water surface elevation.

- Lower all other points in the cross section (that are more than 100 feet away from lateral constraints) to the water surface elevation corresponding to 3,800 cfs.
- The channel geometry generated by applying the above steps was used to develop the indicators for this strategy. Figure B5.1 presents an example cross section with the baseline and modified geometries.

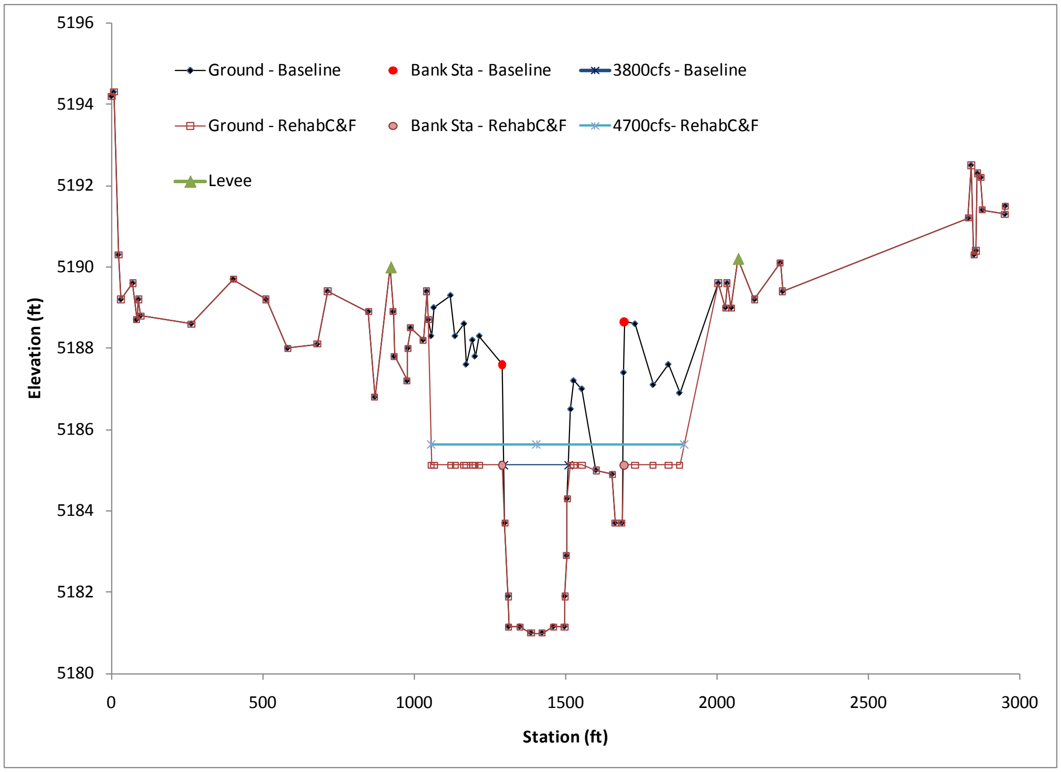


Figure B5.1. Example of cross-section modification for Rehabilitate Channel and Flood Plain.

5.2 Strategy Hydraulics

The unique geometries of section 5.1 were modeled with HEC-RAS, and the hydraulic outputs are one source of data used for the indicators in section 6.1 (the other two sources are the results from the SRH-1D modeling and the meander belt assessment). Boundary conditions were the same as the SRH 1-D model. The first runs used a constant flow of 4,700 cfs and 10,000 cfs. Each geometry was also modeled with stepwise increases of 100 cfs to estimate the flow necessary to go over bank in a reach.

6 Indicators and Indicator Assessment

In an attempt to manage the river in a more at holistic, process-based, reach-wide approach that incorporates habitat protection and enhancement, a myriad of maintenance methods have been identified that can be categorized into six strategies. These six strategies are outlined in section 1.1.

This section will describe the indicators used to compare the strategies for each reach, which will help the managers of the Middle Rio Grande make future maintenance decisions on the potential application of reach-wide approaches. Section 6.1 presents the indicators that are used to assess the strategies, section 6.2 discusses the indicator assessment assumptions, section 6.3 presents the resulting indicators by strategy for each reach, and section 6.4 presents the differentiation of indicator results.

6.1 Indicators

Twenty descriptive indicators have been defined to help compare the strategies for each reach. Some of the indicators are grouped together because of similarities, and these general indicators are labeled from Indicator A to Indicator K. See table B6.1 for a general list and table B6.2 for a more detailed explanation of the indicators. The intent is to have these indicators be as reflective as possible of the physical properties of the strategy implementation. Unless otherwise indicated, the indicators are distance weighted reach-averaged values and reflect a comparison to baseline conditions.

6.2 Indicator Assessment Assumptions

There are six strategies that categorize the myriad of potential maintenance methods available to managers of the Middle Rio Grande. The indicators, as outlined in section 6.1, provide a basis for comparing strategies for each reach. Certain strategies may not be readily represented in this reach-scale, 1D modeling effort. For those strategies, the geometries that are assumed to be representative of the strategy are reported in tables B6.3–B6.10.

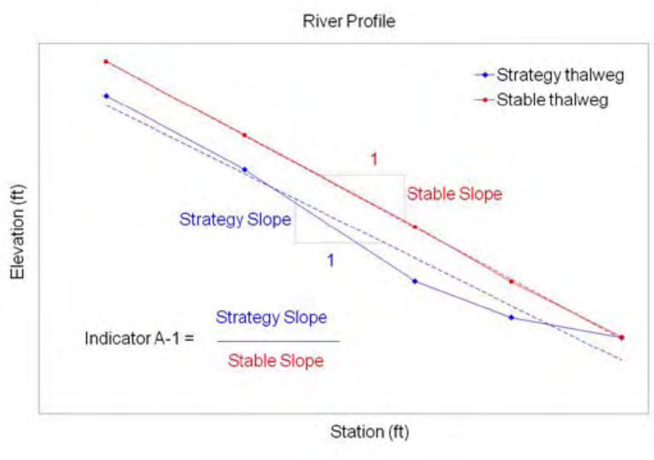
The indicators are developed for the entire domain from Cochiti to Elephant Butte Reservoir for the Baseline, NMF-V, and NMF-H conditions. A strategy is then implemented one reach at a time, with the rest of the domain being made up of the baseline geometry, and the indicators for that reach/strategy combination are

Table B6.1. Indicators and 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 ½ 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-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 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 mm (Strategy only)
2. Percent Sand	Percent of bed material between 0.063 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)

Table B6.2. Indicator Descriptions and Definitions

A. Longitudinal Channel Slope Stability



This indicator is used to compare the strategy slope, the stable slope, and the baseline slope. Strategy slope is the channel reach slope representing the strategy implementation. The stable channel slope is the resulting equilibrium slope from the SRH-1D modeling (NMF-V), and the baseline channel slope is the input geometry as described in section 2.2. The reach slopes are calculated as a linear regression of the channel thalweg points for all of the non-interpolated cross sections within that reach for each appropriate scenario (strategy/baseline/stable).

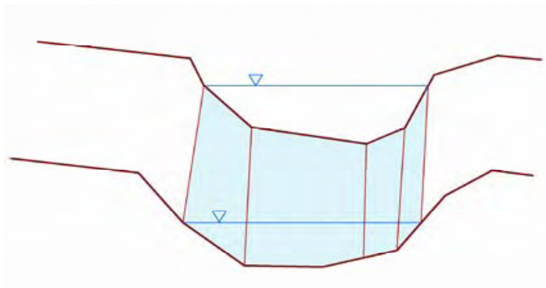
A1. Strategy Slope/Stable Slope. The further this indicator value is from unity suggests greater initial and subsequent maintenance as well as greater anticipated morphological change. The figure above presents the ratio for A1, which can be generalized for A2 and A3 by conceptually substituting the baseline slope in the appropriate place. The dashed lines in the figure represent the linear regression of the thalweg points for all of the non-interpolated cross sections within the reach.

A2. Strategy Slope/Baseline Slope. The further this indicator value is from unity suggests the level of initial investment that would likely be needed to implement the strategy.

A3. Baseline Slope/Stable Slope. This indicator describes the degree of departure of the current geometry relative to the estimated equilibrium condition. This ratio is independent of strategy.

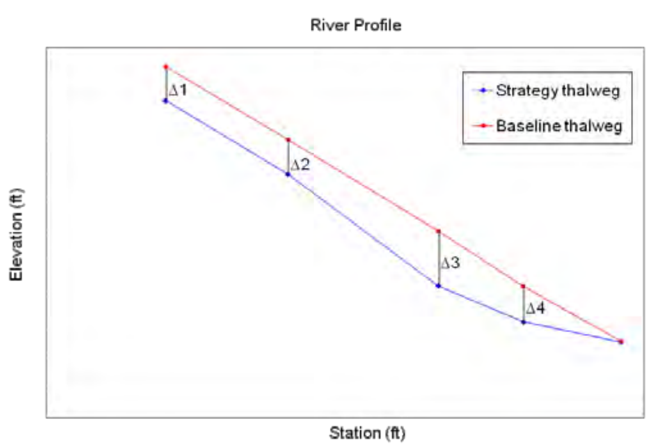
Table B6.2. Indicator Descriptions and Definitions

B. Wetted Area at 4,700 cfs



This indicator is evaluated as the strategy wetted area divided by the baseline wetted area, both evaluated at a discharge of 4,700 cfs. The wetted area is calculated by summing the product of the wetted perimeter for each cross section by the length represented by that cross section. When the wetted perimeter of the strategy is greater than the baseline (indicator >1) then the biological value of the strategy is assumed to increase from the baseline condition due to wetting more bank line habitat and increased overbank flows. When the wetted area of the strategy is less than the baseline condition (indicator <1), then water delivery is assumed to generally improve, owing to smaller seepage losses. If a given reach is currently a losing reach, then reducing the wetted area may have even greater water delivery benefits than for a non-losing reach. A qualitative discussion on losing and gaining reaches along the Middle Rio Grande can be found in S.S. Papadopulos & Associates (2008).

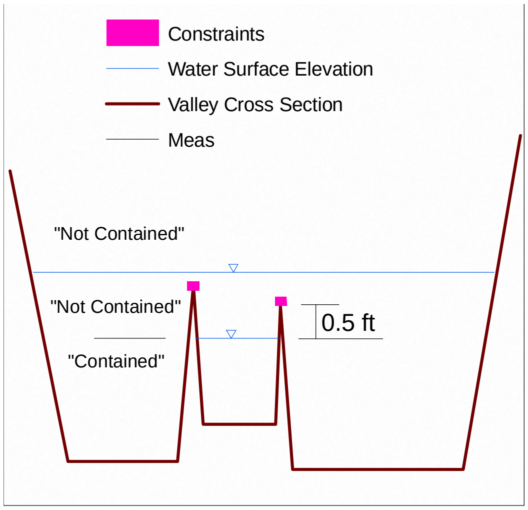
C. Bed Elevation Change



This indicator is evaluated by subtracting the baseline thalweg elevation from the strategy thalweg elevation at each cross section and then distance weighting these differences to develop a reach average. In general, a negative indicator value would be better for water delivery, while a positive value would be better for ecosystem. This is owing to the fact that a raising bed would wet more channel margin habitat areas more frequently, while a lowering bed elevation tends to create a channel that is more disconnected from its historical flood plain.

Table B6.2. Indicator Descriptions and Definitions

D. Containment of 10,000 cfs

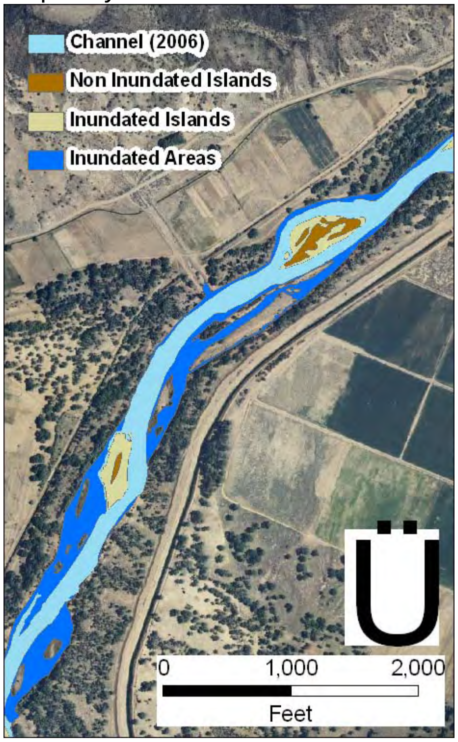


The two possible values for this indicator are “contained” and “not contained” and are determined by comparing the water surface elevation for a discharge of 10,000 cfs to the lowest (left or right) lateral constraint elevation. An indicator value that is “contained” results when the water surface elevation for 10,000 cfs is more than 0.5 ft lower than the lowest lateral constraint elevation for every cross section in the reach. This indicates a greater hydraulic capacity to convey flows without flooding infrastructure given the error in survey data (0.5 foot), recognizing that lateral channel migration can create a public safety issue even at sites with large hydraulic capacity. A value of “not contained” is given when the water surface elevation for 10,000 cfs is either above the lowest lateral constraint elevation or is within 0.5 ft of the lowest lateral constraint elevation for at least one cross section in the reach. In these reaches there is an increased likelihood of the levee being overtopped or the zone of protection for infrastructure (which are not protected by levees) becoming inundated.

Table B6.2. Indicator Descriptions and Definitions

E. Overbank Inundation

The indicator E1 is intended to assess the degree of relative overbank inundation area at a typical high flow (June 2008) for a reach, and E2 is intended to assess the frequency of overbank inundation flows.



E1. High Flow Inundated Area/Channel Area. The June 10, 2008, high-flow aerial photography was digitized and classified by Aerometric (http://www.aerometric.com/). The inundated area in 2008 was compared to channel and island areas digitized from 2006 aerial photography to classify polygons of "Channel," "Inundated Areas," "Inundated Islands," and "Non-Inundated Islands." The term "channel" represents the main stem of the flow conditions as digitized from 2006 photography. "Inundated Areas" do not include the channel or islands defined by the 2006 photography, but do include bars, flood plains, and abandoned channels that were submerged by the June 2008 high-flow event. The islands defined in the 2006 photography were split into "Inundated Islands" and "Non-Inundated Islands" based on whether they were underwater in the 2008 photography. This dataset captures the inundation patterns of the peak June 2008 runoff between Cochiti Dam and the power lines below Black Mesa. Mean daily flows on June 10 vary between (USGS) gauges and are as follows:

08317400 Rio Grande Below Cochiti Dam, NM – 5,280 cfs
08319000 Rio Grande At San Felipe, NM – 5,390 cfs
08330000 Rio Grande At Albuquerque, NM – 5,080 cfs
08354900 Rio Grande Floodway At San Acacia, NM – 3,990 cfs
08358400 Rio Grande Floodway At San Marcial, NM – 3,460 cfs

When indicator values are >1, then the biological value of the strategy is assumed to increase from the baseline condition due to wetting more overbank habitat. When the indicator is <1, then water delivery is assumed to generally improve, owing to smaller evaporation losses. These flows are near the modeled 4,700 cfs used for other indicators. There is much greater accuracy of measuring the actual inundated area in a reach versus using a calculated inundation area based on widely spaced cross sections. Professional judgment will be used in subsequent analyses to help describe changes in effects that would be due to strategies that result in a slope different than baseline conditions.

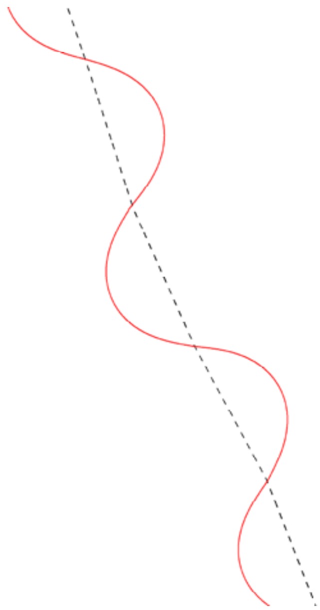
Table B6.2. Indicator Descriptions and Definitions

E2. 4,700 cfs/Overbank Inundation Discharge. This indicator is intended to suggest the frequency of an overbanking event. A flow of 4,700 cfs is a relatively frequent flow event (~2-year peak discharge). It is assumed that smaller flow events occur more frequently such that an overbanking flow lower than 4,700 cfs (indicator value >1) would lead to more frequent overbanking than a higher overbanking flow (indicator value <1). The overbank discharge is based on the HEC-RAS modeling and is the discharge at which ½ of the reach length has less than 100 percent of the flow identified as "in channel. In the HEC-RAS hydraulic model, only two bank points (left and right banks) may be assigned to any given cross section. For this reason, an island that may be in effect an in-channel flood plain (a well-established, vegetated island as opposed to a sandbar) does not get used in determining this overbank discharge other than perhaps having a higher roughness value, which may influence the water surface elevation for a given discharge. Therefore, the overbank flow is, if anything, an overestimate, and the actual flows required to cause overbanking may be lower.

Table B6.2. Indicator Descriptions and Definitions

F. Sinuosity

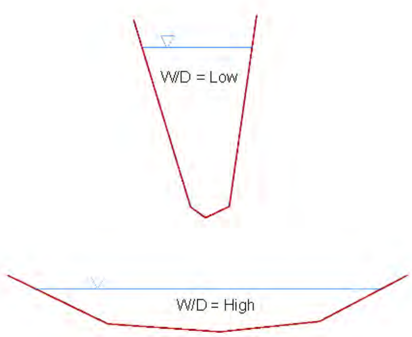
This indicator reports the sinuosity for a reach/strategy combination (F1) and how that sinuosity compares to the baseline sinuosity for that reach (F2).



F.1. Strategy Sinuosity. Sinuosity is commonly defined as the channel length divided by the valley length. The valley length is determined based on the lateral constraints as described in section 4. A line was digitized along the centerline of the lateral constraints, and the length of this line within each reach determines the valley length for that reach. The valley length is independent of strategy. The river length for each reach comes directly from the HEC-RAS model, which is based on the geometry as described in sections 2.2 and 3.5. Table B3.4 presents the baseline sinuosity and NMF-H sinuosity by reach.

F.2. Strategy Sinuosity/Baseline Sinuosity. Some of the strategies involve a river length that is different from the baseline river length. This indicator compares the sinuosity of the strategy to the sinuosity of the baseline condition, which is evaluated as the strategy river length divided by the baseline river length (valley length for a reach is constant and independent of strategy). For cases in which this indicator value is larger than 1, it is assumed that increasing sinuosity would result in eroding banks along the outside of channel bends and new depositional areas on the inside of bends. An indicator value >1 improves the ecosystem, owing to the fact that there are eroding banks and new depositional surfaces, while indicator values <1 would improve or keep water delivery about the same as the current baseline condition.

G. Width-Depth Ratio at 4,700 cfs



This indicator is evaluated as the width-to-depth ratio for the strategy divided by the width-to-depth ratio for the baseline condition, both evaluated at 4,700 cfs. This ratio is used to assess the hydraulic efficiency of the channel shape. A ratio smaller than 1 means that the channel would become narrower and/or deeper. A ratio larger than 1 represents a case in which the channel would become wider and/or shallower. Thus, an indicator value <1 would mean that water delivery could potentially improve as a result of greater conveyance and less water surface evaporation. An indicator value >1 means there is a potential for the channel to widen with more channel margin habitat. This would tend to improve Rio Grande silvery minnow habitat as long as a minimum depth is maintained. A wider channel with more inundated overbank areas is also beneficial for the southwestern willow flycatcher.

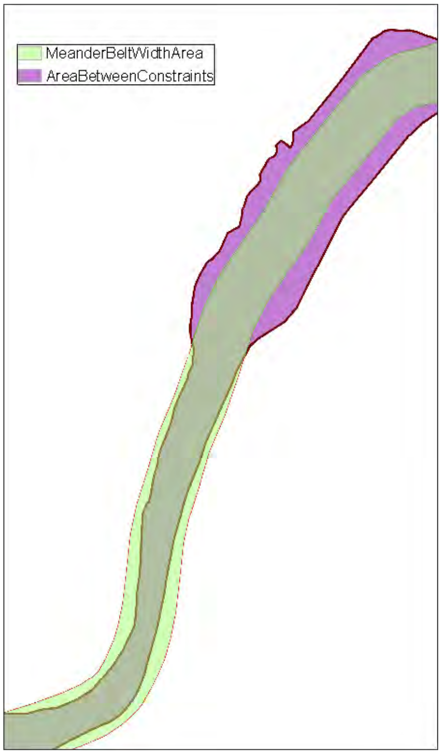
Table B6.2. Indicator Descriptions and Definitions

H. Meander Width

This indicator describes the interaction between the river MBW needed for a stable channel and the available valley between the lateral constraints. The needed MBW is based on a sine-generated curve and has been estimated as described in section 4. It is very important to remember that the needed MBW is centered on a line digitized according to the lateral constraints.

H1. Percent Fit of Length. This indicator represents the portion of the reach length where the meander belt is not confined by lateral constraints. It is calculated by considering the length of the left and right extent of the meander belt. The length of the left meander edge, which fits inside of the lateral constraints, is added to the length of the right meander edge, which fits inside of the lateral constraints, and this sum is divided by the summed length of the left and right edges of the meander belt.

Table B6.2. Indicator Descriptions and Definitions



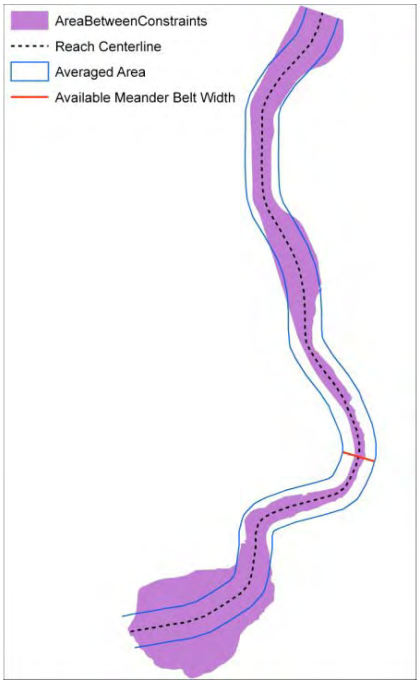
H2. Meander Belt Width Area/Area Between Lateral Constraints

This indicator is intended to assess how well a meandering single-thread channel would fit between lateral constraints on an area basis. The reach average MBW multiplied by the longitudinal length of each reach results in an area of the MBW by reach. Similarly, the area between the constraints is calculated in ArcGIS based on the digitized lateral constraints described in section 4.

An indicator value >1 would mean that the MBW is constrained in at least some locations within the reach. The smaller this indicator value, the more room there is between constraints for natural channel processes to occur.

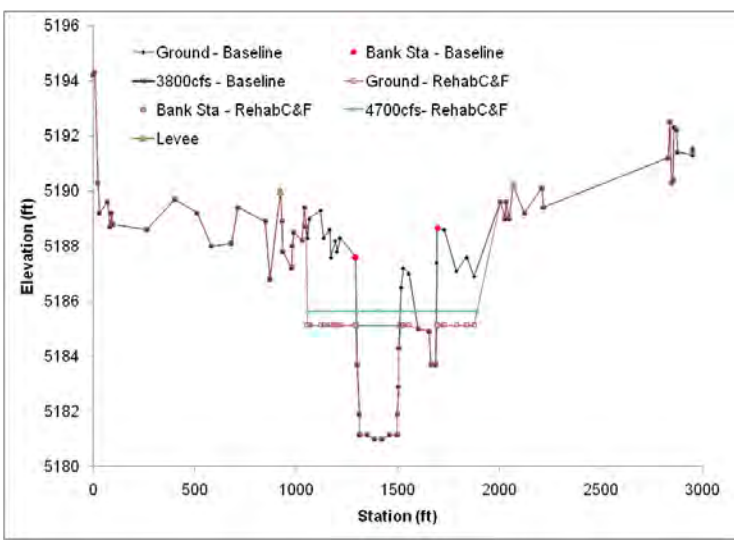
Table B6.2. Indicator Descriptions and Definitions

I. Wetted Width at 4,700 cfs/Width Between Lateral Constraints



The strategy wetted width is the reported top width from HEC-RAS at a discharge of 4,700 cfs. The available MBW is a reach-averaged value and is calculated as the area bounded by the lateral constraints divided by the length of the centerline digitized between the constraints. This indicator is an estimate of how much of the width between lateral constraints is inundated at 4,700 cfs. The maximum possible ratio of 1 means that the entire area is inundated by a flow of 4,700 cfs. The greater this ratio, the more area that is inundated, which assumes there is more opportunity for habitat complexity and is better for the ecosystem. A lower value indicates more effective water conveyance.

J. Wetted Width at 4,700 cfs

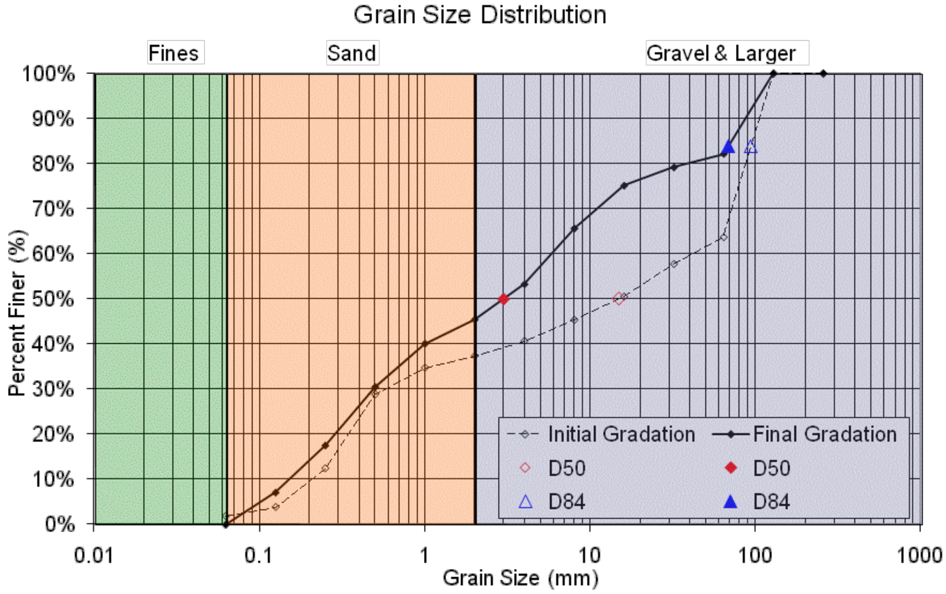


This indicator is calculated as the strategy wetted width (top width) divided by the baseline wetted width, both evaluated at a discharge of 4,700 cfs. An indicator value <1 suggests that the strategy wetted width is smaller than the baseline wetted width, which is better for efficient water conveyance. Conversely, indicator values >1 means there is more potential for increased overbank and or channel margin wetting, which could improve habitat and increase ecosystem function.

Table B6.2. Indicator Descriptions and Definitions

K. Bed Material

The bed material grain size distribution is represented by the following indicators to better describe the characteristic reach properties for a given strategy. The grain size distributions for all of the cross sections in a reach are averaged to produce a representative grain size distribution for a reach by strategy.



K1. Percent Fines. This is the percentage of the strategy grain size distribution that is <0.0625 mm. This indicator added to K2 and K3 equals 100%.

K2. Percent Sand. This is the percentage of the strategy grain size distribution that is >0.0625 mm and <2 mm. This indicator added to K1 and K3 equals 100%.

K3. Percent Gravel. This is the percentage of the strategy grain size distribution that is >2 mm. This includes cobble sized material. This indicator added to K1 and K2 equals 100%.

K4. Strategy D50/Baseline D50. This indicator is calculated as the strategy median grain size divided by the baseline median grain size. An indicator value >1 means that the overall reach bed material is coarser due to the strategy relative to the baseline condition.

K5. Strategy D84/Baseline D84. This indicator is calculated as the grain size representing the 84th percentile of the strategy grain size distribution divided by the grain size representing the 84th percentile of the baseline grain size distribution. An indicator value >1 means that the overall reach bed material is coarser due to the strategy relative to the baseline condition.

developed. For instance, assessment of the strategy Rehabilitate Channel and Flood Plain in Reach 1 (Cochiti Dam to Angostura Diversion Dam) would be completed by having the baseline geometry make up Reaches 2 through 8 and the REHAB geometry (section 5.1) in Reach 1.

The assumptions made in assessing these strategies and applying geometries (including the no action modeling scenario NMF) are outlined as follows:

- **No Maintenance Future Modeling Scenario**. This theoretical no action scenario would be best represented by a 2D mobile bed and bank sediment transport model. Due to time, cost, and data limitations, it was necessary to represent the potential lateral and vertical river response with two separate 1D models:
    - Vertical (NMF-V). This represents the possible 1D vertical adjustments the river might sustain with a fixed alignment and an unchanging river width. The geometry and resulting hydraulics of this scenario are represented by the results of the SRH-1D modeling (Final simulation).
    - Horizontal (NMF-H). This represents the possible 1D adjustment in planform (river length) assuming changes in neither river width nor cross-section elevation. The representative geometry for this scenario is achieved by adjusting the spacing between the baseline geometry cross sections such that the resulting reach slopes are equal to the equilibrium slopes produced by the SRH-1D modeling.
- **Promote Elevation Stability**. Implementations of this strategy generally involve cross-channel features (drop structures, engineered riffles, etc.). Due to fish passage criteria, the maximum height of these features is 1 foot. The indicators using flow rates are assessed at a discharge of 4,700 cfs (except for Indicator D), and it is assumed that this flow rate would likely hydraulically submerge the transverse features, minimizing the difference in hydraulic properties between this strategy and the baseline condition. In addition, properly capturing the geometry of these transverse features would involve a number of tightly spaced cross sections in the vicinity of these features, and disparate cross-section spacing could lead to instabilities in the SRH-1D model. For these reasons, it is assumed that the indicators for this strategy are adequately represented by the indicators for the baseline condition (BASE) and no modeling specific to this strategy was performed.
- **Promote Alignment Stability**. Implementation of this strategy would first allow channel migration and bank erosion until infrastructure becomes threatened, at which time bank protection measures would be performed. The modeling of this strategy includes reviewing Indicator H

(H1 and H2) for the baseline and the NMF-H condition. The assumed representative indicators are either the baseline (BASE) or the NMF-H condition, depending on H1 and H2 for these conditions. Section 6.2 will further discuss which condition is assumed appropriate for each reach.

- **Reconstruct and Maintain Channel Capacity**. This strategy maintains the baseline geometry. Therefore, the indicators for the baseline condition (BASE) are assumed to be representative of this strategy.
- **Increase Available Area to the River**. Implementation of this strategy involves levee setbacks and/or infrastructure relocation depending on the reach. In assessing this strategy, it is assumed that levees are set back and infrastructure relocated to at least allow the calculated MBW to fit within the new lateral constraints. That is, the Indicator H1 is assumed to be equal to 1, and the NMF-H is assumed to be the representative geometry for this strategy.
- **Rehabilitate Channel and Flood Plain**. Implementation of this strategy could involve longitudinal bank lowering and/or bank clearing. The REHAB geometry was specifically developed for this strategy and the hydraulics resulting from implementing the REHAB geometry in HEC-RAS are used in calculating indicator values.
- **Manage Sediment**. Implementing this strategy would involve sediment removal, sediment exclusion, or sediment augmentation depending on whether the reach tends to be aggrading or degrading. Theoretically, the amount of sediment added or removed from the reach would be just enough to establish a balance between sediment supply and the sediment transport capacity of the reach. If a balance is established, it is assumed that minimal channel adjustments would occur, and therefore, the baseline condition geometry (BASE) is sufficient to represent the geometry for this strategy. This strategy assessment does not consider sediment sizes for augmentation at this stage of analysis, only volumes. Volume estimates for augmentation were made by plotting SRH-1D model output for the sediment deposition (tons converted to cubic feet) versus time for a given reach. The early linear portion of the chart provides for a rate of material loss as a function of time, which provides guidance to the volume of sediment augmentation needed. Figure B6.1 exemplifies the augmentation estimation for Reach 3 (Isleta Diversion Dam to Rio Puerco) was just over 100,000 cubic yards per year. The same approach yields an estimated 30,000 cubic yards per year of sediment augmentation for Reach 2 (Angostura Diversion Dam to Isleta Diversion Dam). These are the only two reaches that have been identified as fit for sediment augmentation as a reach strategy.

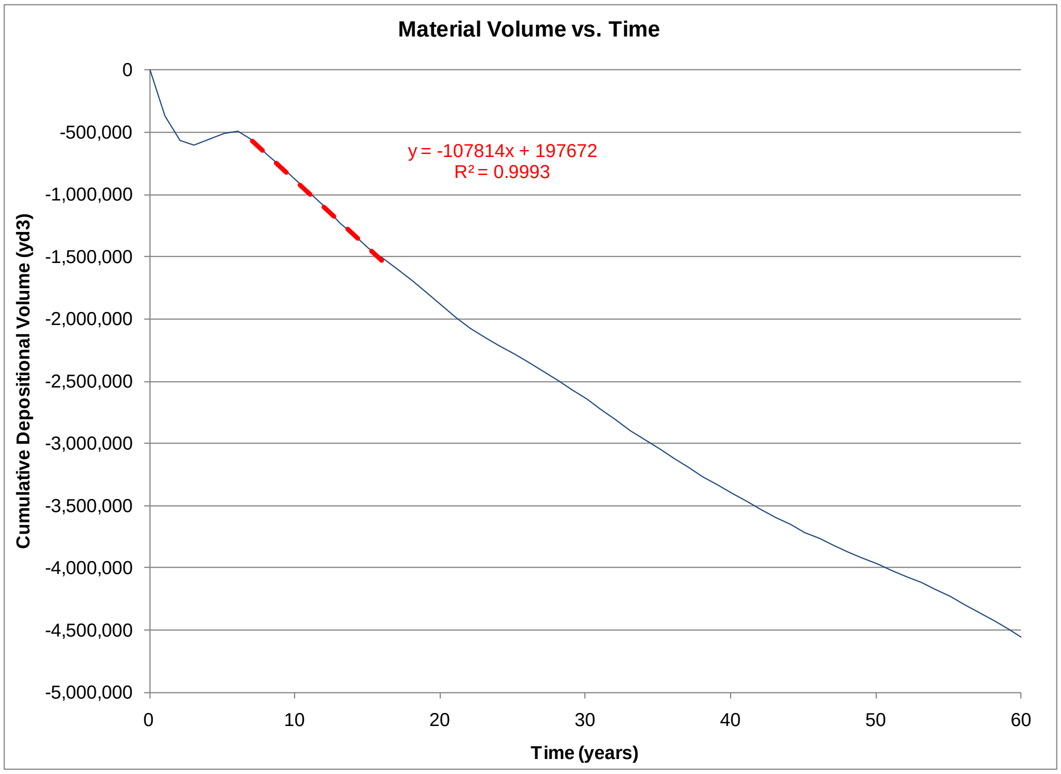


Figure B6.1. Sediment augmentation estimate based on volume of erosion (negative deposition) for Reach 3 (Isleta Diversion Dam to Rio Puerco).

6.3 Resulting Indicators Values

Indicators were developed for all reaches and all strategies regardless of the initial suitability screening process. Unique geometry (and therefore unique indicators) for some of the strategies could not be developed at this level of analysis. The appropriately assumed values are reported in the tables B6.3–B6.10. These tables present the indicators for all strategies and all reaches. Some indicators are not reported for all strategies (e.g., Indicator A3 is only presented under NMF-V, as this indicator is independent of strategy). Also, E1 is based on aerial photographs (not the 1D modeling) and is reported for the baseline condition, as extrapolating this indicator to the various strategies is not possible at this level of analysis. As well, the K indicators are only presented for the baseline condition (Reconstruct/ Maintain Channel Capacity) and for NMF-V (SRH-1D results), as extrapolating bed material gradations for the various strategies involves more uncertainty than for the hydraulics.

Table B6.3. All indicators for Reach 1 (Cochiti Dam to Angostura Diversion Dam)

Cochiti to Angostura	No Maintenance Future[1] Vertical	No Maintenance Future[1] Horizontal	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to River	Rehabilitate Channel and Floodplain	Manage Sediment
A. Longitudinal Channel Slope Stability	--	--	--	--	--	--	--	--
1. Strategy Slope / Stable Slope	1.00	1.00	1.04	1.00	1.04	1.00	1.04	1.04
2. Strategy Slope / Baseline Slope	0.96	0.96	1.00	0.96	1.00	0.96	1.00	1.00
3. Baseline Slope / Stable Slope	1.04							
B. Wetted Area at 4,700 cfs	0.95	1.05	1.00	1.05	1.00	1.05	3.84	1.00
C. Bed Elevation Change	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D. Containment of 10,000 cfs[2]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
E. Overbank Inundation	--	--	--	--	--	--	--	--
1. High Flow Inundated Area / Channel Area					1.94			
2. 4,700 cfs / Overbank Inundation Discharge	0.98	1.15	1.12	1.15	1.12	1.15	1.38	1.12
F. Sinuosity	--	--	--	--	--	--	--	--
1. Strategy Sinuosity	1.10	1.15	1.10	1.15	1.10	1.15	1.10	1.10
2. Strategy Sinuosity / Baseline Sinuosity	1.00	1.04	1.00	1.04	1.00	1.04	1.00	1.00
G. Width-Depth Ratio at 4,700 cfs	0.78	1.00	1.00	1.00	1.00	1.00	8.31	1.00
H. Meander Width	--	--	--	--	--	--	--	--
1. Percent Fit of Length	0.71	0.62	0.71	0.62	0.71	1.00	0.71	0.71
2. Meander Belt Width Area / Area Between Lateral Constraints	0.72	0.82	0.72	0.82	0.72	0.74	0.72	0.72
I. Wetted Width at 4,700 cfs / Width Between Lateral Constraints	0.22	0.27	0.27	0.27	0.27	0.27	0.94	0.27
J. Wetted Width at 4,700 cfs	0.83	1.01	1.00	1.01	1.00	1.01	3.46	1.00
K. Bed Material	--	--	--	--	--	--	--	--
1. Percent Fines	0.00				0.01			
2. Percent Sand	0.06				0.10			
3. Percent Gravel	0.94				0.90			
4. Strategy D50 / Baseline D50	0.85				1.00			
5. Strategy D84 / Baseline D84	0.89				1.00			

[1] The NMF-V and NMF-H indicator values are developed for the entire river and are not developed by reach

[2] A value of "Yes" means containment. A value of "No" means that it is not contained.

Table B6.4. All indicators for Reach 2 (Angostura Diversion Dam to Isleta Diversion Dam)

Angostura to Isleta	No Maintenance Future[1] Vertical	Horizontal	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to River	Rehabilitate Channel and Floodplain	Manage Sediment
A. Longitudinal Channel Slope Stability	--	--	--	--	--	--	--	--
1. Strategy Slope / Stable Slope	1.00	1.00	1.01	1.00	1.01	1.00	1.01	1.01
2. Strategy Slope / Baseline Slope	0.99	0.99	1.00	0.99	1.00	0.99	1.00	1.00
3. Baseline Slope / Stable Slope	1.01							
B. Wetted Area at 4,700 cfs	1.05	1.01	1.00	1.01	1.00	1.01	3.02	1.00
C. Bed Elevation Change	-0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D. Containment of 10,000 cfs[2]	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
E. Overbank Inundation	--	--	--	--	--	--	--	--
1. High Flow Inundated Area / Channel Area					1.75			
2. 4,700 cfs / Overbank Inundation Discharge	0.73	0.76	0.76	0.76	0.76	0.76	1.27	0.76
F. Sinuosity	--	--	--	--	--	--	--	--
1. Strategy Sinuosity	1.04	1.05	1.04	1.05	1.04	1.05	1.04	1.04
2. Strategy Sinuosity / Baseline Sinuosity	1.00	1.01	1.00	1.01	1.00	1.01	1.00	1.00
G. Width-Depth Ratio at 4,700 cfs	1.03	1.00	1.00	1.00	1.00	1.00	6.69	1.00
H. Meander Width	--	--	--	--	--	--	--	--
1. Percent Fit of Length	0.59	0.51	0.59	0.59	0.59	1.00	0.59	0.59
2. Meander Belt Width Area / Area Between Lateral Constraints	0.89	0.93	0.89	0.89	0.89	0.86	0.89	0.89
I. Wetted Width at 4,700 cfs / Width Between Lateral Constraints	0.26	0.26	0.26	0.26	0.26	0.26	0.76	0.26
J. Wetted Width at 4,700 cfs	1.00	1.00	1.00	1.00	1.00	1.00	2.94	1.00
K. Bed Material	--	--	--	--	--	--	--	--
1. Percent Fines	0.02				0.00			
2. Percent Sand	0.26				0.26			
3. Percent Gravel	0.72				0.74			
4. Strategy D50 / Baseline D50	0.76				1.00			
5. Strategy D84 / Baseline D84	0.61				1.00			

[1] The NMF-V and NMF-H indicator values are developed for the entire river and are not developed by reach

[2] A value of "Yes" means containment. A value of "No" means that it is not contained.

Table B6.5. All indicators for Reach 3 (Isleta Diversion Dam to Rio Puerco)

Isleta to Rio Puerco	No Maintenance Future[1] Vertical	No Maintenance Future[1] Horizontal	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to River	Rehabilitate Channel and Floodplain	Manage Sediment
A. Longitudinal Channel Slope Stability	--	--	--	--	--	--	--	--
1. Strategy Slope / Stable Slope	1.00	1.00	1.01	1.00	1.01	1.00	1.01	1.01
2. Strategy Slope / Baseline Slope	0.99	0.99	1.00	0.99	1.00	0.99	1.00	1.00
3. Baseline Slope / Stable Slope	1.01							
B. Wetted Area at 4,700 cfs	0.96	1.01	1.00	1.01	1.00	1.01	3.57	1.00
C. Bed Elevation Change	-0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D. Containment of 10,000 cfs[2]	No	No	No	No	No	No	Yes	No
E. Overbank Inundation	--	--	--	--	--	--	--	--
1. High Flow Inundated Area / Channel Area					2.13			
2. 4,700 cfs / Overbank Inundation Discharge	0.54	0.70	0.69	0.70	0.69	0.70	1.81	0.69
F. Sinuosity	--	--	--	--	--	--	--	--
1. Strategy Sinuosity	1.03	1.04	1.03	1.04	1.03	1.04	1.03	1.03
2. Strategy Sinuosity / Baseline Sinuosity	1.00	1.01	1.00	1.01	1.00	1.01	1.00	1.00
G. Width-Depth Ratio at 4,700 cfs	0.91	1.00	1.00	1.00	1.00	1.00	7.33	1.00
H. Meander Width	--	--	--	--	--	--	--	--
1. Percent Fit of Length	0.97	0.94	0.97	0.97	0.97	1.00	0.97	0.97
2. Meander Belt Width Area / Area Between Lateral Constraints	0.64	0.70	0.64	0.64	0.64	0.70	0.64	0.64
I. Wetted Width at 4,700 cfs / Width Between Lateral Constraints	0.22	0.23	0.23	0.23	0.23	0.23	0.81	0.23
J. Wetted Width at 4,700 cfs	0.96	1.00	1.00	1.00	1.00	1.00	3.59	1.00
K. Bed Material	--	--	--	--	--	--	--	--
1. Percent Fines	0.02				0.01			
2. Percent Sand	0.36				0.50			
3. Percent Gravel	0.62				0.49			
4. Strategy D50 / Baseline D50	2.59				1.00			
5. Strategy D84 / Baseline D84	0.74				1.00			

[1] The NMF-V and NMF-H indicator values are developed for the entire river and are not developed by reach

[2] A value of "Yes" means containment. A value of "No" means that it is not contained.

Table B6.6. All indicators for Reach 4 (Rio Puerco to San Acacia Diversion Dam)

Rio Puerco to San Acacia	No Maintenance Future[1] Vertical	No Maintenance Future[1] Horizontal	Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to River	Rehabilitate Channel and Floodplain	Manage Sediment
A. Longitudinal Channel Slope Stability	--	--	--	--	--	--	--	--
1. Strategy Slope / Stable Slope	1.00	1.00	0.93	1.00	0.93	1.00	0.93	0.93
2. Strategy Slope / Baseline Slope	1.08	1.08	1.00	1.08	1.00	1.08	1.00	1.00
3. Baseline Slope / Stable Slope	0.93							
B. Wetted Area at 4,700 cfs	1.36	0.92	1.00	0.92	1.00	0.92	3.64	1.00
C. Bed Elevation Change	2.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D. Containment of 10,000 cfs[2]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
E. Overbank Inundation	--	--	--	--	--	--	--	--
1. High Flow Inundated Area / Channel Area					1.79			
2. 4,700 cfs / Overbank Inundation Discharge	0.85	0.53	0.51	0.51	0.51	0.51	1.27	0.51
F. Sinuosity	--	--	--	--	--	--	--	--
1. Strategy Sinuosity	1.06	0.98	1.06	0.98	1.06	0.98	1.06	1.06
2. Strategy Sinuosity / Baseline Sinuosity	1.00	0.92	1.00	0.92	1.00	0.92	1.00	1.00
G. Width-Depth Ratio at 4,700 cfs	1.85	1.01	1.00	1.01	1.00	1.01	10.34	1.00
H. Meander Width	--	--	--	--	--	--	--	--
1. Percent Fit of Length	0.76	0.99	0.76	0.76	0.76	1.00	0.76	0.76
2. Meander Belt Width Area / Area Between Lateral Constraints	0.47	0.18	0.47	0.47	0.47	0.18	0.47	0.47
I. Wetted Width at 4,700 cfs / Width Between Lateral Constraints	0.15	0.11	0.11	0.11	0.11	0.11	0.40	0.11
J. Wetted Width at 4,700 cfs	1.36	1.00	1.00	1.00	1.00	1.00	3.67	1.00
K. Bed Material	--	--	--	--	--	--	--	--
1. Percent Fines	0.00				0.02			
2. Percent Sand	0.45				0.36			
3. Percent Gravel	0.55				0.63			
4. Strategy D50 / Baseline D50	0.20				1.00			
5. Strategy D84 / Baseline D84	0.73				1.00			

[1] The NMF-V and NMF-H indicator values are developed for the entire river and are not developed by reach

[2] A value of "Yes" means containment. A value of "No" means that it is not contained.

Table B6.7. All indicators for Reach 5 (San Acacia Diversion Dam to Arroyo de las Cañas)

San Acacia to Arroyo de las Canas	No Maintenance Future[1]		Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to River	Rehabilitate Channel and Floodplain	Manage Sediment
	Vertical	Horizontal						
A. Longitudinal Channel Slope Stability	--	--	--	--	--	--	--	--
1. Strategy Slope / Stable Slope	1.00	1.00	1.04	1.00	1.04	1.00	1.04	1.04
2. Strategy Slope / Baseline Slope	0.97	0.97	1.00	0.97	1.00	0.97	1.00	1.00
3. Baseline Slope / Stable Slope	1.04							
B. Wetted Area at 4,700 cfs	1.28	1.05	1.00	1.05	1.00	1.05	4.00	1.00
C. Bed Elevation Change	1.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D. Containment of 10,000 cfs[2]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
E. Overbank Inundation	--	--	--	--	--	--	--	--
1. High Flow Inundated Area / Channel Area					1.31			
2. 4,700 cfs / Overbank Inundation Discharge	0.77	0.80	0.78	0.80	0.78	0.80	1.34	0.78
F. Sinuosity	--	--	--	--	--	--	--	--
1. Strategy Sinuosity	1.06	1.09	1.06	1.09	1.06	1.09	1.06	1.06
2. Strategy Sinuosity / Baseline Sinuosity	1.00	1.04	1.00	1.04	1.00	1.04	1.00	1.00
G. Width-Depth Ratio at 4,700 cfs	1.49	1.02	1.00	1.02	1.00	1.02	10.31	1.00
H. Meander Width	--	--	--	--	--	--	--	--
1. Percent Fit of Length	0.92	0.84	0.92	0.92	0.92	1.00	0.92	0.92
2. Meander Belt Width Area / Area Between Lateral Constraints	0.54	0.64	0.54	0.54	0.54	0.63	0.54	0.54
I. Wetted Width at 4,700 cfs / Width Between Lateral Constraints	0.21	0.17	0.17	0.17	0.17	0.17	0.67	0.17
J. Wetted Width at 4,700 cfs	1.25	1.02	1.00	1.02	1.00	1.02	3.97	1.00
K. Bed Material	--	--	--	--	--	--	--	--
1. Percent Fines	0.00				0.00			
2. Percent Sand	0.38				0.22			
3. Percent Gravel	0.62				0.78			
4. Strategy D50 / Baseline D50	0.34				1.00			
5. Strategy D84 / Baseline D84	0.81				1.00			

[1] The NMF-V and NMF-H indicator values are developed for the entire river and are not developed by reach

[2] A value of "Yes" means containment. A value of "No" means that it is not contained.

Table B6.8. All indicators for Reach 6 (Arroyo de las Cañas to San Antonio Bridge)

Arroyo de las Canas to San Antonio	No Maintenance Future[1]		Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to River	Rehabilitate Channel and Floodplain	Manage Sediment
	Vertical	Horizontal						
A. Longitudinal Channel Slope Stability	--	--	--	--	--	--	--	--
1. Strategy Slope / Stable Slope	1.00	1.00	0.95	1.00	0.95	1.00	0.95	0.95
2. Strategy Slope / Baseline Slope	1.07	1.05	1.00	1.05	1.00	1.05	1.00	1.00
3. Baseline Slope / Stable Slope	0.95							
B. Wetted Area at 4,700 cfs	2.55	0.95	1.00	0.95	1.00	0.95	2.52	1.00
C. Bed Elevation Change	6.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D. Containment of 10,000 cfs[2]	No	No	No	No	No	No	No	No
E. Overbank Inundation	--	--	--	--	--	--	--	--
1. High Flow Inundated Area / Channel Area					1.53			
2. 4,700 cfs / Overbank Inundation Discharge	4.70	1.74	1.81	1.74	1.81	1.74	4.70	1.81
F. Sinuosity	--	--	--	--	--	--	--	--
1. Strategy Sinuosity	1.02	0.97	1.02	0.97	1.02	0.97	1.02	1.02
2. Strategy Sinuosity / Baseline Sinuosity	1.00	0.95	1.00	0.95	1.00	0.95	1.00	1.00
G. Width-Depth Ratio at 4,700 cfs	3.60	1.01	1.00	1.01	1.00	1.01	3.87	1.00
H. Meander Width	--	--	--	--	--	--	--	--
1. Percent Fit of Length	0.92	1.00	0.92	0.92	0.92	1.00	0.92	0.92
2. Meander Belt Width Area / Area Between Lateral Constraints	0.39	0.20	0.39	0.39	0.39	0.20	0.39	0.39
I. Wetted Width at 4,700 cfs / Width Between Lateral Constraints	0.55	0.21	0.22	0.21	0.22	0.21	0.54	0.22
J. Wetted Width at 4,700 cfs	2.55	1.00	1.00	1.00	1.00	1.00	2.53	1.00
K. Bed Material	--	--	--	--	--	--	--	--
1. Percent Fines	0.32				0.00			
2. Percent Sand	0.55				0.51			
3. Percent Gravel	0.13				0.49			
4. Strategy D50 / Baseline D50	0.12				1.00			
5. Strategy D84 / Baseline D84	0.07				1.00			

[1] The NMF-V and NMF-H indicator values are developed for the entire river and are not developed by reach

[2] A value of "Yes" means containment. A value of "No" means that it is not contained.

Table B6.9. All indicators for Reach 7 (San Antonio Bridge to River Mile 78)

San Antonio to River Mile 78	No Maintenance Future[1]		Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to River	Rehabilitate Channel and Floodplain	Manage Sediment
	Vertical	Horizontal						
A. Longitudinal Channel Slope Stability	--	--	--	--	--	--	--	--
1. Strategy Slope / Stable Slope	1.00	1.00	0.98	1.00	0.98	1.00	0.98	0.98
2. Strategy Slope / Baseline Slope	1.02	1.02	1.00	1.02	1.00	1.02	1.00	1.00
3. Baseline Slope / Stable Slope	0.98							
B. Wetted Area at 4,700 cfs	0.87	0.97	1.00	0.97	1.00	0.97	4.07	1.00
C. Bed Elevation Change	3.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D. Containment of 10,000 cfs[2]	No	No	No	No	No	No	Yes	No
E. Overbank Inundation	--	--	--	--	--	--	--	--
1. High Flow Inundated Area / Channel Area					8.27			
2. 4,700 cfs / Overbank Inundation Discharge	4.70	3.36	3.36	3.36	3.36	3.36	4.70	3.36
F. Sinuosity	--	--	--	--	--	--	--	--
1. Strategy Sinuosity	1.05	1.02	1.05	1.02	1.05	1.02	1.05	1.05
2. Strategy Sinuosity / Baseline Sinuosity	1.00	0.98	1.00	0.98	1.00	0.98	1.00	1.00
G. Width-Depth Ratio at 4,700 cfs	0.89	0.99	1.00	1.00	1.00	1.00	5.97	1.00
H. Meander Width	--	--	--	--	--	--	--	--
1. Percent Fit of Length	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2. Meander Belt Width Area / Area Between Lateral Constraints	0.32	0.26	0.32	0.32	0.32	0.26	0.32	0.32
I. Wetted Width at 4,700 cfs / Width Between Lateral Constraints	0.18	0.20	0.20	0.20	0.20	0.20	0.84	0.20
J. Wetted Width at 4,700 cfs	0.87	1.00	1.00	1.00	1.00	1.00	4.08	1.00
K. Bed Material	--	--	--	--	--	--	--	--
1. Percent Fines	0.50				0.00			
2. Percent Sand	0.47				0.95			
3. Percent Gravel	0.04				0.05			
4. Strategy D50 / Baseline D50	0.20				1.00			
5. Strategy D84 / Baseline D84	1.00				1.00			

[1] The NMF-V and NMF-H indicator values are developed for the entire river and are not developed by reach

[2] A value of "Yes" means containment. A value of "No" means that it is not contained.

Table B6.10. All indicators for Reach 8 (River Mile 78 to Elephant Butte Reservoir)

River Mile 78 to Elephant Butte Reservoir	No Maintenance Future[1]		Promote Elevation Stability	Promote Alignment Stability	Reconstruct and Maintain Channel Capacity	Increase Available Area to River	Rehabilitate Channel and Floodplain	Manage Sediment
	Vertical	Horizontal						
A. Longitudinal Channel Slope Stability	--	--	--	--	--	--	--	--
1. Strategy Slope / Stable Slope	1.00	1.00	1.20	1.00	1.20	1.00	1.20	1.20
2. Strategy Slope / Baseline Slope	0.82	0.83	1.00	0.83	1.00	0.83	1.00	1.00
3. Baseline Slope / Stable Slope	1.20							
B. Wetted Area at 4,700 cfs	0.92	1.21	1.00	1.21	1.00	1.21	12.41	1.00
C. Bed Elevation Change	-5.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D. Containment of 10,000 cfs[2]	No	No	No	No	No	No	No	No
E. Overbank Inundation	--	--	--	--	--	--	--	--
1. High Flow Inundated Area / Channel Area					1.94			
2. 4,700 cfs / Overbank Inundation Discharge	0.55	0.53	0.51	0.53	0.51	0.53	3.13	0.51
F. Sinuosity	--	--	--	--	--	--	--	--
1. Strategy Sinuosity	1.09	1.30	1.09	1.30	1.09	1.30	1.09	1.09
2. Strategy Sinuosity / Baseline Sinuosity	1.00	1.19	1.00	1.19	1.00	1.19	1.00	1.00
G. Width-Depth Ratio at 4,700 cfs	0.85	0.97	1.00	0.97	1.00	0.97	44.53	1.00
H. Meander Width	--	--	--	--	--	--	--	--
1. Percent Fit of Length	0.99	0.96	0.99	0.99	0.99	1.00	0.99	0.99
2. Meander Belt Width Area / Area Between Lateral Constraints	0.17	0.28	0.17	0.17	0.17	0.28	0.17	0.17
I. Wetted Width at 4,700 cfs / Width Between Lateral Constraints	0.05	0.06	0.06	0.06	0.06	0.06	0.74	0.06
J. Wetted Width at 4,700 cfs	0.92	1.02	1.00	1.02	1.00	1.02	12.65	1.00
K. Bed Material	--	--	--	--	--	--	--	--
1. Percent Fines	0.27				0.00			
2. Percent Sand	0.70				0.99			
3. Percent Gravel	0.03				0.00			
4. Strategy D50 / Baseline D50	0.84				1.00			
5. Strategy D84 / Baseline D84	1.13				1.00			

[1] The NMF-V and NMF-H indicator values are developed for the entire river and are not developed by reach

[2] A value of "Yes" means containment. A value of "No" means that it is not contained.

As discussed in section 6.2, the appropriate indicators assumed to represent the "Promote Alignment Stability" strategy depends on the relative values of H1 (the percent fit by length for the MBW) for the baseline condition and for the NMF-H modeling scenario. Five cases were identified to describe the relationship between H1 for the baseline condition and H1 for the NMF-H modeling scenario, and table B6.11 summarizes the case appropriate for each reach:

- **Case I**. Both the baseline and NMF-H MBW fit within the current lateral constraints.
- **Case II**. The baseline MBW fits between the current lateral constraints, but the NMF-H MBW does not.
- **Case III**. The baseline MBW does not fit, the river wants to steepen/straighten, but not enough to the point where the NMF-H MBW fits between current lateral constraints.
- **Case IV**. The baseline MBW does not fit, the river wants to steepen/straighten, and straightens enough to where the NMF-H MBW fits between current lateral constraints.
- **Case**. The baseline MBW does not fit, the river wants to flatten/lengthen, and of course, the NMF-H MBW does not fit within the current lateral constraints.

Table B6.11. Case and Representative Indicators for Strategy: Promote Alignment Stability

Reach	Case	Indicators
1 Cochiti Dam to Angostura Diversion Dam	V	Reconstruct/Maintain Capacity
2 Angostura Diversion Dam to Isleta Diversion Dam	V	Reconstruct/Maintain Capacity
3 Isleta Diversion Dam to Rio Puerco	V	Reconstruct/Maintain Capacity
4 Rio Puerco to San Acacia Diversion Dam	IV	NMF-H
5 San Acacia Diversion Dam to Arroyo de las Cañas	V	Reconstruct/Maintain Capacity
6 Arroyo de las Cañas to San Antonio Bridge	IV	NMF-H
7 San Antonio Bridge to River Mile 78	I	NMF-H
8 River Mile 78 to Elephant Butte Reservoir	II	Reconstruct/Maintain Capacity

It is notable that there were instances when the river slope may have been flatter (implying a wider MBW for NMF-H) at an intermediary time during the modeling. Those "worst case" intermediate slopes, along with the theoretical MBW, are presented in table B6.12.

Table B6.12. Slopes and MBW by Reach

Reach	Slope (ft/ft)			MBW (ft)		
	Baseline	Intermediate	NMF-H	Baseline	Intermediate	NMF-H
1	0.001231	0.001183	0.001183	1,188	1,356	1,356
2	0.000885	0.000878	0.000880	1,495	1,578	1,554
3	0.000782	0.000773	0.000773	1,181	1,298	1,298
4	0.000703	0.000703	0.000757	951	951	363
5	0.000807	0.000780	0.000780	1,158	1371	1,371
6	0.000796	0.000629	0.000836	1,166	2,754	595
7	0.000693	0.000653	0.000709	1,026	1,353	845
8	0.000614	0.000501	0.000511	612	1,028	990

It is also important to assess the possibility of a braided planform developing for any of the future conditions. Braiding assessment is outside the scope of this study, but will need to be conducted as a part of the future modeling.

6.4 Differentiation of Indicator Results

To facilitate using the indicators for rating attributes, it was desirable to bin the results for each indicator into three categories. Only data from the unique strategies were considered (section 5.1). Furthermore, the indicator values for some strategies 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 categories.

Once the appropriate dataset was identified for each indicator, the first step to differentiate 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 being considered significantly different than the median. These first-cut estimates of where to break the values into bins was then further refined using professional judgment:

- **Indicators A: Longitudinal Channel Slope Stability (including A1: Strategy Slope/Stable Slope, A2: Strategy Slope/Baseline Slope, and A3: Baseline Slope/Stable Slope) along with F2: Strategy Sinuosity/Baseline Sinuosity** were assigned break values of 0.97 and 1.03. These reflect studies conducted by Colorado State University in which the Middle Rio Grande was shown to lead to high numbers of priority sites when the sinuosity (or slope) underwent more than a 3-percent change.

- **Indicators B: Wetted Area at 4,700 cfs and J: Wetted Width at 4,700 cfs** are only divided into two categories, with a break value of 2 separating the two categories. A doubling of these indicators is deemed significant.
- **Indicator C: Bed Elevation Change** has breaks at -0.5 and at 0.5 because the error in the vertical data is ±0.5 foot.
- **Indicator D: Containment of 10,000 cfs** is non-numerical and can only have two possible values: "contained" or "not contained." The containment of 10,000 cfs can be found by reach in tables B6.3–B6.10.
- **Indicator E1: High Flow Inundated Area/Channel Area** values are presented, but these values are not binned, as they only represent a snapshot in time and may not be characteristic of the reach.
- **Indicator E2: 4,700 cfs/Overbank Inundation Discharge** was assigned break values of 1 and 2, as an indicator value of 1 indicates that the reach has an overbanking event comparable to the 2-year return interval event, and an indicator value of 2 is representative of a threshold discharge necessary for quality silvery minnow habitat.
- **Indicator F1: Strategy Sinuosity** values are presented, but these values are not binned, as they are simply instructional and do not represent a change in sinuosity.
- **Indicator G: Width-Depth Ratio at 4,700 cfs** was conceived to show that Rehabilitate Channel and Flood Plain would significantly increase the width-to-depth ratio. The break value was determined by taking the average of two numbers: the lowest Rehabilitate Channel and Flood Plain value and the highest of all other values that represent a strategy and reach combination.
- **Indicator H1: Percent Fit of Length** was assigned a break value of 0.9, suggesting that a meander belt that had 90 percent of its length within the lateral constraints was considered "to fit," whereas if less than 90 percent of the meander belt length did not fit, then a significant threat to infrastructure is assumed imminent.
- **Indicator H2: Meander Belt Width Area/Area Between Lateral Constraints** was assigned break values of 0.25 and 0.75, suggesting that there is ample room for river meandering if the meander belt area is less than 25 percent of the area between lateral constraints and that there is limited room for active channel migration if the meander belt area is greater than 75 percent of the area between lateral constraints.

- **Indicator I: Wetted Width at 4,700 cfs/Width Between Lateral Constraints** was assigned a single break value of 0.36.
- All **Indicator K: Bed Material** values are presented, but are not categorized into bins.

The break values for the indicators are summarized in table B6.13, and figures B6.2–B6.20 present plots of the indicator values in which the differentiations between bins are shown by red lines.

Table B6.13. Indicator Break Values

Indicator	Low Break Value	High Break Value
A. Longitudinal Channel Slope Stability		
1. Strategy Slope/Stable Slope	0.97	1.03
2. Strategy Slope/Baseline Slope	0.97	1.03
3. Baseline Slope/Stable Slope	0.97	1.03
B. Wetted Area at 4,700 cfs	N/A	2
C. Bed Elevation Change	-0.5	0.5
D. Containment of 10,000 cfs	N/A	N/A
E. Overbank Inundation		
1. High Flow Inundated Area/Channel Area	N/A	N/A
2. 4,700 cfs/Overbank Inundation Discharge	1	2
F. Sinuosity		
1. Strategy Sinuosity	N/A	N/A
2. Strategy Sinuosity/Baseline Sinuosity	0.97	1.03
G. Width-Depth Ratio at 4,700 cfs	N/A	3.735
H. Meander Width		
1. Percent Fit of Length	N/A	0.9
2. Meander Belt Width Area/Area Between Lateral Constraints	0.25	0.75
I. Wetted Width at 4,700 cfs/Width Between Lateral Constraints	N/A	0.36
J. Wetted Width at 4,700 cfs	N/A	2
K. Bed Material		
1. Percent Fines	N/A	N/A
2. Percent Sand	N/A	N/A
3. Percent Gravel	N/A	N/A
4. Strategy D50/Baseline D50	N/A	N/A
5. Strategy D84/Baseline D84	N/A	N/A

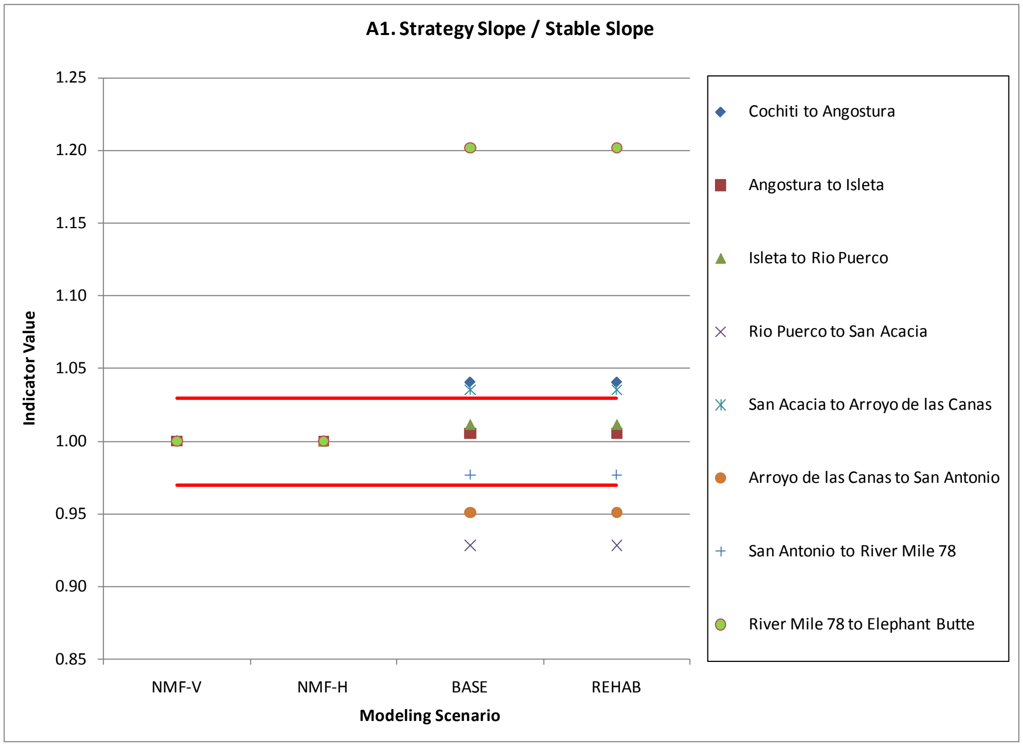


Figure B6.2. Differentiation of indicator values for Indicator A1: Longitudinal Channel Slope Stability: Strategy Slope/Stable Slope.

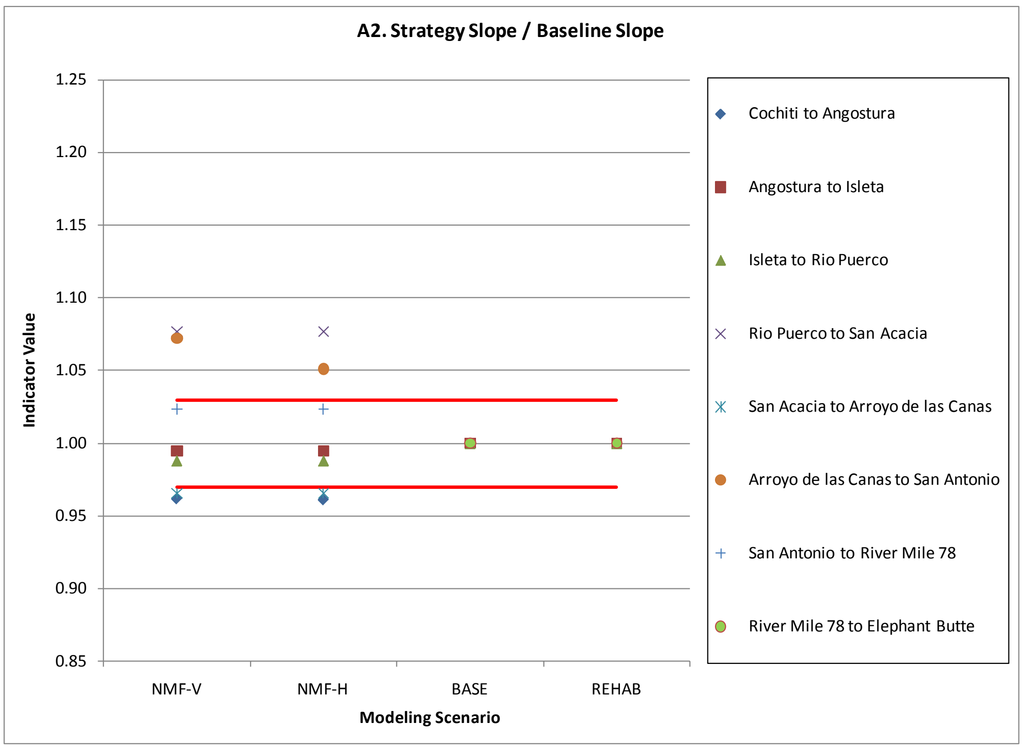


Figure B6.3. Differentiation of indicator values for Indicator A2: Longitudinal Channel Slope Stability: Strategy Slope/Baseline Slope.

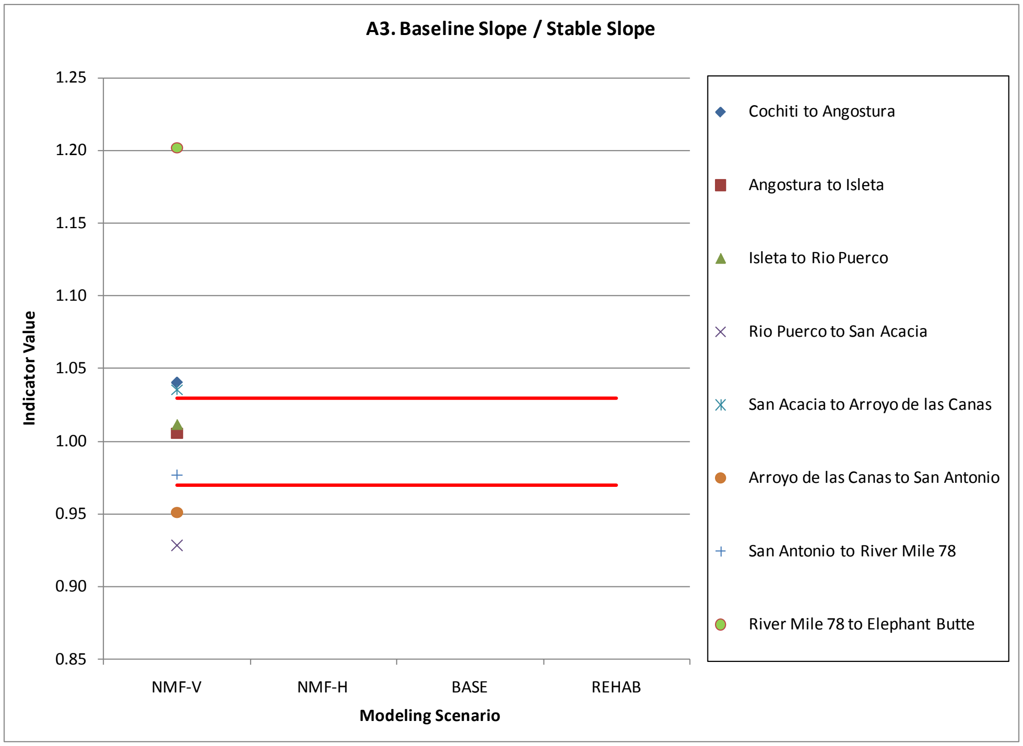


Figure B6.4. Differentiation of indicator values for Indicator A3: Longitudinal Channel Slope Stability: Baseline Slope/Stable Slope.

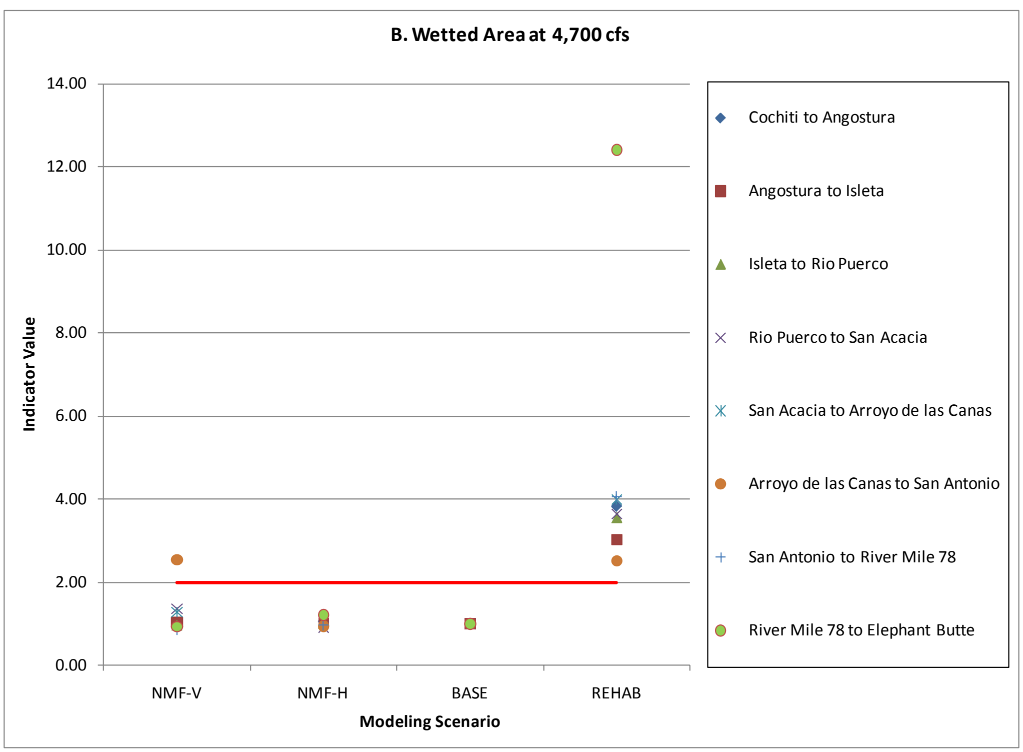


Figure B6.5. Differentiation of indicator values for Indicator B: Wetted Area at 4,700 cfs.

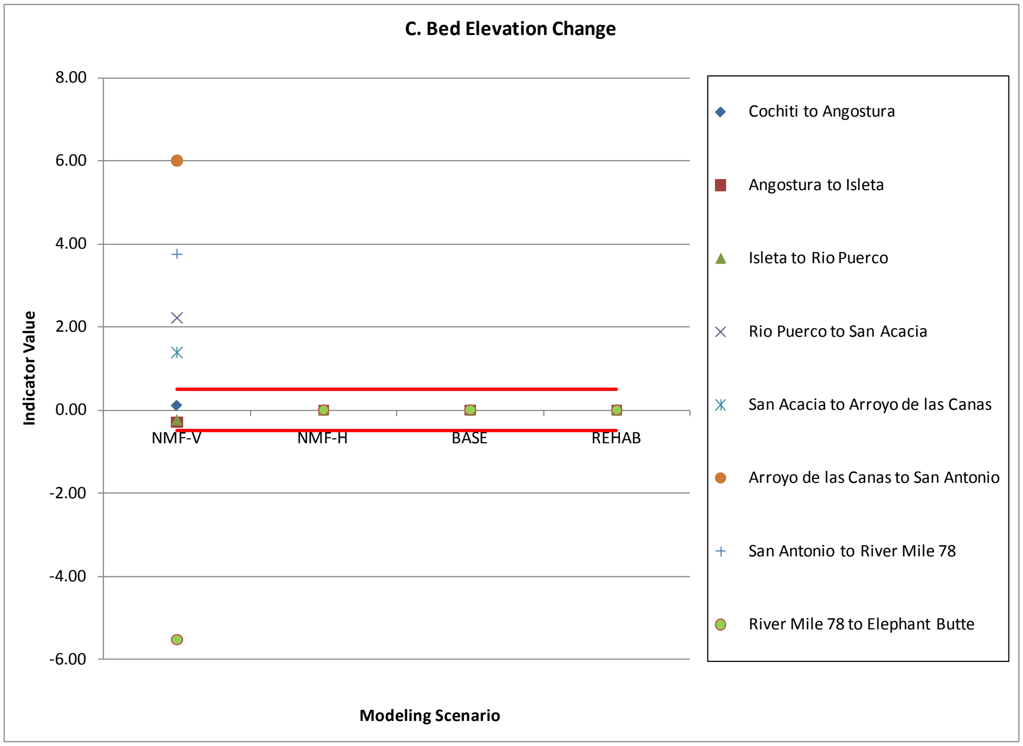


Figure B6.6. Differentiation of indicator values for Indicator C: Bed Elevation Change.

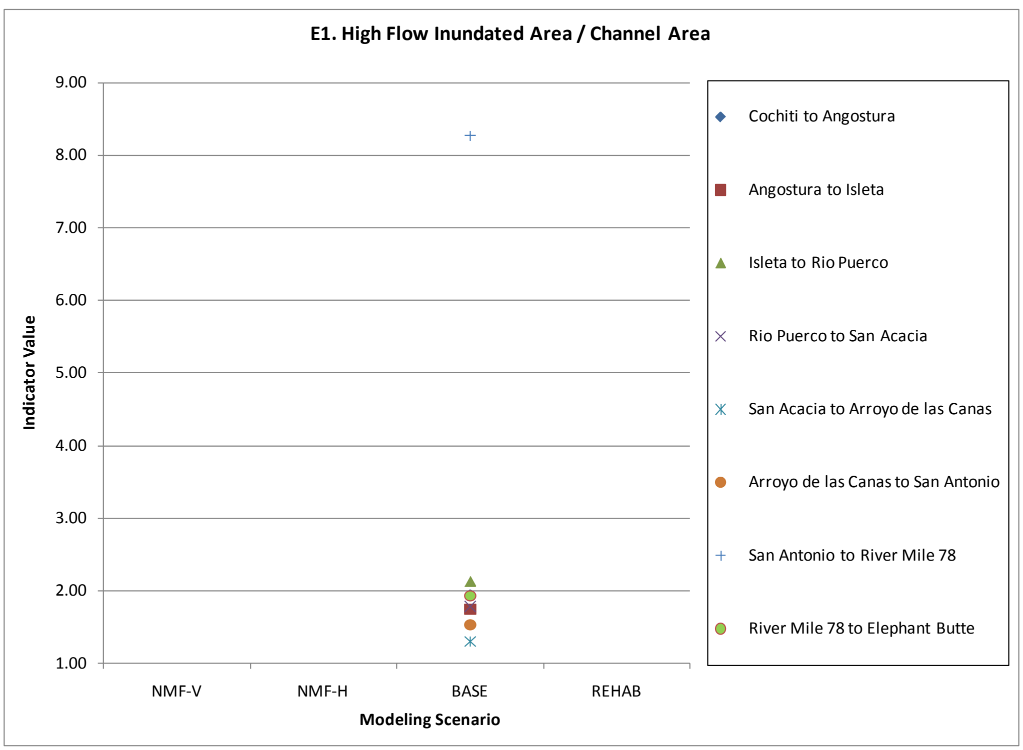


Figure B6.7. Indicator values for Indicator E1: Overbank Inundation: High Flow Inundated Area/Channel Area.

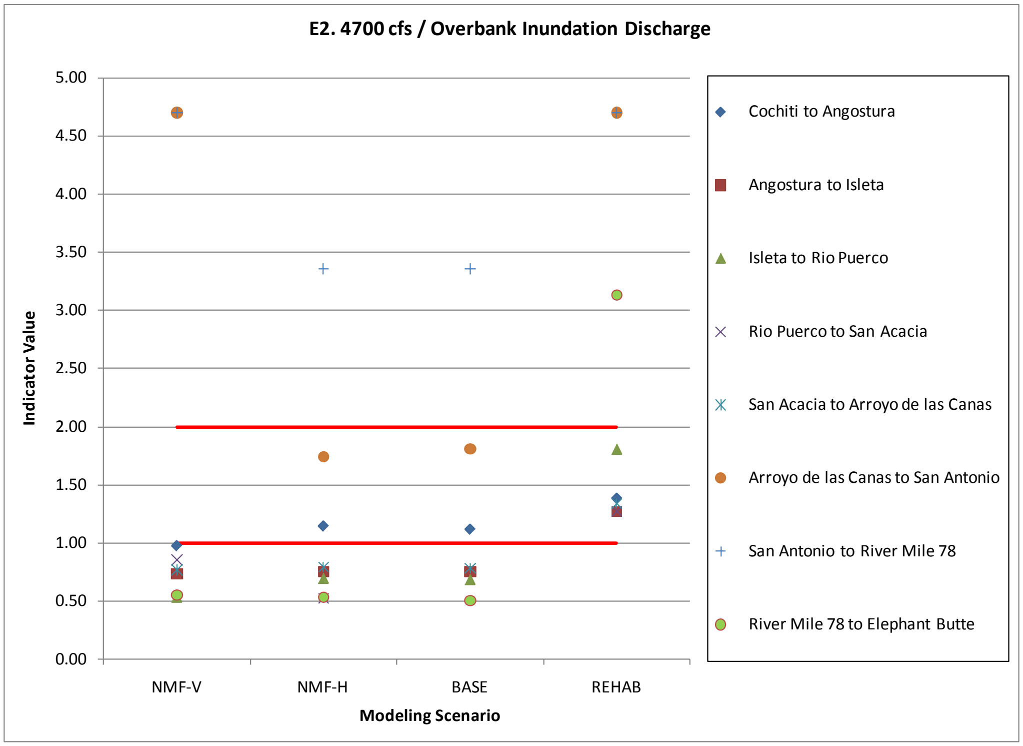


Figure B6.8. Differentiation of indicator values for Indicator E2: Overbank Inundation: 4,700 cfs/Overbank Inundation Discharge.

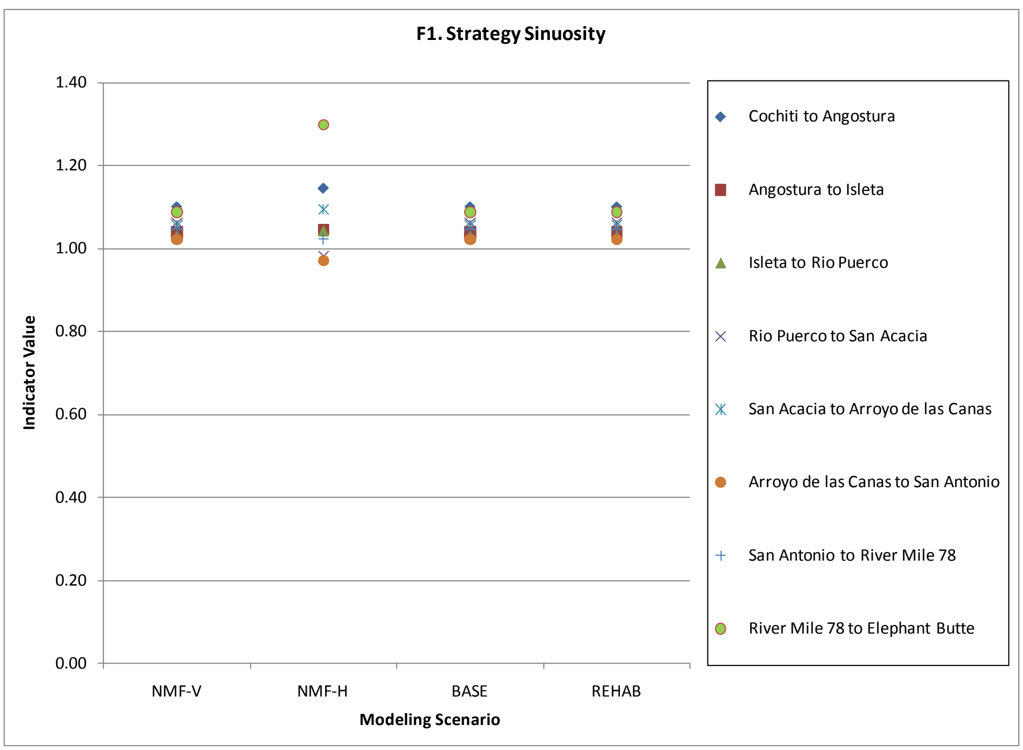


Figure B6.9. Indicator values for Indicator F1: Sinuosity: Strategy Sinuosity.

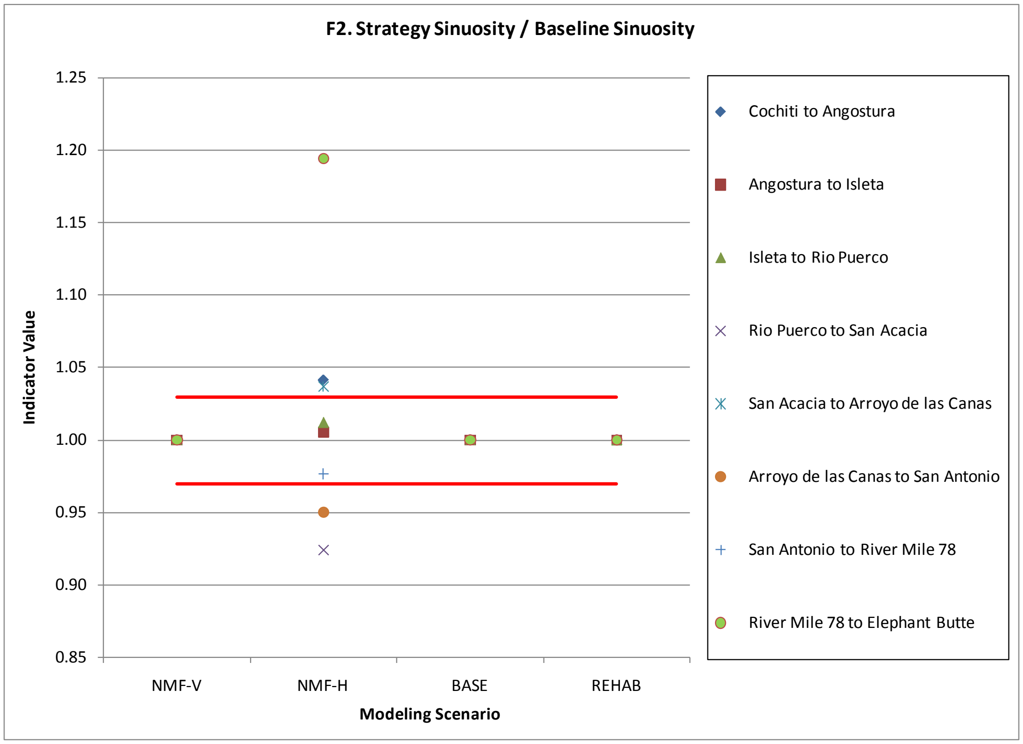


Figure B6.10. Differentiation of indicator values for Indicator F2: Sinuosity: Strategy Sinuosity/Baseline Sinuosity.

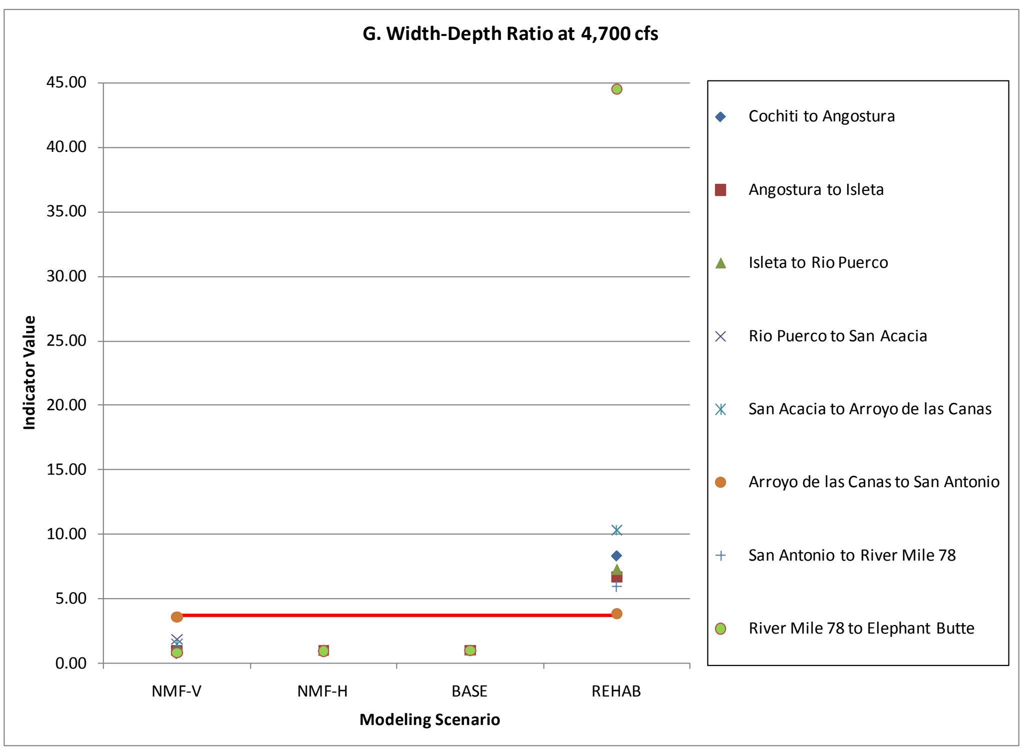


Figure B6.11. Differentiation of indicator values for Indicator G: Width-Depth Ratio at 4,700 cfs.

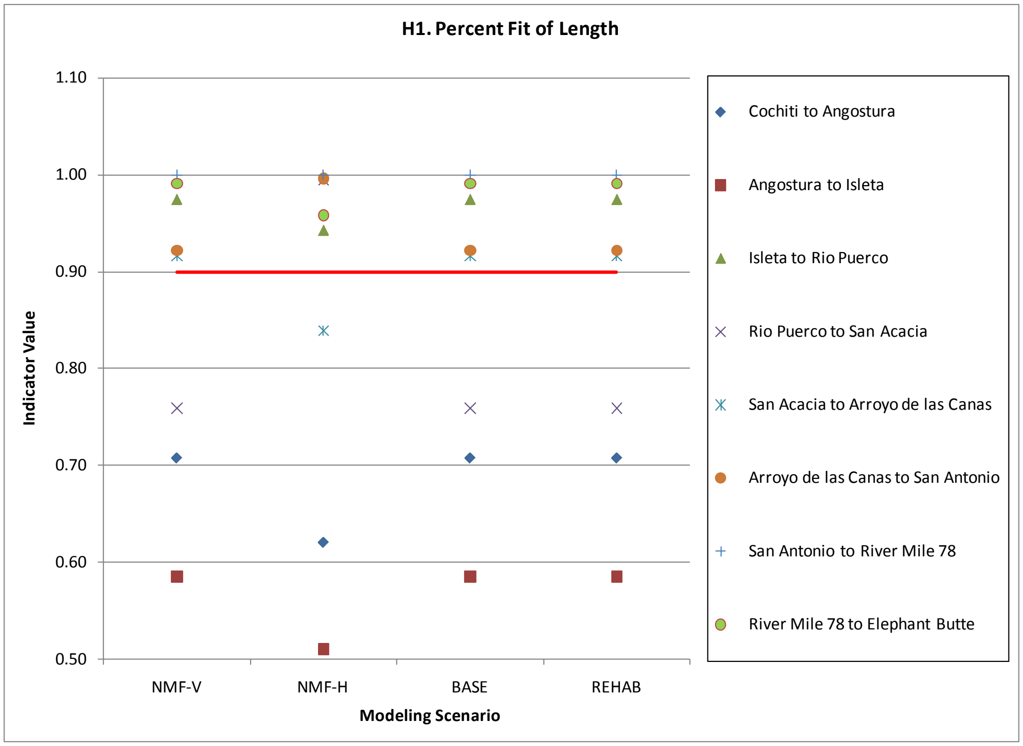


Figure B6.12. Differentiation of indicator values for H1: Meander Width: Percent Fit of Length.

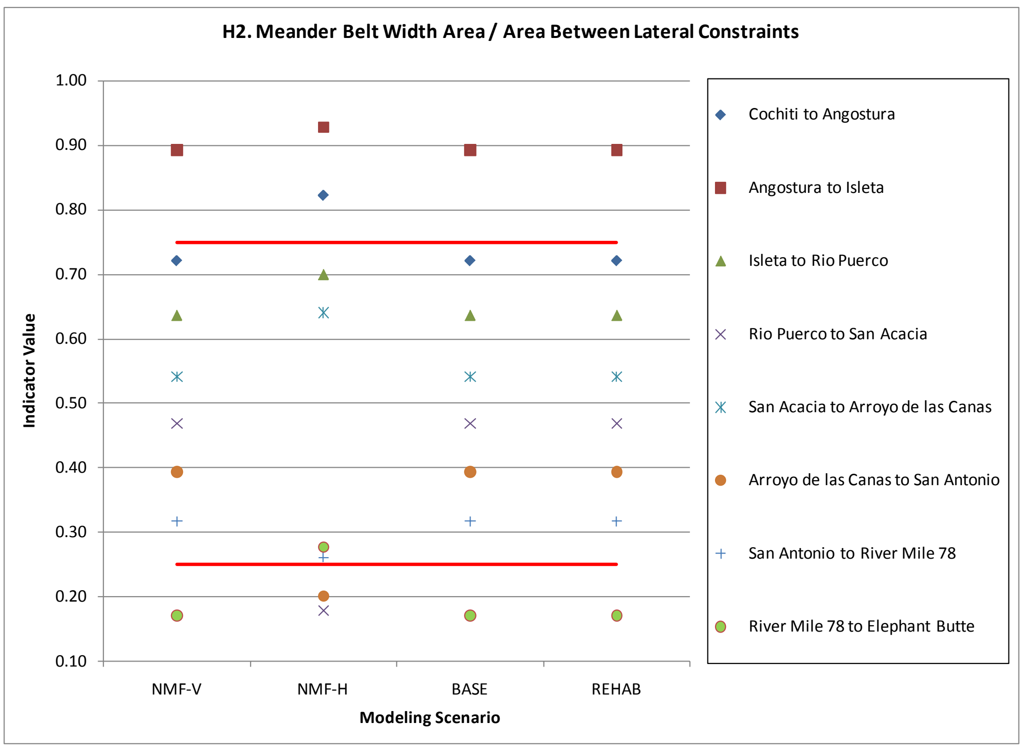


Figure B6.13. Differentiation of indicator values for Indicator H2: Meander Width: Meander Belt Width Area/Area Between Lateral Constraints.

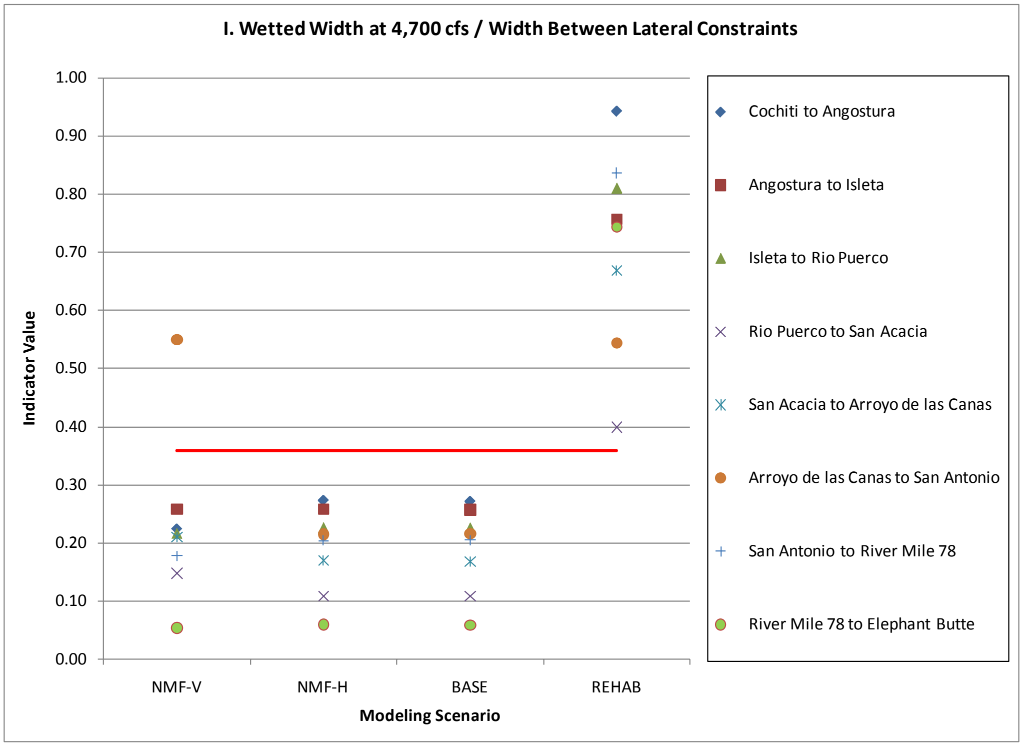


Figure B6.14. Differentiation of indicator values for Indicator I: Wetted Width at 4,700 cfs/Width Between Lateral Constraints.

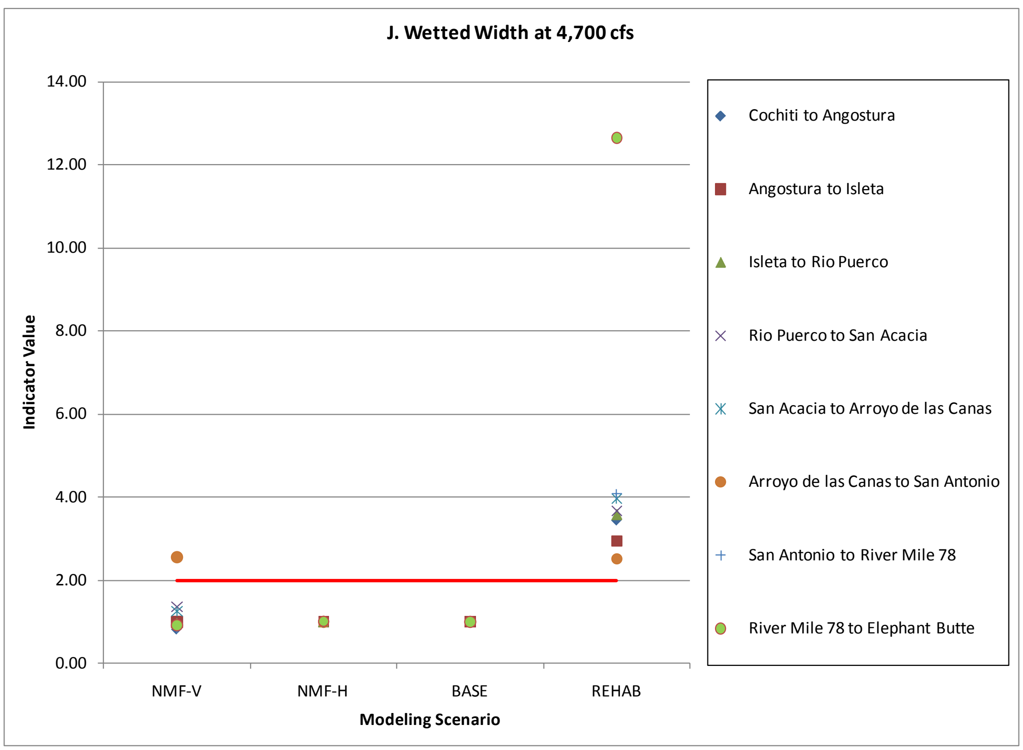


Figure B6.15. Differentiation of indicator values for Indicator J: Wetted Width at 4,700 cfs.

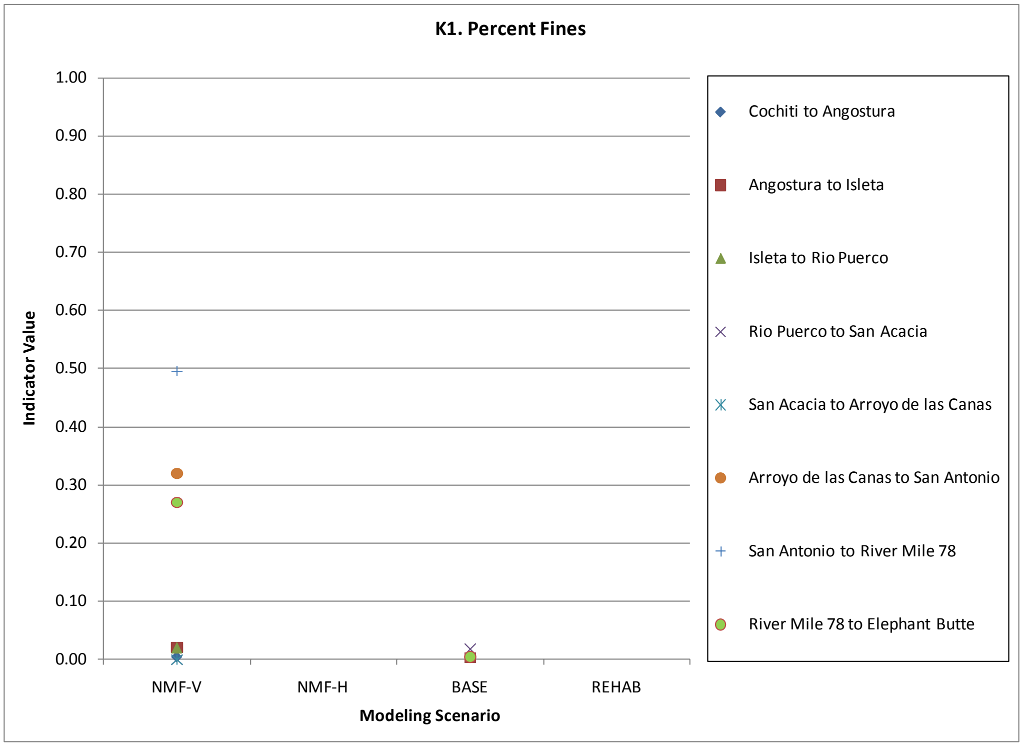


Figure B6.16. Indicator values for Indicator K1: Bed Material: Percent Fines.

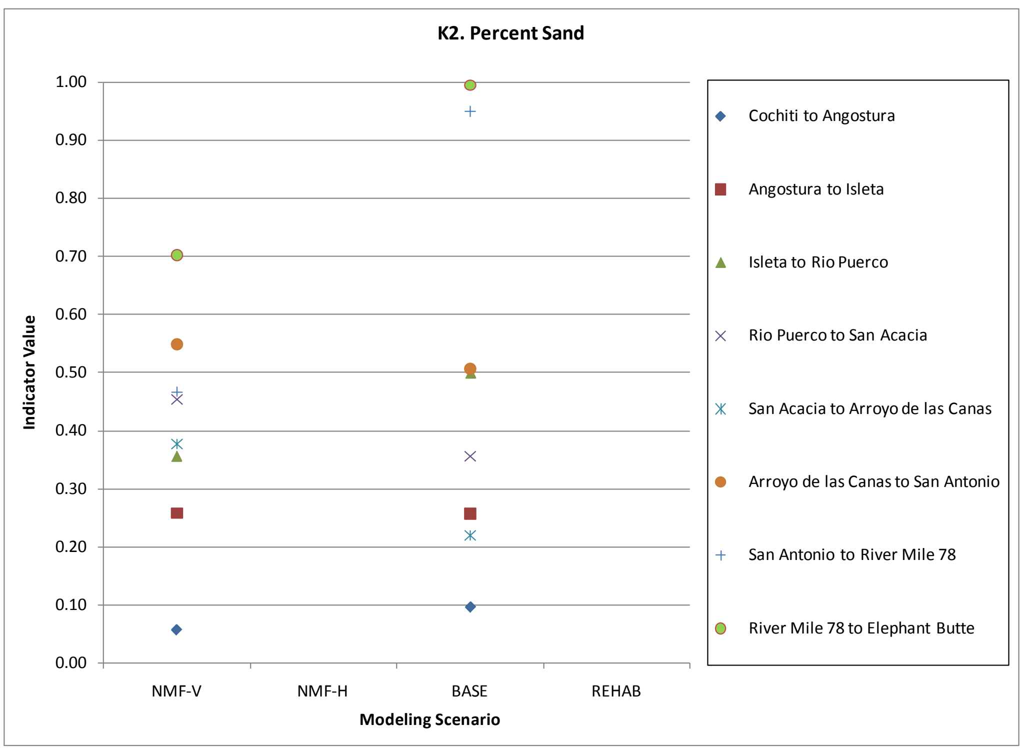


Figure B6.17. Indicator values for K2: Bed Material: Percent Sand.

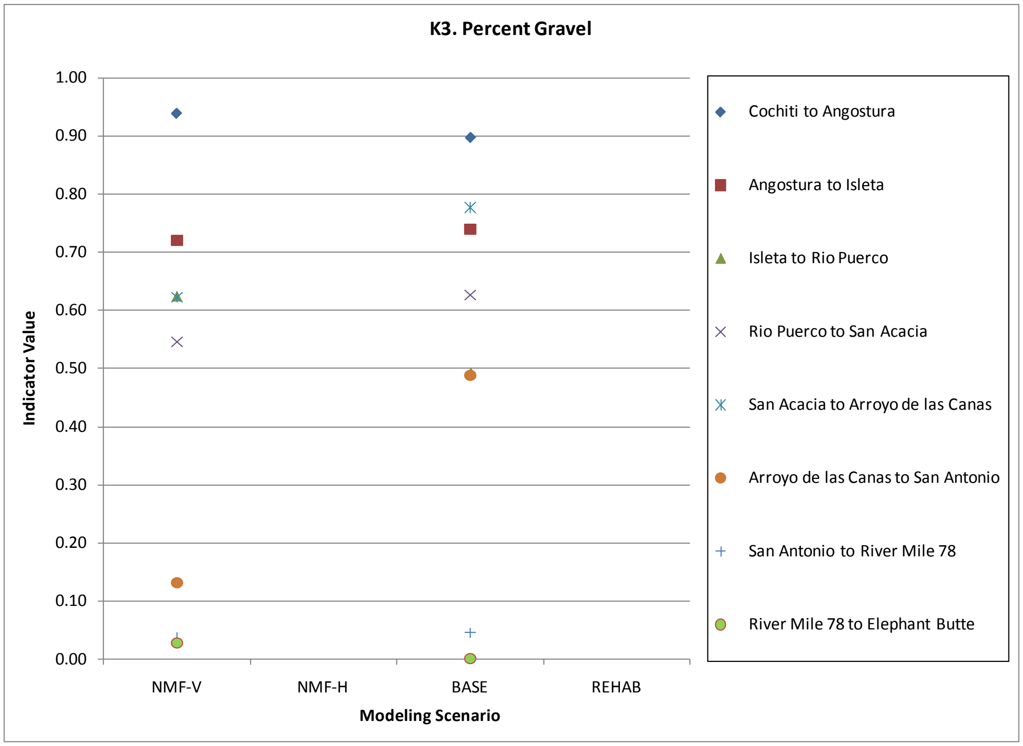


Figure B6.18. Indicator values for Indicator K3: Bed Material: Percent Gravel.

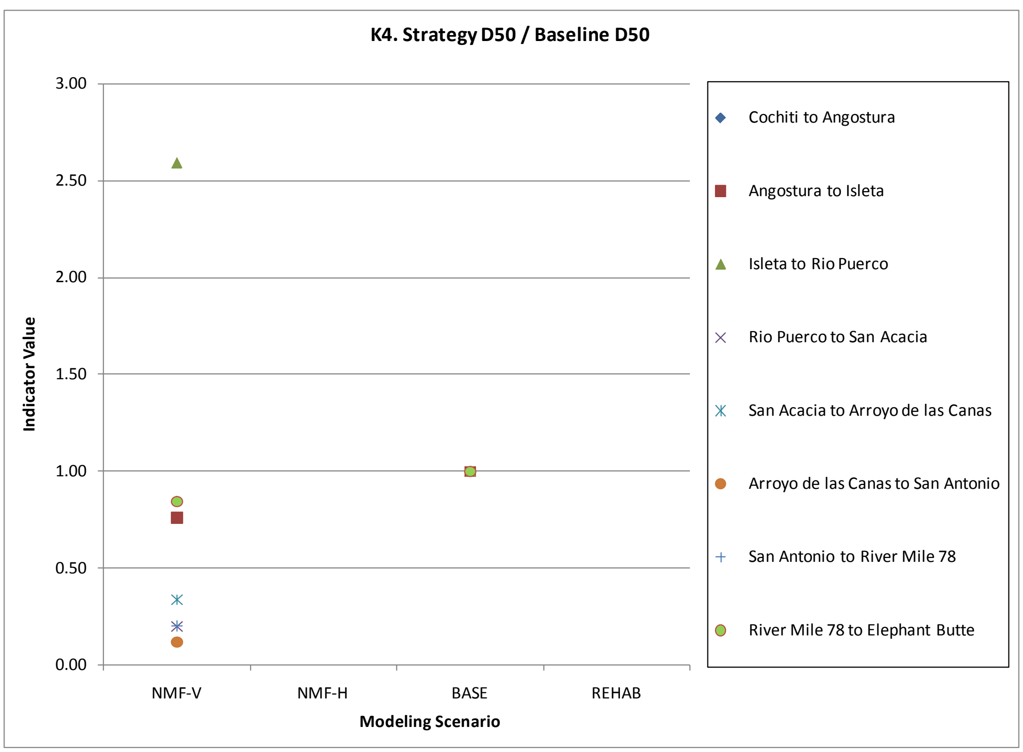


Figure B6.19. Indicator values for Indicator K4: Bed Material: Strategy D50/Baseline D50.

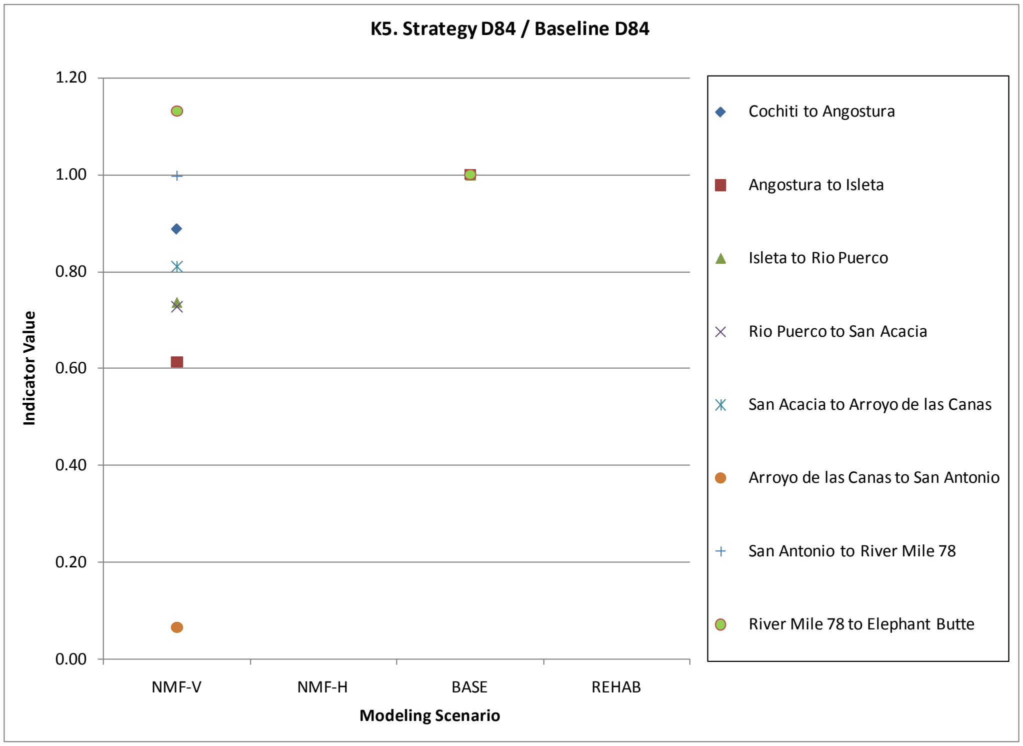


Figure B6.20. Indicator values for K5: Bed Material: Strategy D84/Baseline D84.

7 Next Steps and Future Work

More detailed modeling and other analyses are planned for the reaches of high priority and the strategies for those reaches that prove to merit further analyses. This future work will be conducted by reach and will include a more detailed geometric representation for that reach. Also, the potential width changes that are typically associated with changes in bed slope (sinuosity) and how these changes in width may affect the hydraulics will be considered. A better estimate of the sediment contributions from the tributaries will yield better results in terms of future conditions as well. Work is currently underway to better assess the contributions from the Rio Salado, and there is potential to do likewise on many of the tributaries to the Middle Rio Grande.

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Unique Terms

The analysis approach is discussed in section 4.1 of the main report, Middle Rio Grande River Maintenance Program Comprehensive Plan and Guide.

Evaluation Factors. For this analysis, we rated strategy implementation effects by the attribute of three evaluation factor for each suitable strategy in each reach:

- Engineering Effectiveness Evaluation Factor (as scored by the Attributes for Strategy Performance and River Maintenance Function)
- Ecosystem Function Evaluation Factor (as scored by the attributes for the SWFL and RGSM)
- Economic Evaluation Factor

Goals. Goals are outcome statements that describe desired conditions on the Middle Rio Grande. The updated goals are:

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

Planform Stages. See appendix C, section C1.4.1.3, for a description of the Middle Rio Grande Planform Evolution Model. For further clarification, please refer to Mesong et al. 2010. The planform stages progress from Stage 1–3 on a common pathway; Stages A4–A6 are aggrading conditions, and Stages M4–M8 are migrating conditions. The planform stages, as listed in the previous described order, are as follows:

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

- Stage M7 (Migrating with cutoff channel)
- Stage M8 (Cutoff is now main channel)

Reach Characteristics. Reach characteristics are overall assessments of the existing conditions of the reach to provide information used in prioritizing reaches and in rating the strategy effects by reach. Reach characteristics are:

- Channel Instability Reach Characteristic
- Water Delivery Impact Reach Characteristic
- Infrastructure, Public Health, and Safety Reach Characteristic
- Habitat Value and Need Reach Characteristic (as reflected by southwestern willow flycatcher [SWFL] and Rio Grande silvery minnow [RGSM])

Strategies: Strategies are the basic approaches to achieving the goals on a reach-wide basis, and methods are the means to implement those strategies. The variety of river management practices considered for implementation on the Middle Rio Grande is grouped into six basic strategies:

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