CHANNEL CHANGES AND MAINTENANCE ON THE SAN ACACIA REACH OF THE MIDDLE RIO GRANDE

Robert Padilla, River Analysis Group Leader, Albuquerque Area Office, U.S. Bureau of Reclamation, 555 Broadway NE, Albuquerque, New Mexico, 87102, 505-462-3626, rpadilla@uc.usbr.gov; and Drew C. Baird, Hydraulic Engineer, Technical Service Center, U.S. Bureau of Reclamation, PO Box 25007, Denver, Colorado 80225, 303-445-2564, dbaird@usbr.gov

Abstract The reach of the Rio Grande from San Acacia Diversion Dam downstream to the Narrows of Elephant Butte Reservoir, a distance of about 70 miles, has changed significantly through recorded history from the early 1900's to the present. Many significant changes occurred during the period from the 1980's to 2008. Because of high water years beginning in 1979, Elephant Butte Reservoir filled to capacity in 1985. This led to delta sediments being deposited (aggradation) in the channel for a distance of about 40 miles upstream of the full reservoir pool location. Aggradation at the USGS San Marcial Gage amounted to about 15 ft during this period. The river channel and riparian zone in many reaches is perched above the valley floor. During this same period, the reach from San Acacia Diversion Dam downstream for about 12-13 miles has experienced bed lowering (degradation). Maximum degradation or bed lowering has been about 12 ft. Bed level profiles, discharge, peak flows, reservoir contents, and river bed elevations at the San Marcial Gage and in the river near San Acacia are shown to illustrate these changes. Various channel maintenance methods are utilize in this reach to meet the suite of needs that include water delivery, improved ecosystem function, maintenance of peak flow channel capacity, increasing habitat for the Rio Grande Silvery Minnow and Southwestern Willow Flycatcher, protection of riverside infrastructure, and preserving valley drainage infrastructure. The various channel maintenance methods are summarized.

INTRODUCTION

Alluvial rivers develop their channel form depending upon the magnitude, frequency and the character of the flow regime; size and magnitude of the sediment load and valley slope (Knighton, 1998). When the flow and sediment magnitudes and frequencies are altered by reservoir construction and subsequent water operations, water withdrawals, levee construction and river channelization, morphology can change significantly. The alluvial Middle Rio Grande has long been recognized for its striking characteristic. The surrounding desert lands, large headwater snow packs and summer monsoonal thunderstorms produce wide ranges of water and sediment flows. As the river flowed from the mountainous region to the flatter Middle Rio Grande Valley sediment was deposited resulting in river bed aggradation (i.e. river bed raising by sediment accumulation). The ancestral Middle Rio Grande was a relatively wide aggrading channel with a shifting sand bed and shallow banks. The planform was braided, relative straight or slightly sinuous (Crawford et al. 1993). It is estimated that the Middle Rio Grande Valley New Mexico (Figure 1) has been aggrading for the last 11,000 to 22,000 years (Leopold et. al., 1964, and Hawley, et. al., 1976). Thus, the river is not in a state of dynamic equilibrium. The maximum degradation is believed to have occurred about 22,000 years ago, when the Rio Grande was about 60-130 ft. below the current valley floor. Since then, the Middle Rio Grande has been slowly aggrading because tributary inflows contribute more sediment than the river can transport (Crawford et. al. 1993). Attempts have been made for many hundreds of years to divert the Rio Grande using brush and rock dams. Completion of the irrigation works by the Middle Rio Grande Conservancy District (MRGCD) in 1936 marked the start of the period of active river control. After the formation of the MRGCD, non-engineered spoil levees were constructed parallel to the river. These levees were protected by sediment fences and vegetation but were often washed out during high spring runoff lows. Due to a variety of reasons, including unusually high flood flows in the early 1940's and the aggrading stream bed throughout the Middle Rio Grande Valley, the MRGCD sought assistance from the federal government. This assistance was provided by the United States Bureau of Reclamation (Reclamation) and the Army Corps of

Engineers (Corps) through the Middle Rio Grande Project authorized by the Flood Control Act of 1948 and supplemented by the Flood Control Acts of 1950.

Various river management, engineering and operational schemes have been applied to the Middle Rio Grande in the reach between San Acacia Diversion Dam and the Narrows of Elephant Butte Reservoir (San Acacia Reach) causing large scale channel changes. In addition upstream reservoir construction and water operations and water withdrawals have influenced this reach of river. Figure 1 shows the major reservoirs and diversion dams in the Middle Rio Grande Basin and the location of the reach between San Acacia Diversion Dam and the Narrows of Elephant Butte Reservoir. The narrows of Elephant Butte Reservoir is about 25 miles downstream of San Marcial (Figure 1). Reclamation's authorization, as part of the Middle Rio Grande Project is to provide channel rectification and maintenance. Channel rectification and maintenance has evolved, since the project authorization, and continues to do so to meet dynamic river conditions along with environmental and economic needs. Several large upstream sediment and flood control reservoirs and extensive channelization, were constructed involving large scale efforts between the 1950's and the 1970's (Figure 1). Channel activities in this period included various river training works involving installation of steel Kelner jetties, cleared floodways, pilot channels, and the Rio Grande low flow conveyance channel (LFC). These activities occurred before the advent of federal laws intended to preserve and protect environmental resources (i.e. National Environmental Policy (1969), Clean Water (1972), and Endangered Species (1973) Acts).

In the decade following the initial channelization, channel maintenance in the San Acacia reach consisted of maintaining the channelized alignment, dredging the LFC and vegetation and clearing to keep the constructed width and nominal channel capacity. Recognizing its new federal responsibilities, channel morphological adjustment owing largely to extensive system management, and the need for longer term economic feasibility, Reclamation changed its maintenance practices. Maintenance between the mid 1980's and the late 1990's focused on specific locations where river migration threatened nearby infrastructure. At these specific locations bank protection was installed or the channel relocated. In the aggradational delta reach of Elephant Butte Reservoir, pilot channel maintenance continued to promote effective water delivery.

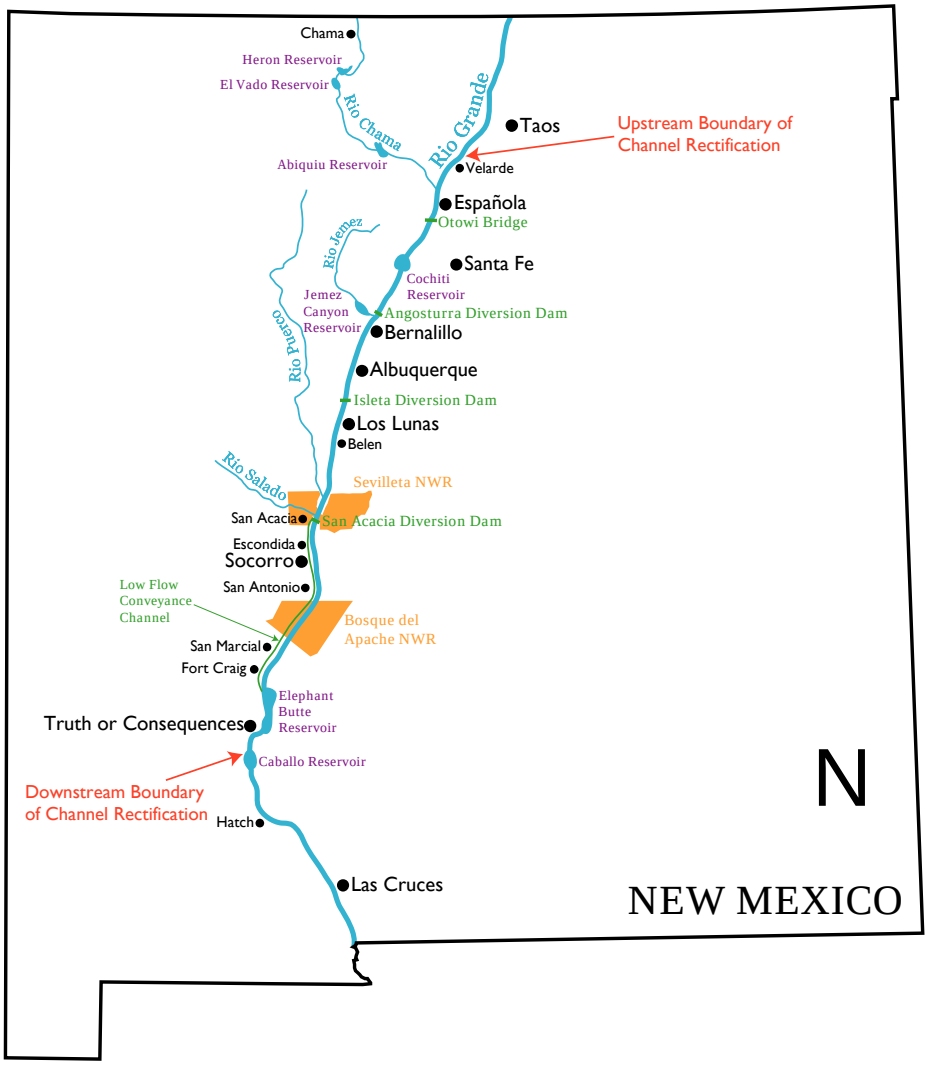

Figure 1 Middle Rio Grande Project Channel Rectification Map.

In the late 1990's, Reclamation re-evaluated its river maintenance practices to address habitat needs to benefit the endangered Rio Grande silvery minnow (Hybognathus amarus) and the south western willow flycatcher (Empidonaxt traili extimus) listed as federal endangered species in 1994 and 1995 respectively. Maintenance strategies changed to begin looking at a holistic, process-based, reach wide approaches that incorporate habitat protection and enhancement. Specific activities for maintenance involved: 1) bio-technical methods with limited riprap use for bank protection; 2) floodplain reconnection; 3) infrastructure relocation; 4) channel realignment work to emulate historical channel processes; pilot channel reconstruction through the delta of Elephant Butte reservoir with environmental features, 5) levee raising and maintenance, and 6) integrating adaptive management concepts that work with or assist channel processes to proactively manage uncertainties in channel response and ecosystem health.

In this paper, the history of the San Acacia Reach is briefly reviewed, historic and current geomorphology presented, together with historic and current channel maintenance practices. A qualitative assessment of future river conditions and maintenance practices is presented.

CHANNEL CHANGES

Hydrology and Sediment Water and sediment flows have changed dramatically effecting channel pattern, sinuosity and hydraulic geometry. At the San Marcial Gage from 1903 to 1942 annual flows averaged about 1,200,000 acre-ft per year, from 1943 to 1978 annual flows averaged about 590,000 acre-ft, from 1979 to about 1997 annual flows averaged about

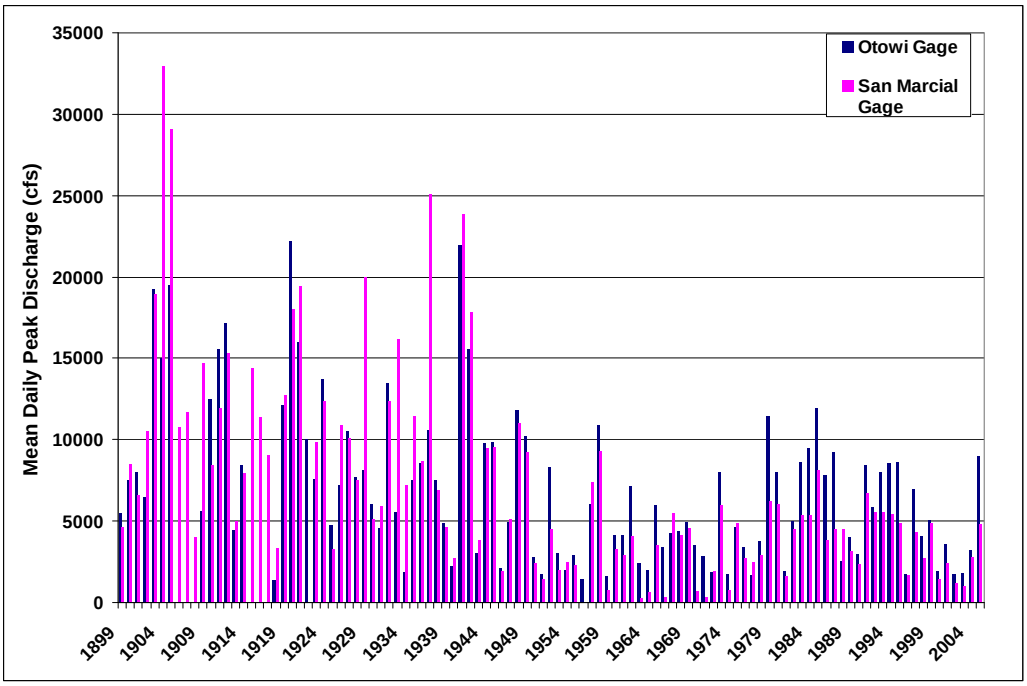

Figure 2 Mean Daily Peak Discharge (cfs) at the Otowi and San Marcial Gages.

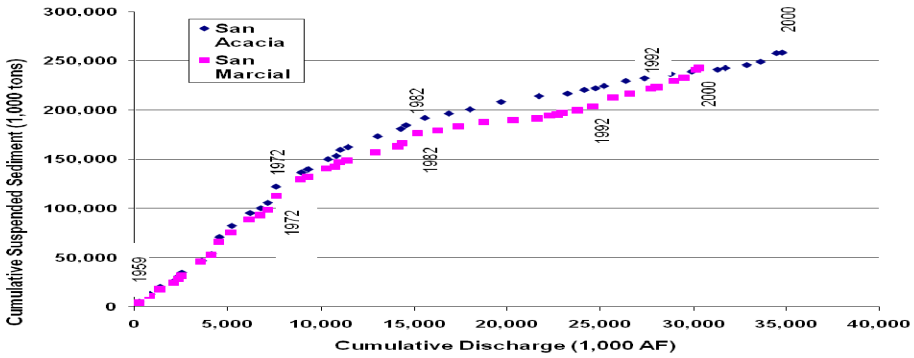

Figure 3 Cumulative Discharge (cfs) plotted versus cumulative suspended sediment (tons) discharge for the period 1959 to 2000 at the San Acacia and San Marcial Gages.

1,100,000 acre-ft per year and from 1998 to 2008 flows averaged about 570,000 acre-ft per year. In other words, 44% of the record is about 570,000 acre-ft per year, and about 56% of the record is about 1,100,000 acre-ft per year. Annual flood peaks have reduced during the period of record from a range of about 20,000 to 30,000 cfs to less than 10,000 cfs (Figure 2). The amount of sediment being transported per unit flow has changed significantly as well. Figure 3 shows the cumulative discharge plotted against cumulative suspended sediment for the period from 1959 to 2000. The sediment transport rate has

reduced during this period. In addition, the relationship between the sediment transport at the San Acacia and San Marcial Gages has changed. From about 1965 to 1980 more sediment was supplied to the reach, as measured at the San Acacia gage, than was being transported by the San Marcial gage indicating sediment accumulation. Beginning in about 1980 and continuing until about 1990 the rate at each gage was about the same. Sediment began to be mined from the reach from about 1990 to about 2000.

Elephant Butte Storage Completed in 1916, the Elephant Butte Reservoir water surface elevation forms the downstream boundary base level elevation for the San Acacia Reach. Table 1 shows the correlation between reservoir inflow and water surface elevation. The range of change in reservoir water surface elevation in Table 1 is more than 100 ft.

Channelization From the early 1950's to the early 1970's this reach of river was realigned and channelized. The LFC and its spoil levee were also constructed. The LFC extended from San Acacia Diversion Dam to the Narrows of Elephant Butte a distance of about 75 miles. From the 1960's to the mid 1980's all river flows up to 2,000 cfs were diverted into the LFC at the Dam to improve water

Table 1 Average Annual Flow at the San Marcial Gage (acre-ft) and Average Water Surface Elevation in Elephant Butte Reservoir (ft.) for various time periods.

Time Period	Average Annual Flow at San Marcial Gage (Acre-Ft)	Time Period	Average Water Surface Elevation in Elephant Butte Reservoir (ft)
1896 to 1944	1,100,000	1920-1944	4,400
1945-1978	570,000	1944-1985	4,350
1979-1999	1,100,000	1985-2001	4,448
		2001-2008	4,330

delivery efficiency in the reach. When flows exceeded the LFC capacity of 2000 cfs the additional flow volume was routed downstream via the main river channel. After the mid 1980's, the LFC was no longer operated for surface water delivery due to the lack of an outfall which was inundated by a full Elephant Butte Reservoir pool. The LFC currently functions as a shallow ground water drain and irrigation return flow channel and endangered species habitat considerations limit considerations for future surface operation. Figure 4, shows a pre-channelized reach without a riverside levee and LFC. Figure 5 shows the same location after the river was realigned, channelized and the river side levee and LFC constructed. Figure 6 shows the river bank line position changes between 1935 and 2006.

Figure 4 Pre-channelized river without a riverside levee (1930's)

Figure 5 Post-channelized river with a riverside levee and LFC (late 1950's or early 1960's)

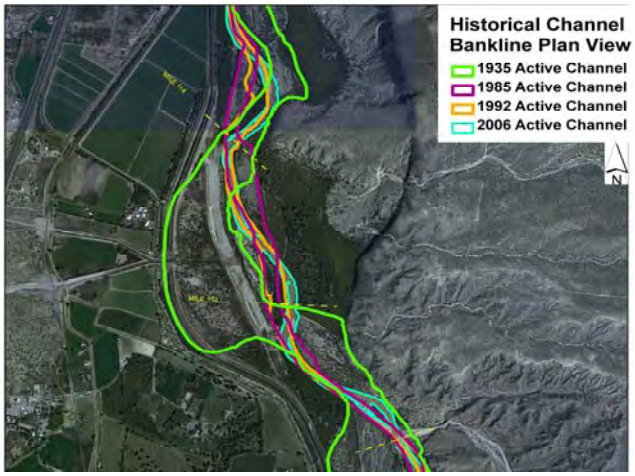

Figure 6 Historic Active Channel Bankline Plan View from 1935 to 2006. This is the same location as figures 4 and 5.

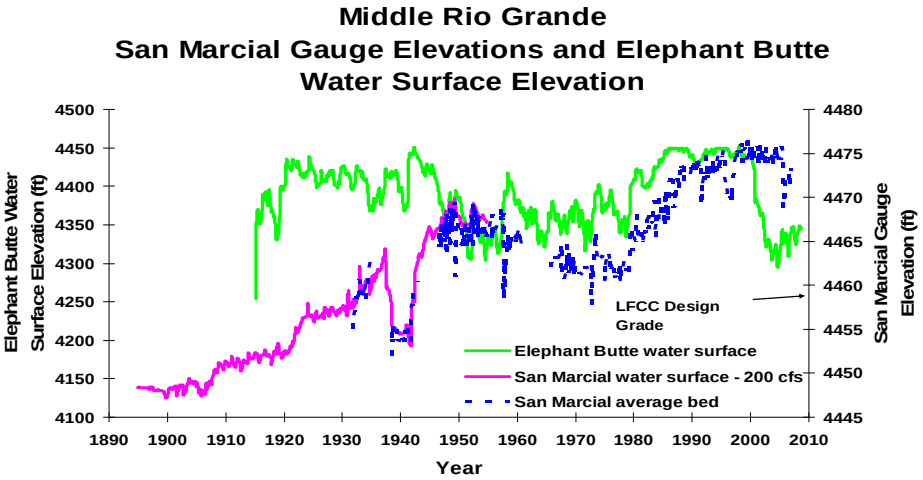

Figure 7 San Marcial Gage Bed and Elephant Butte Water Surface Elevation Histogram.

Channel Response Changes in hydrology, sediment supply and transport, reach base level, channelization/realignment, and LFC and levee construction have significantly impacted the San Acacia reach channel. Figure 7 illustrates the correlation between reservoir water surface elevations and the river bed elevation at the San Marcial Gage. Sediment accumulation in the reservoir delta has caused the bed of the river to rise about 40 ft at the narrows between 1915 and 2007, and 25 ft at the San Marcial Gage between 1915 and 2002 (Figures 7 and 8). About 10 miles downstream of the San Marcial Gage (RM 60) the river bed has risen about 35 ft between 1915 and 2002. Between 2002 and 2007 the river bed has lowered about 4 ft and about 10.5 ft at the San Marcial Gage and RM 60 respectively. This is due primarily to the base level lowering followed by subsequent pilot channel work following the valley thalweg for improving water delivery. Conversely owing to reduced sediment supply and sediment mining in the reach beginning about 1965 (figure 3) the bed elevation downstream of San Acacia Diversion Dam has lowered about 11 ft between 1962 and 2007. As a result of channelization, and reduced peak flows and sediment loads, the reach average main channel width reduced from 1810 ft wide in 1918 to 380 ft in 1972. It is possible that the 1918 width is larger than the longer term dynamic equilibrium width due to grazing and logging practices in the contributing watersheds basin during the late 1800's (Scurlock, 1998). Between 1972 and 1985 the river widened to 630 ft given the fact that vegetation had been cleared and a large spring runoff peak in 1985 widened the river to the new vegetation line. The river narrowed to 320 ft by 2006. After channelization in the 1950's to the 1970's the river has remained a more single thread channel while there has been some active bank erosion and lateral migration between 1992 and 2006 (figure 6). It is hypothesized that the lateral migration is a result of reduced peak flows, reduced sediment supply, and channel incision in the period of time after channelization was completed.

CHANNEL MAINTENANCE PRACTICES

Under the Middle Rio Grande Project, Reclamation is authorized to perform channel rectification and maintenance works. Project purposes including providing for effective delivery of water to Elephant Butte Reservoir, protection of riverside infrastructure, and reduction of channel aggradation to provide for

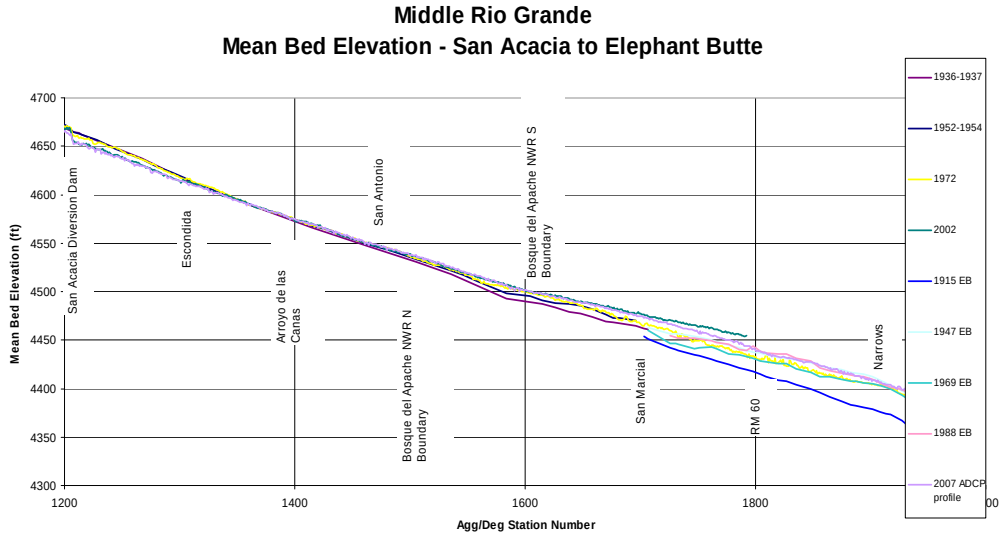

Figure 8 Temporal Changes in mean bed elevation between San Acacia Diversion Dam.

Table 2 River Maintenance practices by time period for the river channel between San Acacia to about the Bosque del Apache National Wildlife Refuge (Upstream Reach) and reach downstream to the Narrows of Elephant Butte Reservoir (Downstream Reach).

Time Period	**Upstream reach (see figure 1)**	**Time Period**	**Downstream reach (see figure 1)**
1960's to the mid 1980's	Channelized river reaches were maintained in their original channelized alignment, vegetation clearing over long reaches.	1960's to about 1980 (Elephant Butte Reservoir Water Surface Elevation about 4350 ft)	Dredging of the Low Flow Conveyance Channel near the Narrows of Elephant Butte Reservoir, maintaining channelized reaches in their original alignment, sediment plug removal and vegetation clearing.
Mid 1980's to the late 1990's	River migrated outside of originally constructed alignment until threatened nearby infrastructure then eroding banks stabilized, selective vegetation clearing	1980 to about 2001 Elephant Butte Reservoir Water Surface Elevation about 4448 ft.)	Excavation through the Reservoir Delta to re-establish/maintain a river channel to the reservoir pool. River migrated outside of originally constructed alignment until threatened nearby infrastructure then eroding banks stabilized, levee raising, pilot channels through sediment plugs and selected vegetation clearing
Late 1990's to the present	More holistic, geomorphic process-based and reach wide approaches. Bio-engineering with stone toe, floodplain reconnection, infrastructure relocation, channel realignment to emulate historic channel processes, and adaptive management.	2001 to present (Elephant Butte Reservoir Water Surface Elevation about 4350 ft)	Excavation through the Reservoir Delta to re-establish/maintain a river channel to the reservoir pool with environmental features. River migrated outside of originally constructed alignment until threatened nearby infrastructure then eroding banks stabilized, levee raising with re-vegetation, and pilot channels through sediment plugs.

current valley drainage and for the irrigation system to Elephant Butte Reservoir. Table 2 shows the channel rectification and maintenance practices for both the San Acacia to about the Bosque Del Apache NWR reach and from the BDANWR to the Narrows of Elephant Butte Reservoir.

San Acacia to about the Bosque Del Apache NWR In this reach, channel incision and lateral migration have been occurring as described above. Figure 9 shows a location several miles downstream of San Acacia diversion dam where channel incision and lateral migration occurred and the river migrated towards the levee. This is a location where the river was relocated during original LFC and spoil levee construction during the channelization phase of the project (Figures 4, 5 and 6). A project was constructed to re-locate this infrastructure allowing the river channel to continue to migrate laterally in the

pre-channelization alignment, while maintaining the function of the levee and LFC. Figures 10 and 11 show the infrastructure relocation. Due to incision and lateral migration an inset floodplain is forming in this reach. Relocation of the infrastructure which allows continued migration will increase the size of the inset floodplain thus increasing the amount of potential future floodplain connectivity.

Bosque Del Apache NWR to the Narrows of Elephant Butte Reservoir As the channel continues to fill with sediment maintaining valley drainage is becoming increasingly difficult. The design grade of the LFC near the San Marcial gage is more than 10 ft lower in elevation than the river bed (Figure 7). The elevation in the LFC is necessary to provide drainage of the irrigation system and the Bosque Del Apache NWR. This makes it necessary to maintain two channels thru the majority of the delta of Elephant Butte Reservoir. Dredging and maintenance of a river channel through the delta of Elephant Butte reservoir provides for reduced upstream river bed aggradation. Excavation and maintenance of a channel in the delta is economically accomplished using amphibious excavators (Figure 12). In addition to valley drainage, maintenance of the channel through the delta prevents water loss due to evaporation and evapo-transpiration by preventing river flows from spreading across the valley flow. Currently dredging and maintenance is accomplished with some environmental features. Widened and overbank flow areas, variable width areas, and alternative bar formations are part of the environmental features.

SUMMARY AND CONCLUSIONS

The San Acacia Reach of the Middle Rio Grande has experience vast channel changes including channelization, levee construction, LFC construction, reduced sediment loads, aggradation, incision and lateral migration, and peak flows, vegetation clearing along the channel banks, and an altered downstream

Figure 9 River Mile 114 site (several miles downstream of San Acacia Diversion Dam) where the river is migrating in to the riverside levee and LFC channel. Note this is the location where the river channel was relocated as shown in Figures 4, 5 and 6.

Figure 10 River Mile 114 project site. The new alignment for the levee and LFC has been cleared of upland and riparian vegetation.

base level control (Elephant Butte Reservoir). Channel rectification and maintenance practices are intended to provide for effective water deliver, reduction of channel aggradation, preserve valley drainage, and protect riverside infrastructure. Currently maintenance practices include more holistic, geomorphic process-based and reach wide approaches. Bio-engineering with stone toe, floodplain reconnection, infrastructure relocation, channel realignment to emulate historic channel processes, and adaptive management, are part of the current approach.

Figure 11 River Mile 114 project site. The levee and LFC have been reconstructed and the previous LFC is being filled.

Figure 12 Reconstruction and maintenance of the river channel through the delta of Elephant Butte Reservoir.

This reach of river will continue to evolve with incision likely continuing to progress downstream, while the delta of Elephant Butte reservoir will remain a depositional reach over the long term. Both of these conditions creates management challenges to meet original project purposes while preserving and enhancing endangered species habitat and ecosystem health.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions of Paula Makar, Anita Wood, Jan Oliver, Cheryl Rolland, Tamara Massong, Carolyn Donnelly, Steven Gonzales, Ron Ferrari, Kent Collins, Tetra Tech EMI, Suzanne Devergie who provided photographs and technical information for this paper. Their contributions are gratefully acknowledged.

REFERENCES

Crawford, C.S., Cully, A.C., Leutheuser, R., Sifuentes, M.S., White, L.H., and Wilbur, J.P., (1993), "Middle Rio Grande Ecosystem: Bosque Biological Management Plan," U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

Hawley, J.W., Bachman, G.O., and Manley, K., (1976), "Quaternary Stratigraphy in the Basin and Range and Great Plains Provinces, New Mexico and Western Texas," Pg. 235-274, in Mahaney, W.C. (ed.) Quaternary Stratigraphy of North America. Dowden, Hutchinson and Ross, New York.

Knighton, David, (1998), "Fluvial Form and Process: A New Perspective," Arnold, London.

Leopold, L.B., Wolman, M.G., and Miller, J.P., (1964), "Fluvial Processes in Geomorphology," W.H. Freeman and Co., San Francisco.

Scurlock, Dan. 1998. "From the Rio to the Sierra: An environmental history of the Middle Rio Grande Basin". General Technical Report RMRS-GTR-5. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.