STREAM RESTORATION WITHIN A CONFINED SPACE: A CASE STUDY ON THE MIDDLE RIO GRANDE

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BACKGROUND

The Rio Grande downstream of Cochiti Dam, as described by Happ (1948), Dewey et al. (1979), Lagasse (1980), Salazar (1998), Makar et al. (2006), and Makar and AuBuchon (2012), has seen the frequency of large magnitude floods and the sediment supply decrease over the last few decades. This has decreased the mobility of the medial and point bars and allowed the vegetation to become established, further amplifying the stability of the banks and the channel planform. Since the closure of Cochiti Dam in 1973, the downstream channel has continued to narrow through incision and vegetation encroachment, isolating the main channel from its floodplain. Richard (2001) and Shah et al. (2006) found that Cochiti Dam has had a high trapping efficiency, close to 98%, which as Lagasse (1980), Scurlock (1998), Massong et al. (2008), and Bauer (2009) described has led to the exposure of a dominant gravel fraction in the bed material in the first 30+ miles downstream of Cochiti Dam. Recent analyses by AuBuchon and Bui (2014) showed that within the first 5 miles of the Rio Grande below Cochiti Dam the active channel width has fluctuated around 200 feet and the slope has flattened to about 0.0012 over the last 2-3 decades. In addition, the channel planform has abandoned some of its variability with a decrease in the average number of channels from 2-3 prior to 1962 to about 1-2 since 1972. The sinuosity still fluctuates slightly, although not to the extent that it did prior to 1962, suggesting that there are local areas of instability, amidst the observed stability.

In 2011, the watershed of the Peralta Arroyo was burned by the Las Conchas fire, which has affected the stability of the slopes on the upper watershed. This has resulted in rainfall runoff events moving a significant volume of water and sediment into the lower portions of the Peralta Arroyo watershed. On September 13, 2013, a rainfall runoff event occurred over this watershed and brought enough sediment downstream to the confluence with the Rio Grande that the river was completely blocked (see Figure 1). Collected survey data revealed that about 2–5 feet of sediment was deposited in the Rio Grande from this event, in essence creating a miniature dam on the river. This sediment block created an opportunity for overbanking flows on a terrace that had been isolated from the main channel for decades. The backed up water also created engineering and reservoir operation concerns.

The engineering and reservoir operation concerns included being able to safely release floodwaters stored in Cochiti and minimizing the risk of unconsolidated spoil levee failure, property flooding, and ineffective farm field drainage. For the short term these were addressed by excavating a pilot channel through the sediment block on the main channel. A longer term design was required though to avoid future intervention and allow the natural fluvial and riverine processes to occur with as much freedom as possible while still addressing engineering and reservoir operation concerns.

Figure 1 Sediment deposit at Peralta Arroyo confluence. Photograph taken on 9/17/13.

DESIGN

Key aspects that were used to develop the long term design were 1) observations of the river's response when the channel was blocked, 2) analysis of sediment (channel competency and capacity), 3) addressing the engineering and reservoir operation concerns, and 4) encouraging overbank flows on the eastern terrace.

The first aspect concerns two observations made of the river's response to the sediment block in the river. The first was the observation of incision due to head cutting (see Figure 2) on the southern end of the eastern terrace. As the overbanking flow paths merged together and dropped into an abandoned river channel, enough energy was developed to start carving new channel locations. While the overbank flows only lasted for about 1.5 months, some of the carved new channels extended back a hundred feet or more, incising 1-3 feet. Massong et al. (2010) found that the general governing process for locational changes through this reach of the Rio Grande is lateral migration. Over the years the lateral migration of the banks has decreased through this reach of the Rio Grande, as the coarse fraction in the bed and the dense vegetation growth on the banks helped to minimize further bed and bank erosion. The observation of incision on the eastern terrace reveals that under the right circumstances, and given enough time, a slightly different planform change process may occur in this reach. Since the eastern terrace has significantly less vegetation and more sand than the existing channel banks and bed, respectively, there is less resistance to erosion. As erosion proceeds with time, conditions may set up that cause the Rio Grande to "avulse" from its existing path to a new main channel location on the eastern terrace.

Figure 2 Incision on southern end of eastern terrace. Left: Vertical drop at one of the incision fingers during the overbanking flow. Right: One of the longer incision fingers. Photographs were taken on 9/17/2013 and 10/17/2013 respectively.

The second observation was where and how overbanking occurred on the eastern terrace. Once a pilot channel had been cut through the sediment block on the Rio Grande, flows were increased from Cochiti Dam until a flow of about 2,200 cfs was reached. The observed flow paths at the 2,200 cfs flow rate (orange flow arrows) are shown in Figure 3. While overbank flows were occurring, standing water at the toe of the east side, unconsolidated spoil levee was not observed. On October 21, 2013 releases were made at Cochiti Dam to temporarily increase the flow to 3,500 cfs and then about 5,300 cfs in an effort to assess the current capacity of the system. Figure 3 shows the measurement and observations made that day by AuBuchon and Bui (2013). These observations helped identify some of the features that would be needed in the long term design to address engineering and reservoir operation concerns (discussed later).

The second key aspect considered two basic questions addressing sediment. The first question is whether the flow of a design channel would be competent to move the material found in the eastern terrace. The second question is whether a design channel would have the capacity to transport sediment (both incoming and self-generated through morphological adjustments) at flows between 5,000 and 6,000 cfs. This flow range has been the observed maximum flow releases during the spring snow-melt runoff on the Rio Grande from Cochiti Dam over the last decade.

To address the first question, soil samples were collected at five locations in the eastern terrace. Samples were collected with a hand auger to a depth of about 2.5 feet below the eastern terrace surface. The results of the gradation analysis on the soil samples are summarized in Table 1. The results in Table 1 were used to calculate the critical shear stress for particle mobility using the Shield's approach for incipient motion as described by Yang (1996). A one-dimensional hydraulic model provided the necessary inputs to calculate the normal shear stress according to Brown (1996). The critical and normal shear stress results were then compared to provide an estimate of the initial bed stability (Table 2). From these results it is seen that a design channel would be competent to move the majority of the material in the eastern terrace with sustained

high flows of 5,000 cfs or higher. However, there are larger particles present in the eastern terrace that the channel may not be competent to move, suggesting an armor layer could develop.

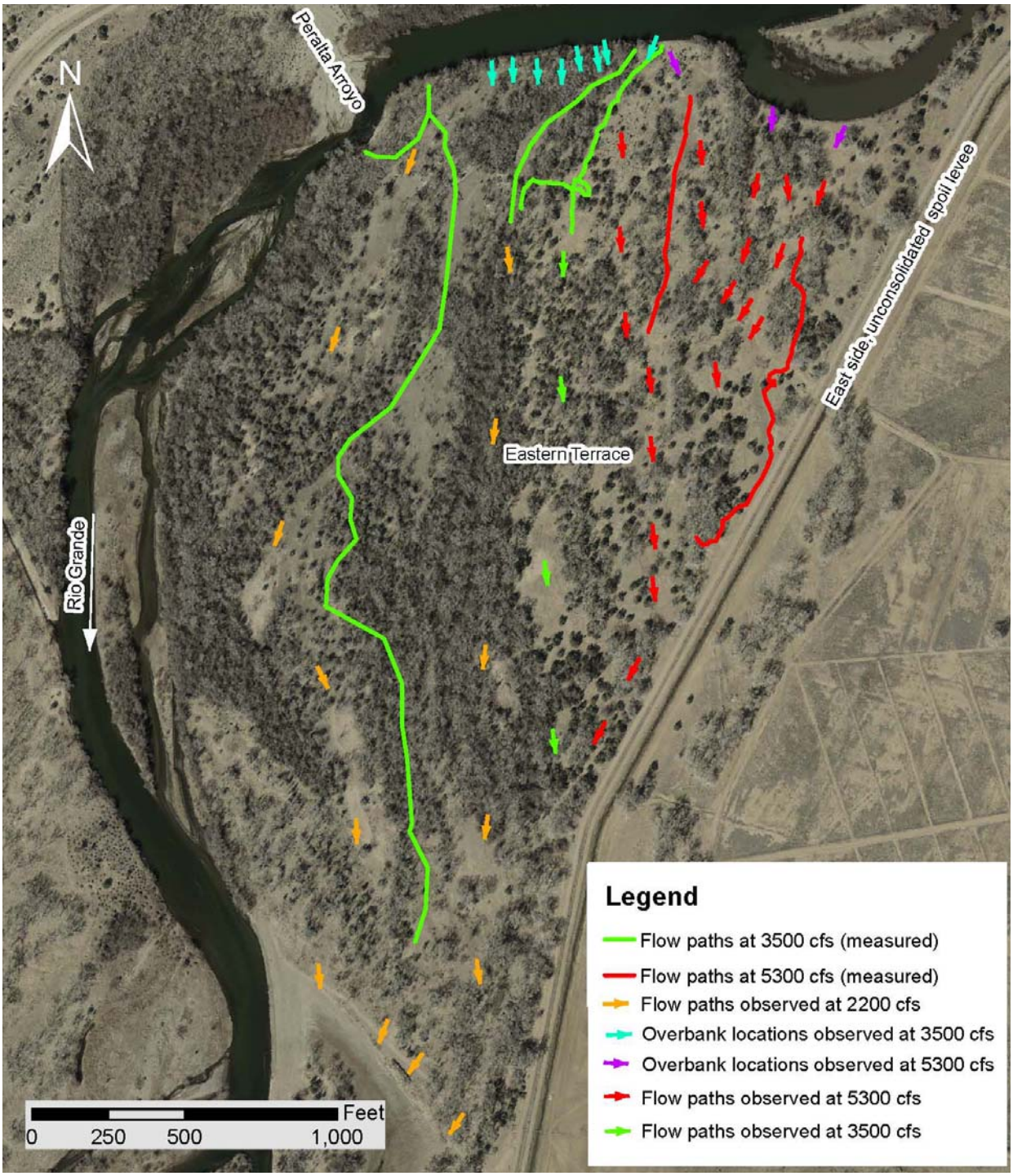

Figure 3 Observed flow paths on the eastern terrace during a short term high flow release in 2013. The background map is from Reclamation's 2012 aerial photography of the Rio Grande.

Table 1 Gradation results (median size – d_{50} and one standard deviation coarser than the median size – d_{84}) of eastern terrace bed material samples. Sample numbers are listed geographically by sample location from upstream to downstream.

Sample #	D_{50} (mm)	Description (D_{50})	D_{84} (mm)	Description (D_{84})
5	0.07	Very fine sand	20	Coarse gravel
1	0.062	Very fine sand	0.31	Medium sand
4	0.084	Very fine sand	10.5	Medium gravel
2	0.0083	Fine silt	14	Coarse gravel
3	14	Medium gravel	100	Small cobbles

Table 2 Critical and normal shear stress results (median size – d_{50} and one standard deviation coarser than the median size – d_{84}) of eastern terrace bed material samples. Sample numbers are listed geographically by sample location from upstream to downstream.

Sample #	D_{50} Critical shear stress (lb/ft^2)	D_{84} Critical shear stress (lb/ft^2)	Normal shear stress at 5,000 cfs (lb/ft^2)	Normal shear stress at 6,000 cfs (lb/ft^2)
5	<0.1	0.3	0.5	0.6
1	<0.1	<0.1	0.5	0.6
4	<0.1	0.2	0.4	0.5
2	<0.1	0.2	0.4	0.5
3	0.2	1.5	0.2	0.3

An additional assessment was also made to look at the competence of a design channel to erode its banks given the information available about the material in the eastern terrace. This assessment was made using the Bank Stability and Toe Erosion Model (BSTEM) described by Simon et al (2000), Simon and Collison (2002), Pollen-Bankhead and Simon (2009), and Simon et al. (2010). The initial channel condition runs with the BSTEM model (no vegetation establishment) projected unstable bank conditions for the design channels, except in the areas where there was a coarser bed material fraction. The presence of coarse particles and the possibility of future vegetation growth (Figure 4) indicate that the banks of a design channel through the eastern terrace may become more stable over time.

To address the second sediment question we first need to understand the available incoming sediment supply. Richard (2001) noted that although the sediment supply on the Rio Grande has been decreasing since the late 1950s, there was a pronounced decrease in the sediment supply immediately below Cochiti Dam after its closure. In the years leading up to the Cochiti Dam closure, the Rio Grande had an annualized average suspended sediment concentration around 2,000 mg/L. This dropped to an annualized average suspended sediment concentration of about 40 mg/L after the closure of Cochiti Dam. An estimate of the incoming sediment supply may be obtained by assuming the annualized average suspended sediment concentration is reflective of the sediment input immediately below the dam and assuming a representative flow rate. The median flow rate (590 cfs) at the USGS gaging station on the Rio Grande below Cochiti Dam, NM (08317400) was used to provide a representation of the flow rate since the closure of Cochiti Dam. The daily incoming sediment supply then for the reach immediately below the dam is roughly 60 tons per day.

Figure 4 First season vegetation growth on bed of design channel near outlet of flow path 2, looking upstream. Photograph was taken on 10/1/2014.

The transport capacity of any channel is very dependent upon slope. The localized slope of the Rio Grande around the Peralta Arroyo confluence is shown in Figure 5 before and after the September 2013 rainfall-runoff event on the Peralta Arroyo. The January 2009 survey data reflects relatively unchanging slope conditions (0.0012) since the early 2000s. The slope increase seen in the 9/20/13 data set (estimated slope of around 0.0038) reflects the large sediment input after the September 2013 event. The third data set reflects conditions on the Rio Grande 2 months after the September 2013 event, and about 1 month after a pilot channel was constructed through the sediment block on the main channel. The slope of the river bed from this data collection effort was found to be around 0.0011. Comparing the localized slope values of the Rio Grande for all three surveys reveals the impact a temporary higher sediment load has on the local river morphology and also the tendency of the river to adjust towards a certain slope value based on average sediment loads.

Based on the previously discussed observations of head cutting on the eastern terrace and the measured slope adjustments around the Peralta Arroyo, an initial slope value of 0.0028 was used for the design channels on the eastern terrace. This steepened slope is not expected to be stable, but was chosen to help induce morphological change. It is expected that the slope of any design channel on the eastern terrace will eventually adjust to around the observed reach tendency, unless the eastern terrace is abandoned as a flow path entirely or the sediment load changes significantly.

Using this initial design slope and the channel hydraulics (derived from a 1-dimensional hydraulic mode) a rough idea of the sediment transport capacity of the design channel at 5,000 cfs was estimated. The estimation approach used a Monte Carlo error analysis assuming hydraulic relations for wide, steady, uniform flow as described by Wilcox et al. (2009). Using this approach, the transport capacity of the initial design channel at 5,000 cfs is calculated to be almost a 100x greater than the estimate of incoming sediment supply discussed previously. The transport capacity of the design channel with an adjusted slope near the reach tendency is estimated to drop to almost a third of this value. This would indicate that the initial channel design has the capacity to transport the incoming sediment load and sediment eroded from the bed and banks as morphological adjustments occur. It also indicates that as adjustments occur, especially along the longitudinal profile, the transport capacity would also decrease with time.

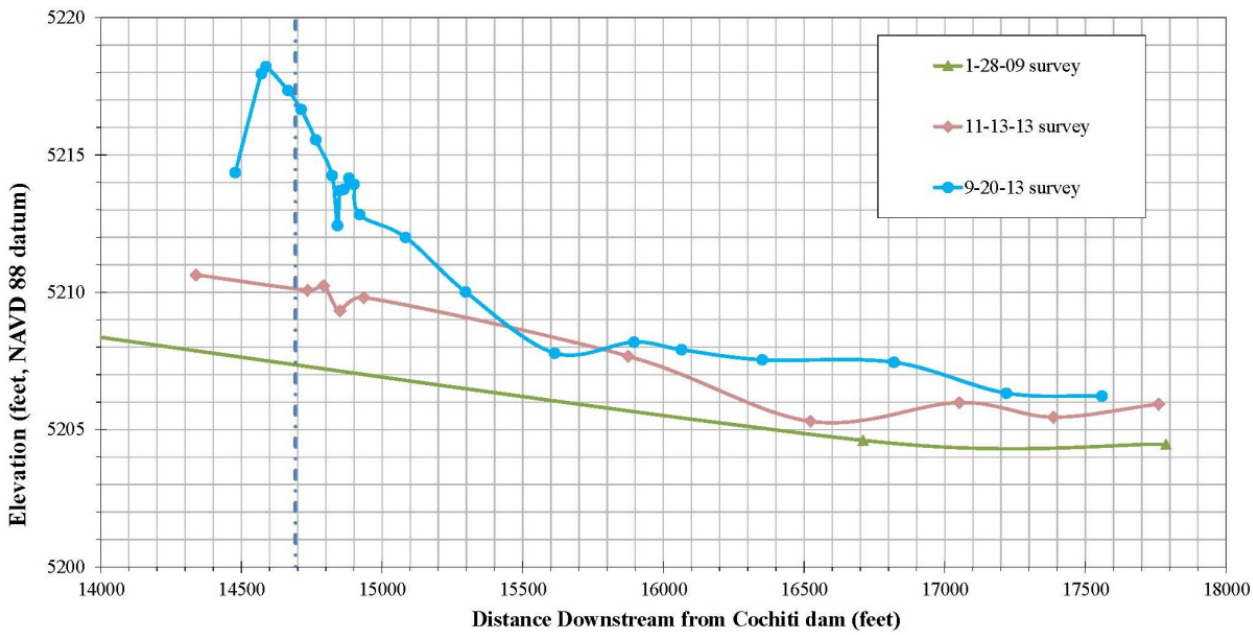

Figure 5 Rio Grande Profile between ~ 200 feet upstream and ~0.5 miles downstream of Peralta Arroyo.

The third key aspect of the long term design was addressing the engineering and reservoir operation concerns. From a reservoir operation perspective the primary concern with a potential sediment block is being able to safely evacuate stored floodwater in Cochiti Dam in a timely manner. Within a week of the September 13, 2014 event, upstream rainfall events had brought in almost 30,000 acre-feet of water to Cochiti Dam. Because of the sediment block at Peralta Arroyo, this water could not be safely released. While the construction of a pilot channel through the sediment block resolved this concern, it was desirable to solve this concern in the future without requiring the intrusion of construction equipment into the river. To mitigate this future risk for the long term design, multiple design channels with different inlets were designed in the eastern terrace. This provided redundancy to bypass the Peralta Arroyo confluence in case a similar event occurred in the future.

Engineering concerns also arose due to the flooding that occurred as a result of the sediment block. The three primary engineering concerns were unconsolidated spoil levee failure due to seepage, property flooding, and ineffective farm field drainage. The concern with the unconsolidated spoil levee failure is associated with pooling of this water at the toe which created seepage on the landward side, as shown in Figure 6. This issue was addressed by placing design features on the eastern terrace to intercept and redirect overbanking flows. Observations of the overbank flow paths, as shown in Figure 3, were directly used to strategically place design features to intercept and redirect flow heading to the unconsolidated spoil levee. The property flooding risk is directly related to the failure of the unconsolidated spoil levee, since the soil levee separates the river from the nearby agricultural land and nearby communities. Because of this relationship any reduction in the risk of levee failure also reduces the property flooding risk. The elevated water levels associated with the sediment block were the primary concern behind the farm drains not operating as designed. By incorporating multiple pathways in the design for the water to be conveyed downstream, the risk of future sediment blocks creating elevated river water levels is minimized.

Figure 6 Seepage and pooling at the unconsolidated spoil levee. Left: Observed seepage on the landward side of the spoil levee. Right: Water pooled on the river side of the spoil levee. Photographs were taken on 9/26/2013 and 10/21/2013 respectively.

The fourth and final aspect of the long term design involved encouraging opportunities for overbank flows to help increase the morphological diversity of the channel. The observations of the overbank flow paths shown in Figure 3 were used to help identify locations where overbanking flows occurred and did not pose a risk to the unconsolidated spoil levee. A temporary spoil levee was then constructed to help contain higher flows within this area. This allowed overbanking flows, such as seen in Figure 7, access to slightly over half of the area observed to be flooding at a flow of 3,500 cfs, and about a third of the flow at 5,000 cfs.

Figure 7 Overbanking flows on the eastern terrace at 3,500 cfs. Photograph was taken on 10/21/2013.

The consideration of all 4 key aspects of the long term design led to the final design, as shown in Figure 8. This design included construction of three channels on the terrace (yellow lines) following locations where the main overbanking flow paths were observed. It also included strategically excavating and placing material (red line) to intercept and redirect overbanking flows away from the unconsolidated spoil levee into the constructed channels. A final component of the design was to place excavated material, as a spoil berm (green line), on the east side of the excavated channels. This provides an immediate channel capacity between 5,000 and 6,000 cfs, while still allowing overbank flooding to occur. The inclusion of multiple channels, a redirection berm and ditch, and a spoil berm also provided a level of redundancy that allows for complex system responses without the need for substantial intervention.

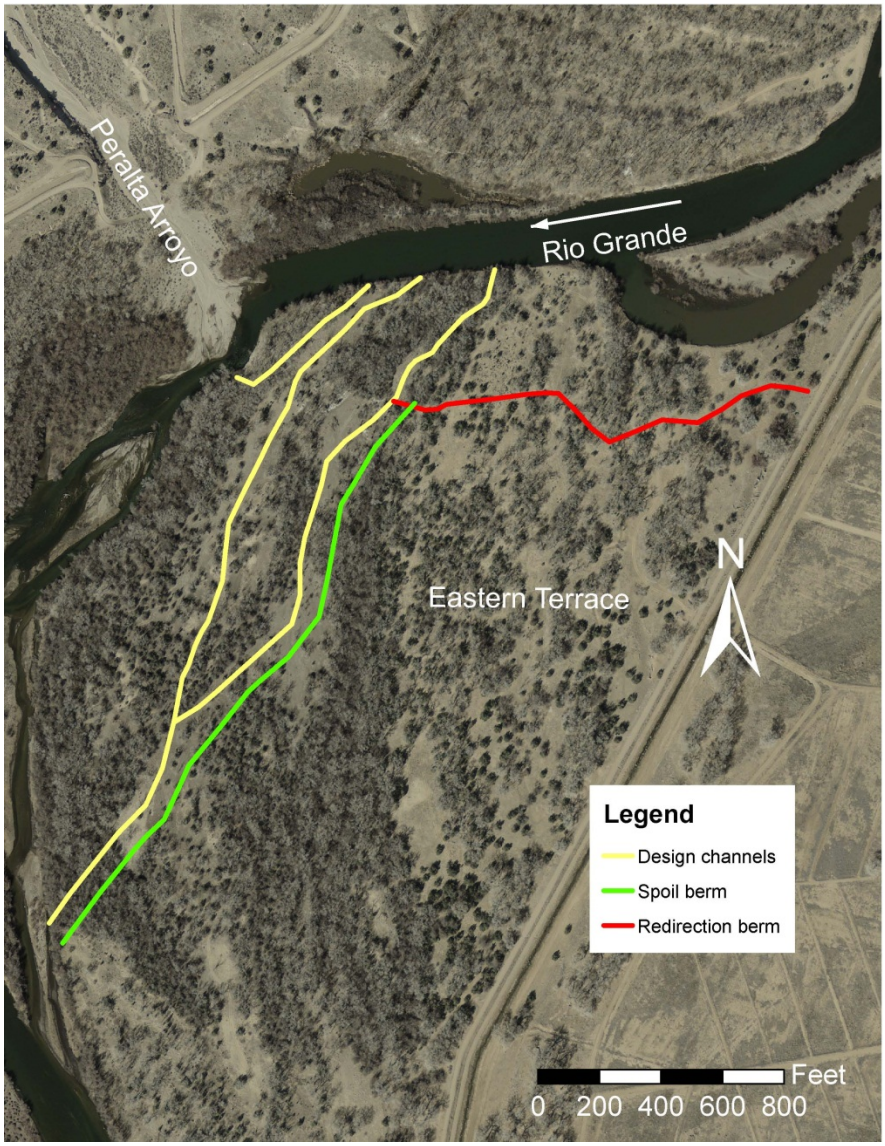

Figure 8 Long term design components for the eastern terrace flow augmentation. The background map is from Reclamation's 2012 aerial photography of the Rio Grande.

EXPECTED RESPONSE

The long term design was constructed in the spring of 2014. In late spring/early summer a small spring snow-melt runoff of slightly less than 2,000 cfs caused a few of the design channels to flow, see Figure 9. While very little morphological change occurred, the channel was visually winnowing finer material, like the sands, and transporting them downstream, as shown in Figure 9. Since the channel banks and bed are expected to adjust, the presence of large trees left at the edges of the construction footprint will hopefully also provide local conditions, as the trees fall into the river, where complex flow patterns will develop. These flow patterns may aid in the formation of channel complexity and create greater diversity in the morphology of the channels.

Figure 9 Looking downstream on one of the constructed channels. Left: Channel during spring runoff flows. Right: Channel after the spring runoff flows. Note the presence of sand deposits from upstream winnowing in the channel. Photographs were taken on 5/9/14 and 10/1/14, respectively.

A long term design that allows for dynamic change within a restrained system was facilitated by considering 4 key aspects. These aspects included observing the river's response to a disturbance event, analyzing the sediment (channel competency and capacity), addressing the engineering and reservoir operation concerns, and encouraging the continuation of overbank flows. This design process allowed the Rio Grande within this confined river reach more freedom to self-adjust, creating opportunities for diverse morphological features to develop on a previously abandoned floodplain terrace.

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