Geomorphic Evolution Model for the Middle Rio Grande Extended Abstract

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Abstract

The Middle Rio Grande (MRG) valley in New Mexico spans 232 miles from the mouth of White Rock Canyon south to Elephant Butte Reservoir (Figure 1, after Massong et al. 2010). Large historical floods and sediment loads have played a significant role in shaping the MRG. During the recession of historical floods, sediment would deposit in the main channel. During the next high flood, the river would bypass these sediment deposits and flow into the low point in the valley creating an avulsion (Scurlock, 1998). Construction of the levee system in the 1930s narrowed the river corridor. Beginning in the 1950s large flood control dams were constructed, and the river channelized (Maker and AuBuchon, 2012). There were also natural changes in precipitation and reduced sediment loads from ephemeral tributaries (Massong et al. 2010) that changed channel morphology (Massong et al. 2010).

With reduced flooding and sediment load there has been a change in channel processes towards a more predictable evolutionary process. We propose a geomorphic evolution model that builds upon the planform evolution model developed by Massong et al. (2010). Our updated model adds representative cross sections for each evolutionary stage. We also add an empirical evolution model for the geomorphic effects of base level changes associated with water surface elevation trends in Elephant Butte Reservoir with representative channel profiles, planform and cross sections.

Geomorphic Background

The Spanish explorers in the 1500s observed a large river and periods of channel evolution and avulsions, aggradation, and other large scale channel shifts driven by large floods (Scurlock, 1998). As agricultural and communities developed there was a desire to control the river system. Diversion dams, levees, and channelization projects were implements for managing the river (Scurlock 1998). Beginning in the 1930s the historical floodplain was narrowed significantly by levees; however, these were inadequate. Starting in the 1950s, construction of several large flood control dams, channelization, and levee reinforcement began (Lagasse 1980). Flood peaks and average river flows began reducing during the later part of the 20th century, with the last large flood occurring in 1942.

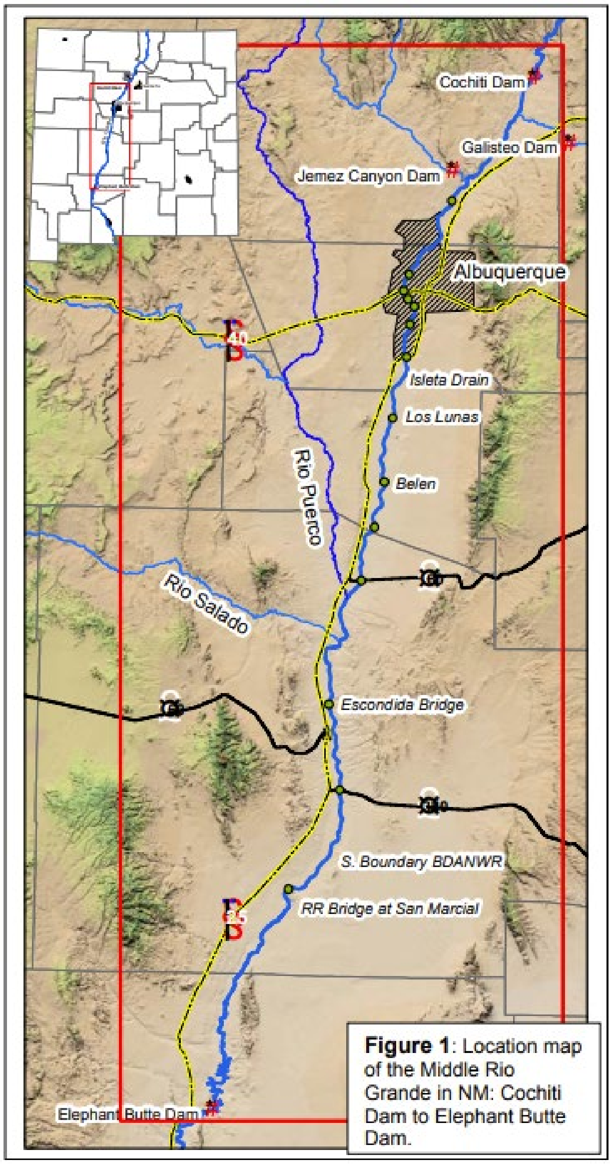

Figure 1. Location map from Massong et al. (2010)

In the late 1800s to early 1900s there were arroyos (ephemeral tributaries) delivering large amounts of sediment due to channel incision (Gellis 1992). As most of this incision began to stabilize the sediment load to the MRG naturally decreased (Gellis 1992 and Gorbach et. al. 1996, Love 1997, Gellis 2002, and Gellis et al. 2003). Large flood control dams were constructed with the goal of reducing flood peaks and sediment loads. The most influential large dam is Cochiti Dam (Figure 1), located north of Albuquerque NM, which began to control flows and sediment in 1973. The historically aggrading Rio Grande channel narrowed and degraded between Cochiti Dam and the Elephant Butte Reservoir Delta with a "more systematic pattern of change" (Massong et. al. 2010). in the middle Rio Grande reach (MRG) from Cochiti Dam to Elephant Butte Dam (Figure 1). This was due to a natural reduction in sediment supply coupled with reservoir filling, river channelization and levee construction/reinforcement.

In contrast, the reach within the delta zone of Elephant Butte Reservoir has experienced sediment deposition more than 20 miles upstream of the historical full pool location at the RR Bridge at San Marcial (Figure 1). During periods of full reservoir, channel aggradation has ensued, while a falling reservoir stage induces channel degradation and narrowing occurs.

River Geomorphic Evolution Model

A plan view geomorphic evolution model (Figure 2), developed by Massong, et. al (2010) describes channel changes initiated first by reductions in peak flows and sediment load, and then two distinct geomorphic paths that create very different channel forms. The process defining these two paths are relative sediment load and transport capacity. Where there is deficient transport capacity relative to supply, the channel will fill with sediment, eventually leading to the channel completely filling with sediment, creating an opportunity for channel avulsion. For reaches with excess transport capacity the channel evolves by continuing to degrade and narrow leading to meandering and lateral migration. During channel degradation and subsequent lateral migration, stored sediments from previous aggradation are re-activated by eroding the channel bed and banks.

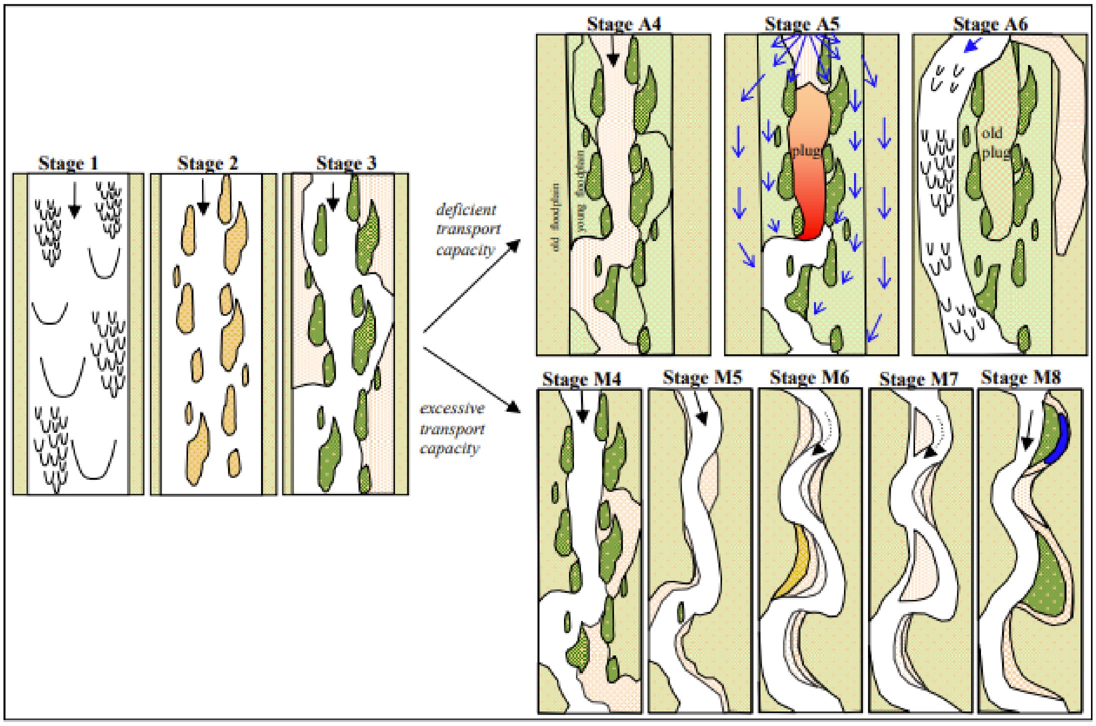

Figure 2. Middle Rio Grande planform evolution model (from Massong et al.., 2010).

We add typical cross sections to the Massong et. al. (2010) planform evolution model to create a geomorphic evolution model containing planform and channel shape (Figure 3 and Figure 4). Stage 1 to Stage 3 is commonly found in the MRG mostly during the 1950s through the early 1960s or 1970s. Stage 1 has shallow depths with low banks, wide active mobile bed with macro-dunes that were readily mobilized during peak flows (Figure 3). During Stage 2 islands emerge, the cross-section width reduces and depth increases (Figure 3) with the reduction in natural sediment supply along with construction of upstream reservoirs and reduced peak flows. By Stage 3 the emerged islands in Stage 2 begin to attach to the bankline. In the Isleta and Belen reaches, evolution through Stage 2 and 3 occurred in the early 2000s (Massong et al., 2010).

Stages of Aggrading Reach

When the sediment load is close to or exceeds the transport capacity of the river's main channel the transition from Stage 3 to Stage 4 occurs. Some channel filling may occur in Stage 3 so the transition to Stage 4 may be nearly imperceptible. During Stage A4 natural levees form along the channel banks as the main channel deposition causes channel perching. Flows are connected with the floodplain as the main channel continues to fill (Massong et. al 2010). When sediment deposition in the channel continues, more of the main river flows out into the floodplain. Flows spill from the main channel onto the floodplain, but with a smaller sand concentration than what remains in the channel. The loss of streamflow to the floodplain results in less flow to transport sand through the main channel and an accelerated rate of sediment deposition. As this process ensues, eventually the river channel becomes blocked or plugged, Stage A5 (Figure 3). Sediment deposition will continue in the floodplain after a plug has formed. When subsequent high flows occur, the river seeks to find a path lower in the floodplain and a new channel can form around the reach plugged with sediment, Stage A6. The new river path by-passes the old, plugged channel, and a new channel becomes well-formed when it can efficiently transport water and sediment.

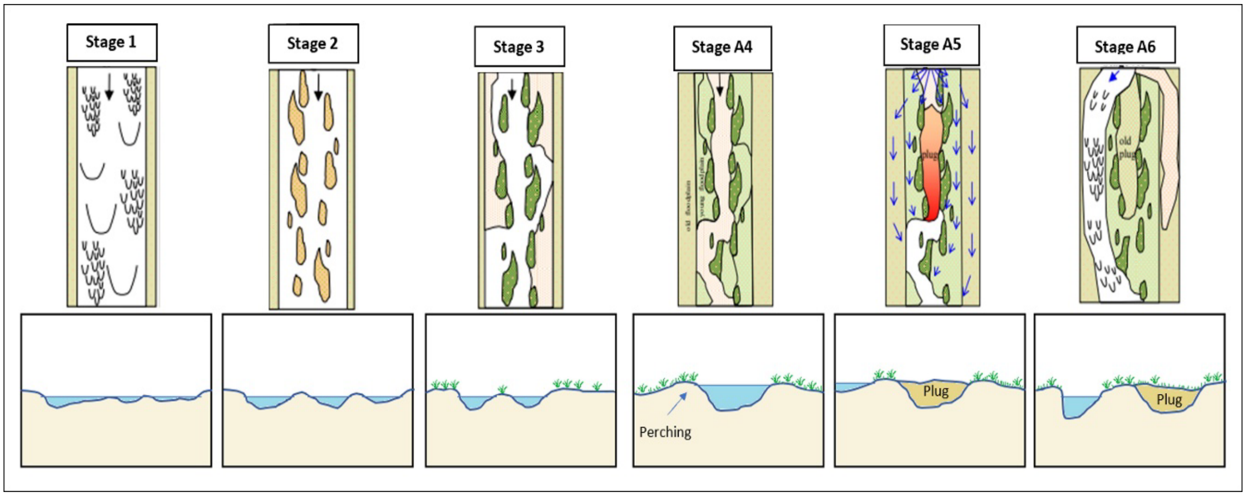

Figure 3. Middle Rio Grande planform evolution model when transport supply exceeds capacity. Channel aggradation occurs leading to perching and sediment plug formation.

Stages of Meandering and Migrating Reach

After Cochiti Dam began controlling flow, reducing peaks and sediment supply, reaches downstream of the dam developed excess transport capacity. This was in addition to the naturally occurring sediment load reduction from many ephemeral tributaries. High flow side channels fill with sediment and convert to floodplains and a defined thalweg develops in Stage M4 as the channel erodes vertically and increases its channel size (Figure 4). Stage M5 continues the incision and channel depth increases while the channel enlarges to captures flows in the main channel. In Stage M5, the channel bed continues to degrade until either the bed material coarsens sufficiently to protect the bed from erosion, or the channel reaches some sort of stable shape where the stream's available energy to transport sediment is relatively equal to the sediment supply (Massong et al 2010). Many reaches may remain in Stage M5.

For those channels that continue to incise the degradation may reach the lower extent of the riparian vegetation root zone such that the rate of lateral migration increases (Massong et al. 2010), Stage M6. Stage M6 completes the conversion to a single thread, slightly meandering channel with all flows being captured in the main channel. Point bar features develop on the insides of bends further developing the lateral migration pattern. Defined pool and riffle zones are well developed in M6. In Stages M5 and M6, the channel degrades until either the bed material coarsens sufficiently to prevent further incision, or the channel length increases sufficiently to reach a quasi-equilibrium state where the available river available energy to transport sediment is relatively equal to sediment supply. Continuing lateral migration and point bar development, as seen on many point bars on the MRG may results in a side channel cutting through the point bar, Stage M7 (Figure 4). This new side channel can grow, conveying increasing amount of water and sediment until eventually it conveys all the water and sediment. This allows the previous main channel to become abandoned, experience sediment deposition and vegetate and function as a floodplain, Stage M8 (Figure 4).

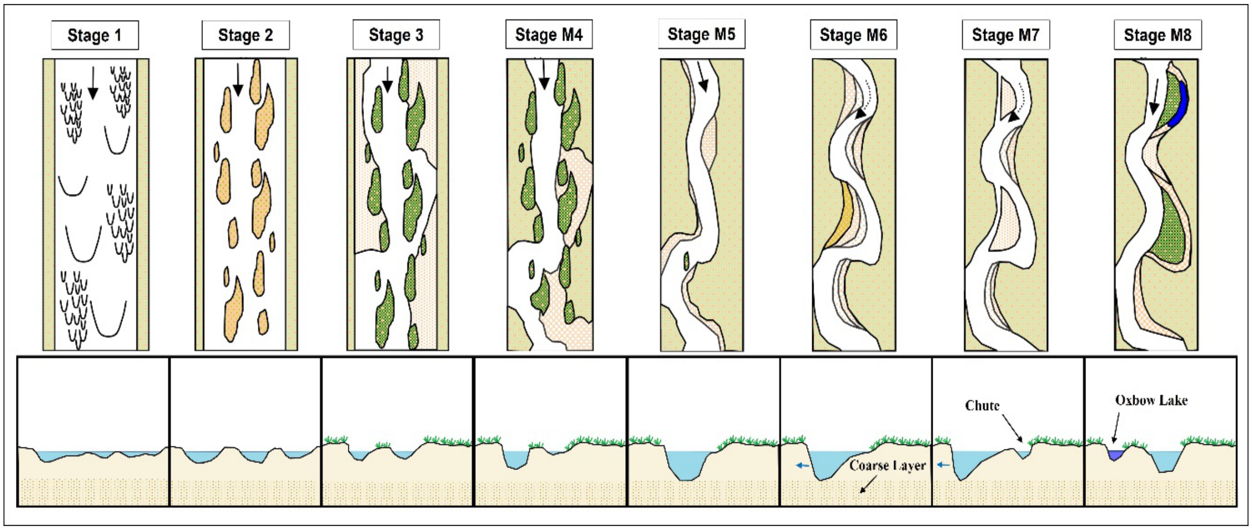

Figure 4. Middle Rio Grande geomorphic evolution model when transport capacity exceeds supply. Channel degradation occurs and a single channel develops with lateral migration.

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 rising reservoir, the upstream bed aggrades while during periods of lowering reservoir water surface elevation the bed degrades. We developed a reservoir delta geomorphic elevation model (Figure 5) 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.

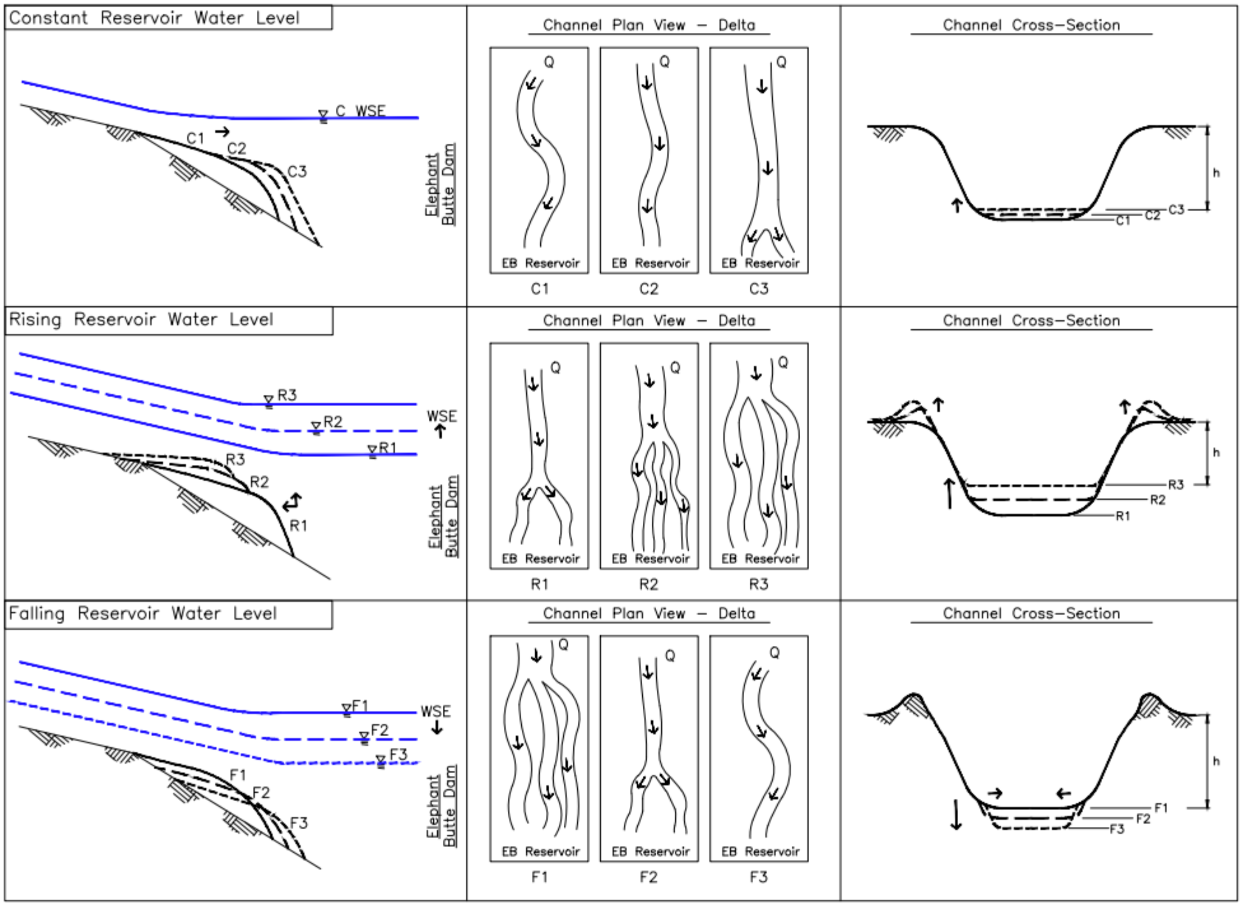

Figure 5. Reservoir Delta Geomorphic Evolution Model

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 progressively over time (Figure 5, top row). The upstream channel will continue 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 will form (middle panel Figure 5).

For the case where the reservoir is rising, the pivot point migrates upstream as does delta deposition (Figure 5). 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 natural riverside levees formed as water flows overbank encountering increased resistance to flow than the main channel causing flow velocity to decrease depositing suspended sediment (Figure 5). The river channel bank height will reduce, and channel width increase as channel aggradation continues. 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 and planform but could experience aggradation to the extent that channel plugs will form as in Stage A5.

When inflow volume decreases the reservoir level may fall leading the deposited sediment pivot point to migrate downstream (Figure 5). 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. The natural levees formed during higher reservoir stages will remain the bank height increases, and channel width narrows as the upstream river channel degrades.

Conclusions

We propose a geomorphic model of the MRG that includes planform and representative cross sections for each of the evolutionary stages contained in the planform model developed by Massong et al. (2010). We also add an empirical evolution model that represents the geomorphic effects of base level changes associated with water surface elevation trends in Elephant Butte Reservoir. The proposed model provides additional descriptions of channel stages that provide a communication tool, aid in assessment of river geomorphology, and evaluation of the effects of management actions on the MRG. Additional investigation, as the river continues to evolve may lead to refinement of these evolution models.

Acknowledgements

We thank Tristen Anderson, Chelsey Rasmussen, and Brianna Corsi, for assisting with preparation of figures.

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