Changing Middle Rio Grande Channel Morphology: Bosque Del Apache National Wildlife Refuge to Elephant Butte Reservoir

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Abstract

The Elephant Butte Reach (EBR) of the Middle Rio Grande (MRG) spans about 39 miles from the southern boundary of Bosque Del Apache National Wildlife Refuge to Elephant Butte Reservoir in New Mexico. Analyses of spatial and temporal trends in channel geometry and morphology are reported. Hydrology, hydraulics, and water surface elevation (WSE) changes in Elephant Butte Reservoir caused significant morphological changes of the Middle Rio Grande over the past century. This reach was divided into six sub-reaches based on channel width and geomorphic controls. It is shown, for the period from 1962 to 2012, reservoir WSE has the most influence on channel bed elevation and width. We propose a reservoir delta geomorphic evolution model that describes channel processes in the delta and the backwater-affected upstream sub reaches. This geomorphic evolution model applies to relatively constant reservoir WSE, and for rising and falling reservoir levels. The proposed geomorphic model includes the position of the pivot point (point between the topset and foreset delta slope)

Introduction

The MRG valley in New Mexico spans 232 miles from the mouth of White Rock Canyon, near Cochiti Dam, south to Elephant Butte Reservoir (Figure 1). The EBR spans about 39 miles from the southern boundary of Bosque Del Apache National Wildlife Refuge to Elephant Butte Reservoir (Figure 2). Between about 1885 and 1942 there were numerous large floods ranging from 20,000 cfs to 100,000 which played a significant role in shaping the historically much wider Rio Grande channel (Makar and AuBuchon, 2013). Prior to the construction of Elephant Butte Dam the river was aggrading at the San Marcial gage (Leopold et al. 1964) located at the railroad bridge at San Marcial (Figure 1). Since Elephant Butte Dam construction the bed elevation in the EBR has been influenced by the reservoir WSE, with the channel aggrading during periods of rising reservoir WSE and degrading when the reservoir recedes. During the 1950s and 1960s the river was channelized, and an additional channel was constructed adjacent to the river from San Acacia Diversion Dam to Elephant Butte Reservoir. This channel, called the Low Flow Conveyance Channel (LFCC), conveyed irrigation return flows and river flows up to 2,000 cfs. Flows above the 2,000 cfs LFCC capacity remained in the river channel and floodway. A levee was constructed between the LFCC and the river channel. Riverbed aggradation results in the river having a lower ability to pass peak flows without levee overtopping and flooding the LFCC and adjacent agricultural and developed lands. The river within the EBR also provides habitat for the endangered Rio Grande Silvery Minnow, and this analysis is also used for determining available habitat for spawning, rearing and adult habitat.

At the San Marcial River (Floodway) gage (USGS Gage 08358400) discharge and suspended sediment data are available for the period October 1, 1949, to present. There is also discharge data measured at the San Marcial LFCC gage (USGS Gage 08355490) for the period from December 1, 1951, to present. Reclamation established a set of cross sections, and periodically collected aerial imagery, beginning at Cochiti Dam and proceeding south to the Narrows of Elephant Butte reservoir. These cross sections were spaced about 500 feet (ft) apart with measurements being made in 1962, 1972, 1992, 2002 and 2012. They are called the aggradation/degradation (agg/deg) lines. In addition to the agg/deg lines the thalweg channel profile was measured in the EBR in 1999, 2004, 2005, 2007, 2012, and 2019.

Within the EBR, six sub-reaches (EB1 to EB6) were established based on channel width and geomorphic controls (Figure 2). We evaluate riverbed elevations and channel width from 1962 to 2012 using the agg/deg data. We also evaluate riverbed elevations using the 1999 to 2019 channel profile data. We found that reservoir WSE has the most influence on channel bed elevation and width. We propose a reservoir delta geomorphic evolution model that describes channel profile, planform, and width changes and the reservoir backwater effect. This geomorphic evolution model applies to three cases: relatively constant reservoir WSE, and for rising and falling reservoir levels. The proposed geomorphic model includes the position of the pivot point (point between the topset and foreset delta slope, USBR 1987).

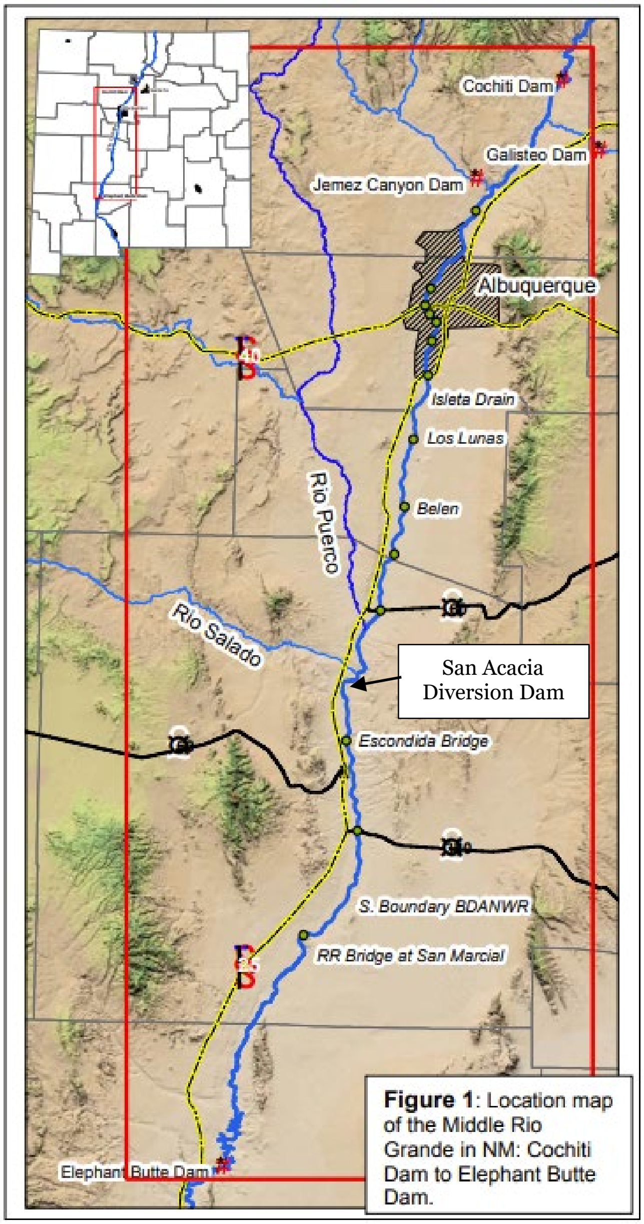

Figure 1. Location Map from Massong et al. (2010).

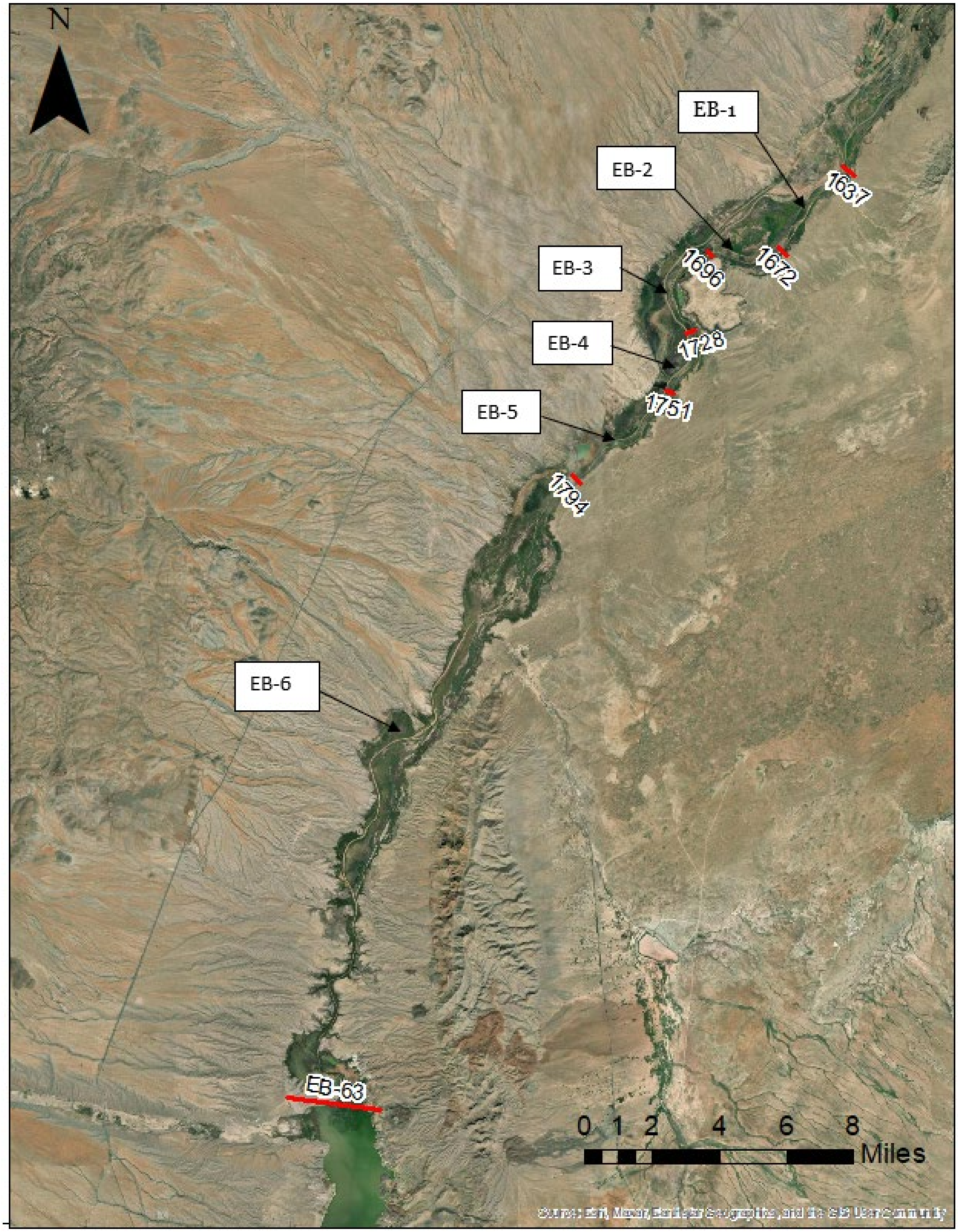

Figure 2. Sub reach designation and Aggradation/Degradation range line numbers between the South Boundary of the Bosque Del Apache National Wildlife Refuge and the Narrows of Elephant Butte Reservoir.

Flow, Sediment, and Elephant Butte Reservoir Water Level

The MRG geomorphology in the EBR has been influenced by river diversions, upstream dams, peak floods, periods of drought, levee construction and channelization (Figure 3). Reduction of peak flows from above 50,000 cfs (Makar and Aubuchon 2012) to about 5,000 cfs or less and reductions in sediment supply have resulted in a narrower channel. There have also been changes in annual flow volume, with smaller flow volumes between 1949-1979, a period of higher flow volumes from 1979 to 1999, and lower annual volumes from 2000 to the present (Figure 4). The floodway flow volumes combined with the LFCC, are the inflow to Elephant Butte Reservoir (Figure 4). In Figure 4 the green line is the total inflow volume to the reservoir (sum of floodway and LFCC at San Marcial).

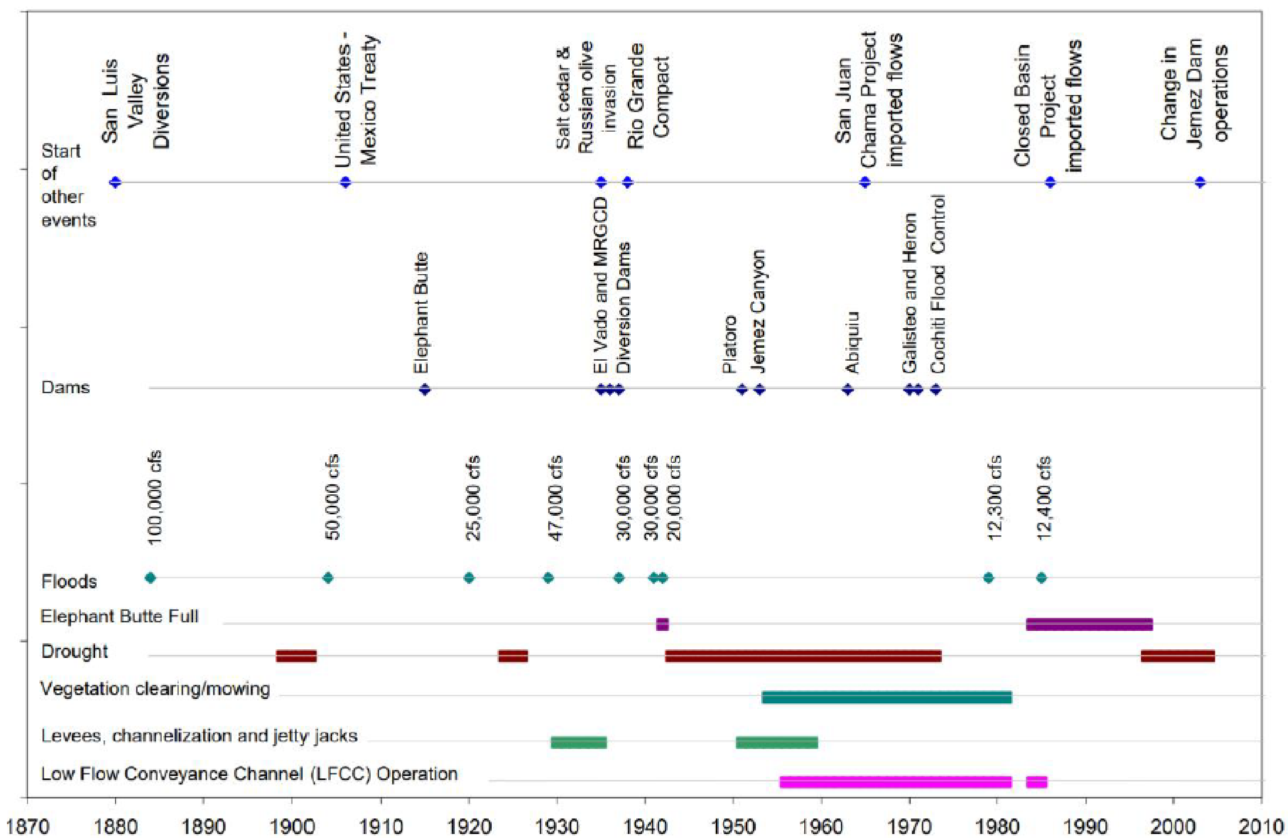

Figure 3. Timeline for Significant events for the Middle Rio Grande (Makar and AuBuchon 2012)

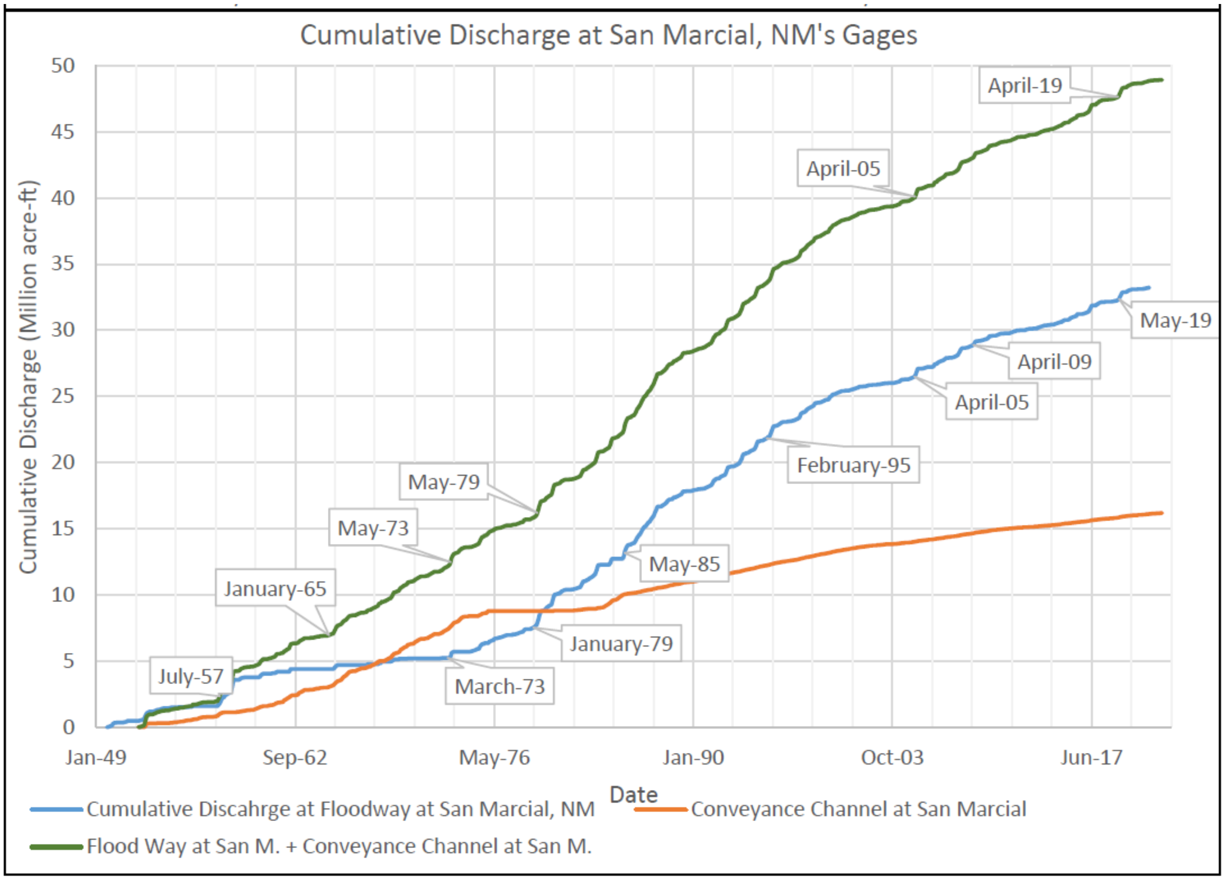

Figure 4. Cumulative annual inflow volumes to Elephant Butte Reservoir. Dates on each curve indicate times when the cumulative discharge has a change in slope of a large single year event. The Conveyance Channel at San Marcial was under re-construction during the period of no flow between about 1976, and 1984.

Comparing cumulative annual flow volume to cumulative annual sediment load shows that there was a reduction in sediment concentration in about 1975, and then a larger reduction in about 1982 before an increase around 1990 (Figure 5). Analysis of suspended sediment sizes showed a significant portion of sand load (Sperry et al. 2022). It is not precisely known when the effects of Cochiti dam affected suspended sediment loads at San Marcial. It is likely that somewhere around 1975 to 1982 changes in the water-sediment relationship were a result of Cochiti dam (about 185 miles upstream) which began to control flows in 1973. During the period of low reservoir inflow from about 1943 to 1978 the reservoir WSE was historically low (Figure 6), while during the period from 1979 to about 1999 the reservoir filled, and subsequently the WSE elevation decreased after about 2000.

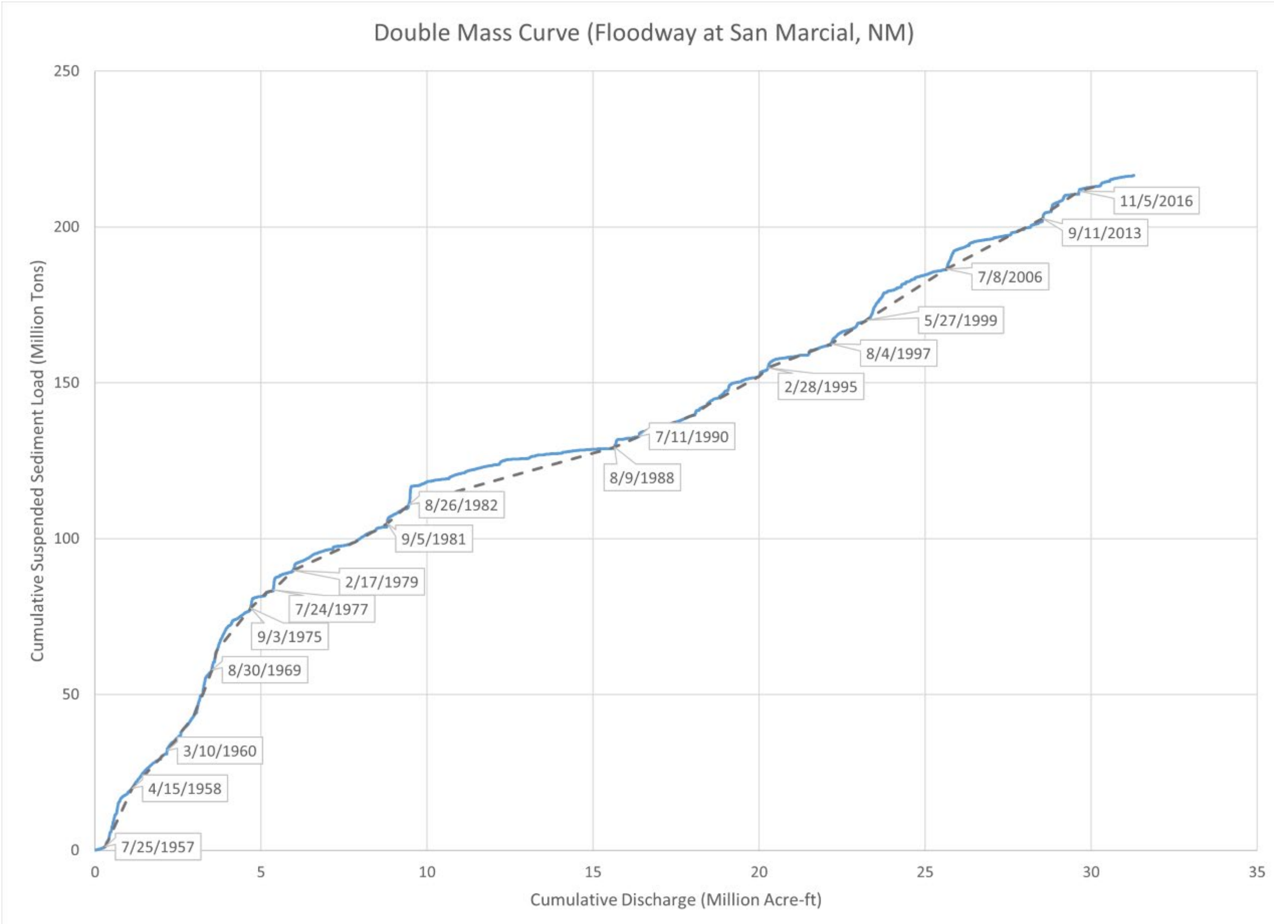

Figure 5 Cumulative annual discharge vs cumulative suspended sediment concentration. Dates on each curve indicate times when the cumulative discharge has a change in slope of a large single year event. The dashed line shows periods of relatively constant sediment load per unit of water.

Bed Elevation and Width Changes

In the EBR, channel width changes are a result of effects of the peak flows and sediment load but more significantly the elevation of the Elephant Butte WSE for the period of 1962 to 2012. The bed elevation in 1962 and 1972 (Figure 7) are about the same with some degradation, owing to the relatively low reservoir WSE (Figure 6). Between 1972 and 1992 the bed elevation rose considerably, ranging from about 5 ft (agg/deg 1637) to about 15 ft (agg/deg 1794). The bed elevation continued to rise (Figure 7) while Elephant Butte remained essentially full between 1992 and 1999. When the reservoir WSE receded in 2000 the bed lowered between the data sets in 2002 and 2012 (Figure 7).

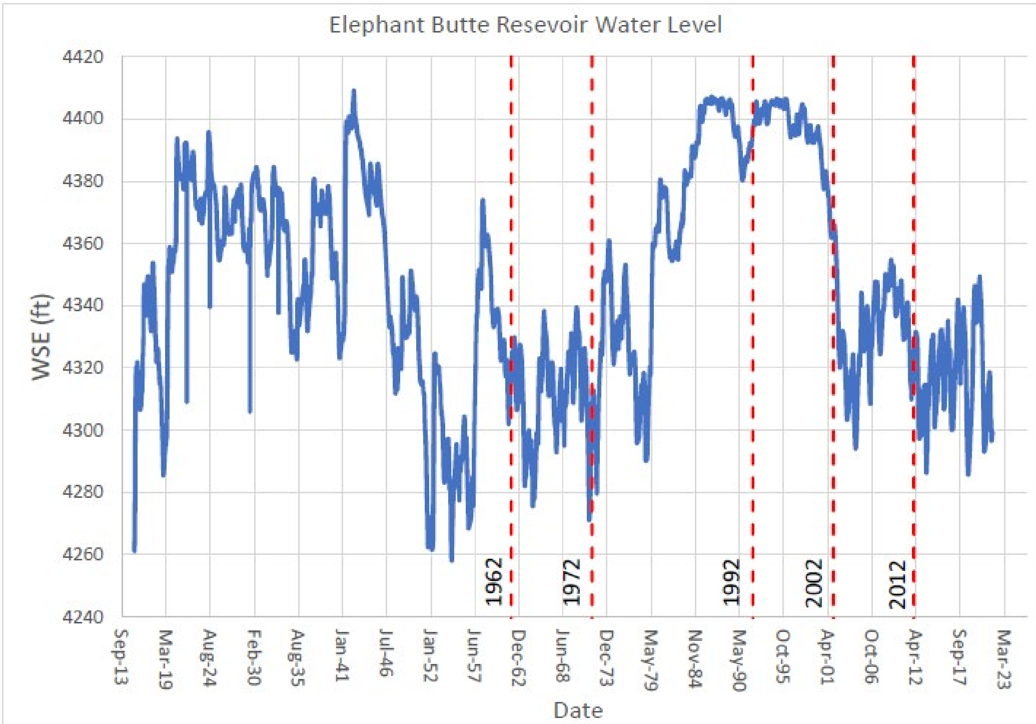

Figure 6. Elephant Butte Water Surface Elevation. Vertical lines indicate years of aerial imagery and agg/deg line data. Local project datum is 45.0 lower than the North American Vertical Datum of 1988.

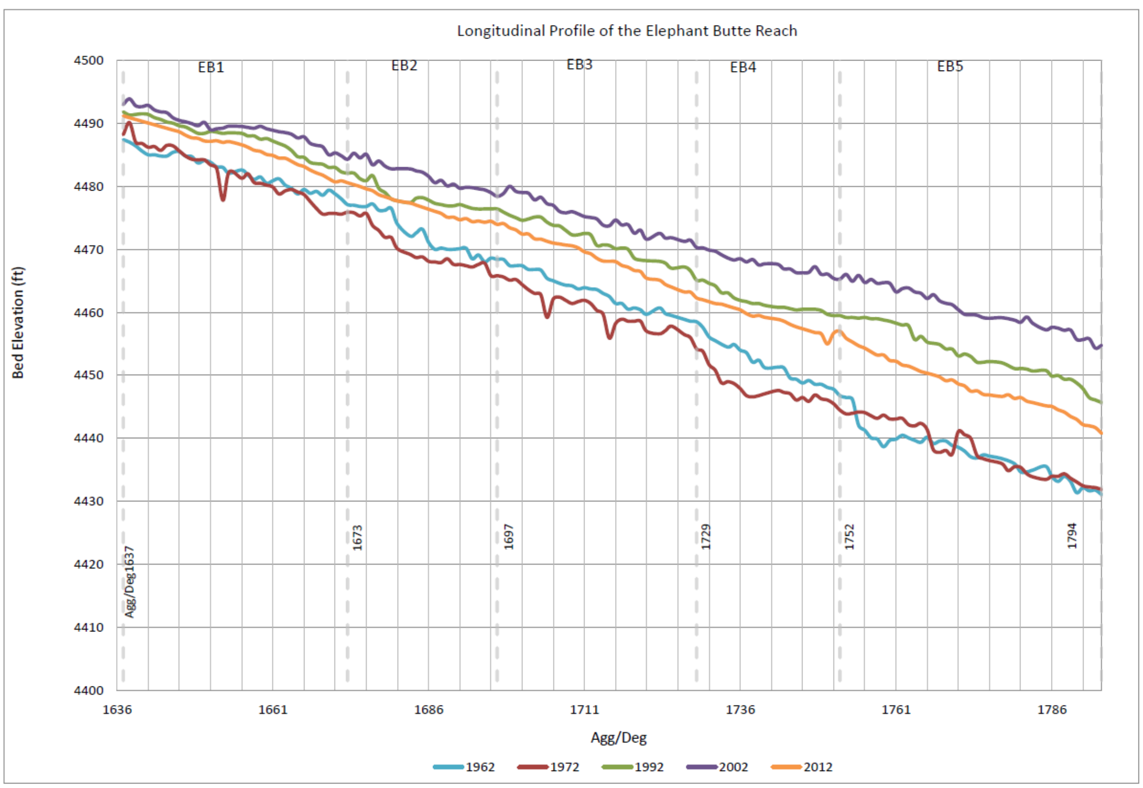

Figure 7. Longitudinal profile of the EBR for the period from 1962 to 2012. North American Vertical Datum of 1988

The cross-section bed elevation changes are illustrated in Figure 8 for the same period 1962 to 2012. Between 1962 and 1972 the bed elevation lowered, and between 1972 to 2002 the bed elevation increased during a period of high reservoir levels (Figure 6). In both 1962 and 1972, the river was perched above the floodplain. When the reservoir WSE rose in 1979-1999 not only did the main channel aggrade but the perching became more pronounced (Figure 8). Noteworthy is that as the main channel bed elevation has decreased as the reservoir WSE has receded, beginning in 2000, the extensive floodplain perching remains. This is due to the erosive forces of the increased energy gradient created by the lowering reservoir WSE being confined to the main channel. A 1-dimensional hydraulic model (HEC-RAS) was developed for the EBR (Sperry et al. 2022) for the agg/deg line data sets from 1962 to 2012. Cumulative top width at 1,000 cfs for the period from 1962 to 2012 is shown in Figure 9. At 1,000 cfs the width trends are basically the same as those when the flow is between 3,000 and 5,000 cfs (Sperry et al 2022). When the reservoir was low between 1962 and 1972, the width decreased as the channel was incising (Figure 9). As the reservoir WSE rose between 1972 and 1992, the bed aggraded (Figure 7) and the width increased (Figure 9) and continued to increase until 2002. When the reservoir receded the bed lowered (Figure 7), and the width decreased below what it was in 1972 (Figure 9) for all sub reaches except EB6. The large width increase in 2002 in EB5 is attributed to this being the active delta of the reservoir pool.

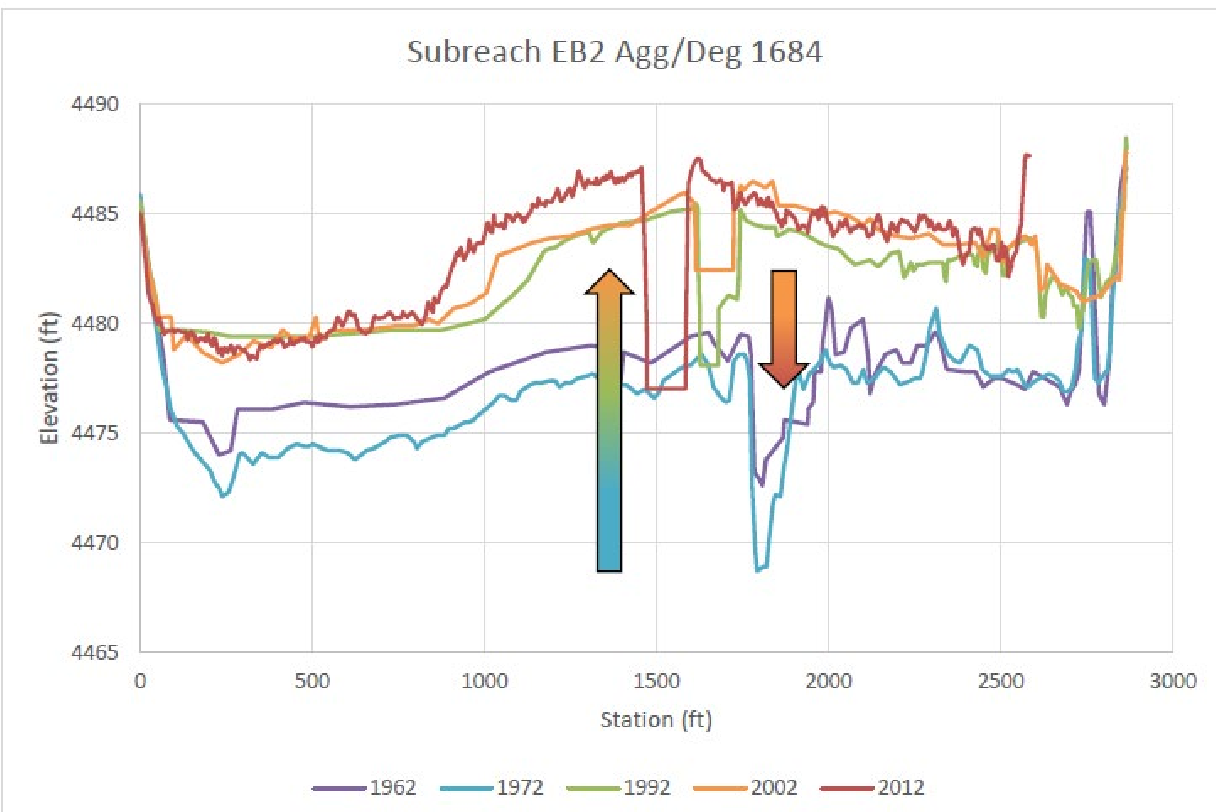

Figure 8 Cross section, sub reach EB2 for Agg/Deg 1684 for the period from 1962 to 2012.

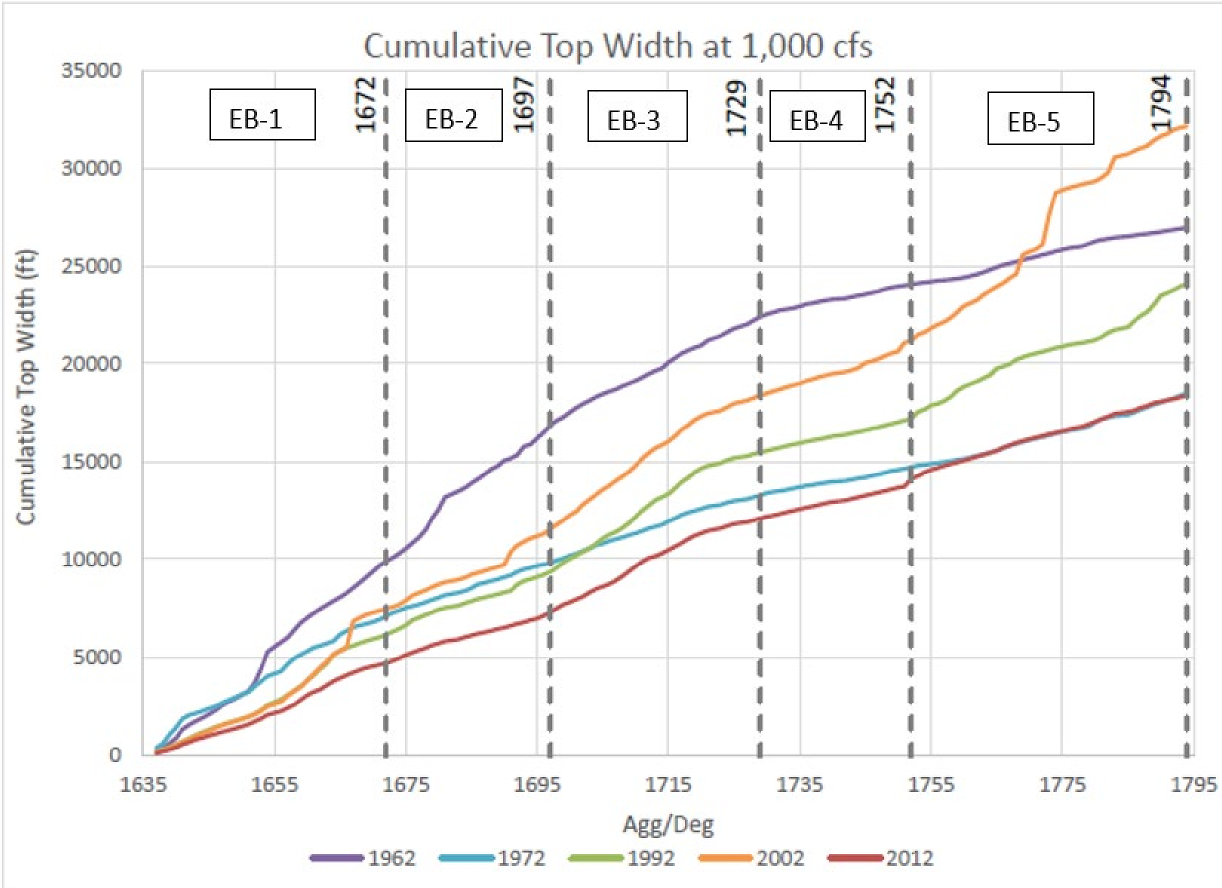

Figure 9. Cumulative top width at 1,000 cfs for the period 1962 to 2012.

Reservoir Delta Geomorphic Evolution Model

The reservoir level has a very large impact on channel aggradation, channel perching, bank height, and channel degradation. During periods of a rising reservoir, the upstream bed aggrades with increasing width, while during periods of lowering reservoir WSE the bed degrades and the channel narrows (Figure 7 and Figure 9). We developed a reservoir delta geomorphic elevation model (Figure 10) for constant reservoir water level conditions, rising reservoir water levels, and falling reservoir water levels. The geomorphic evolution model includes channel profiles, channel plan views and typical cross section shape.

When the reservoir water surface elevation is held approximately constant, sediment deposition causes the pivot point (point between the topset and foreset delta slope, USBR 1987) to migrate downstream towards the dam (Figure 10) progressively over time. The upstream channel continues to aggrade, and the channel plan form moves from a more meandering plan view to a straighter channel and then an active delta reach with distributary channels (middle panel Figure 10).

For the case where the reservoir is rising, the pivot point migrates upstream as does delta deposition (Figure 10). The distributary channels in the active delta can increase in number and longitudinal distance. Braided channel conditions can develop as the reservoir continues to rise, created by locally reduced hydraulic energy gradient from the rising reservoir. The upstream riverbed will experience aggradation leading to channel perching as water flows overbank. The top of bank is hydraulically rougher than the main channel, causing flow velocity to decrease depositing suspended sediment (Figure 8 and Figure 10). The river channel bank height will reduce, and channel width increase as channel aggradation continues (Figure 8 and Figure 9 and Figure 10). Continued rising of the reservoir water level can inundate previous delta formed at lower reservoir stage. Far upstream the river may remain in its current location in planform but could experience aggradation.

When inflow volume decreases the reservoir level may fall leading the deposited sediment pivot point to migrate downstream (Figure 10). The channel planform will tend to establish a single thread channel over time as one of the distributary channels begins to capture more of the flow and become the dominate channel. Channel perching, formed during higher reservoir stage will remain as the bank height increases, and channel width narrows as the upstream river channel degrades (Figure 9 and Figure 10).

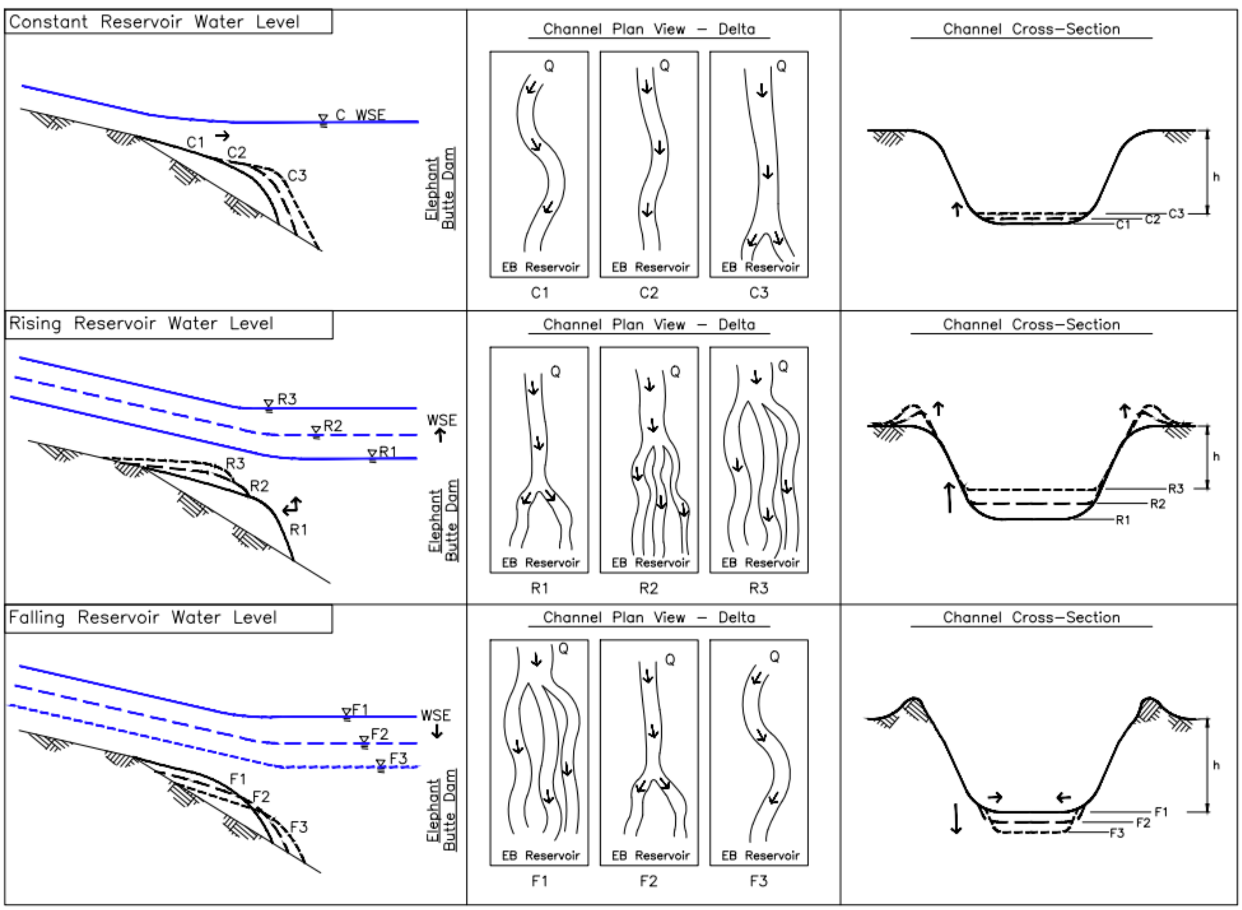

Figure 10. Reservoir Geomorphic Evolution Model

Figure 11 illustrates the main channel longitudinal profile associated with a falling reservoir pool after 1999. The pivot between the topset and foreset slopes in the delta is located at about agg/deg station number 1850 in 1999. As the reservoir receded active bed degradation occurred between about agg/deg 1805 and 1860, while upstream the bed remained about the same elevation.

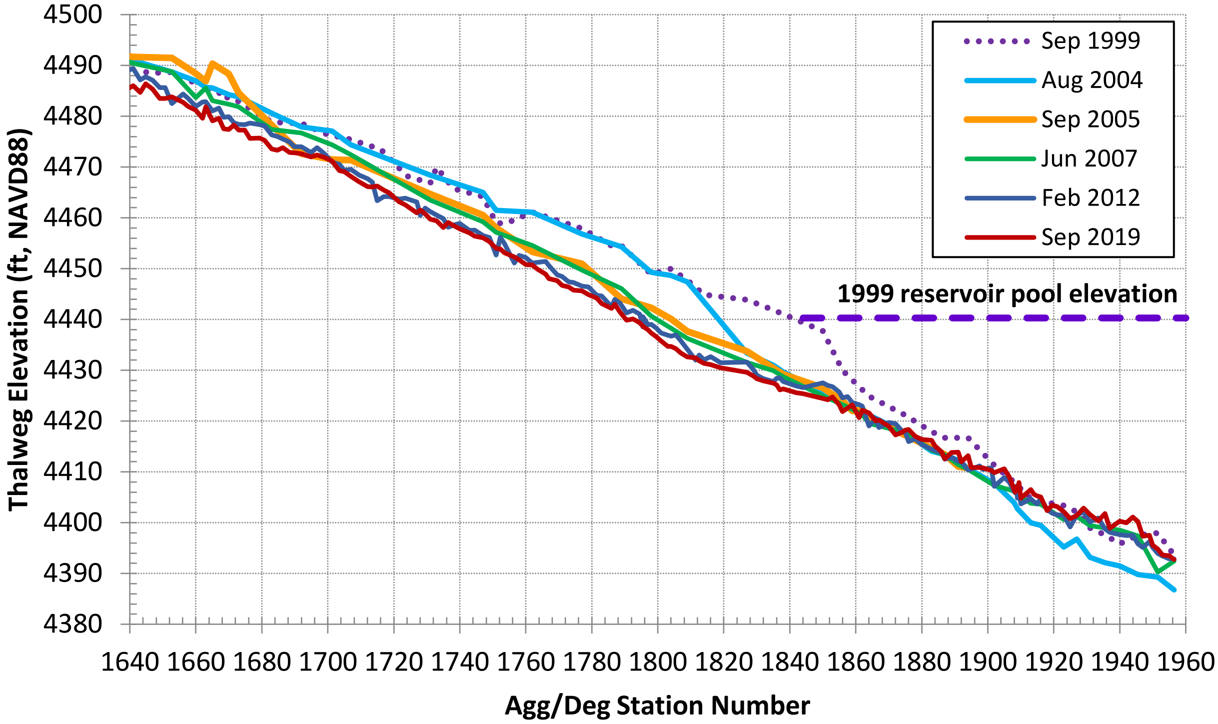

Figure 11. Longitudinal profiles associated with falling reservoir pool after 1999. Note headcut progression upstream of Agg/Deg 1840 and deposition downstream of Agg/Deg 1900.

Between August 2004 and September 2005, the formerly aggraded channel incised. Degradation continued through September 2019 (Figure 11). A slightly meandering channel develops while the reservoir level is falling, is shown in Figure 12, corresponding to stage F3 (Figure 10). In the active short delta region there remains distributary channels (Figure 12 and 13). Thus, in the falling reservoir case the channel may simultaneously contain the F2 and F3 planforms.

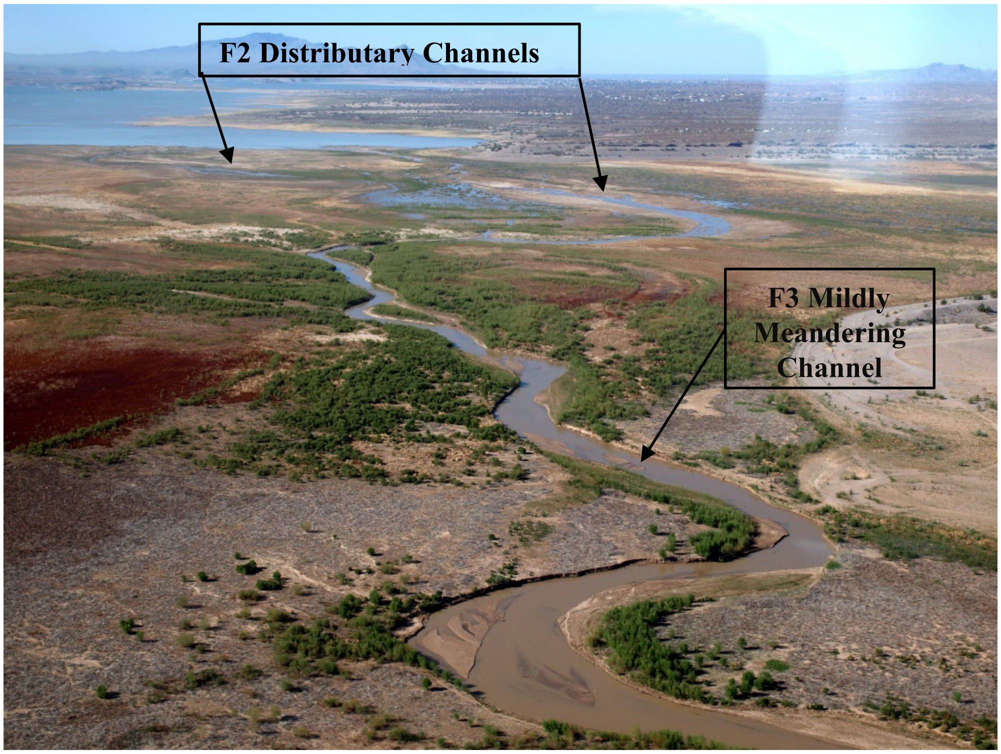

Figure 12. Picture looking downstream in 2013 where the reservoir pool receded about 100 vertical feet since 1999. Note the single thread slightly meandering channel approaching the reservoir and multi-thread in the active delta.

Figure 13. Picture looking upstream in 2013 showing exposed delta sediments that were formerly inundated when the reservoir was full. Note the distributary channels in the active delta.

Conclusions

For the period from 1962 to 2012 the water surface elevation at Elephant Butte Reservoir has been more influential on channel width and bed elevation than peak flow hydrology and sediment supply. During periods of relatively constant, but low reservoir water surface elevation, the upstream channel degraded, and the channel narrowed. When the reservoir level rose, the channel bed aggraded and the channel widened, and falling reservoir level resulted in channel narrowing while channel perching remained. We propose a delta geomorphic evolution model that describes the geomorphic effects of base level changes associated with water surface elevation trends in Elephant Butte Reservoir. The proposed model describes channel profile, planform, and cross sections for channel evolution stages to provide a communication tool that will aid in assessment of delta geomorphology and evaluation of the effects of water surface elevation changes.

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References

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

Makar P., and AuBuchon, J. 2012. Channel Conditions and Dynamics of the Middle Rio Grande River. Technical Services Division, Albuquerque Area Office, Bureau of New Mexico, Albuquerque, NM.

Massong, T., Makar, P., Bauer, T., 2010. Planform Evolution Model for the Middle Rio Grande, NM. Proc. 2nd Joint Federal Interagency Conference, Las Vegas, NF June 27 – July 2010.

Scurlock, D. 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, Rock Mountain Research Station. 440 pg.

Sperry, J., Schied, A., and Julien, P.Y., 2022. Middle Rio Grande Elephant Butte Reach Report. Colorado State University, Engineering Research Center, Department of Civil and Environmental Engineering, Fort Collins, CO. 80524.

United Stages Bureau of Reclamation (USBR). 1987. Design of Small Dams. U.S. Department of the Interior, Engineering and Research Center, Denver, CO, pp 529-564.