HYDROLOGIC ANALYSIS OF MESCAL CANYON WATERSHED AND GEOMORPHIC ASSESSMENT OF LOWER MESCAL ARROYO CONFLUENCE

Vincent Benoit, Hydrologic Technician, Bureau of Reclamation, 555 Broadway NE Ste 100 Albuquerque NM, 8710, Office: 505-462-3628, Cell: 435-757-0936, Email: vbenoit@usbr.gov

INTRODUCTION

Mescal Arroyo empties into the Rio Grande roughly two miles downstream of Elephant Butte Dam. Mescal arroyo is fed by a watershed with a contributing area of roughly 14,000 acres. The vertical relief throughout the watershed ranges from 5,800 feet at the peak of Caballo Cone to an elevation of 4,250 feet at the mouth of the arroyo. The main channel of the Rio Grande above the confluence of the arroyo and river is constrained by natural features and influenced by Mescal Arroyo. Flanked on either side by steep mountainous terrain, the Rio Grande is constricted in width and its channel location is restricted. These constraints are primarily above the confluence of the river and the arroyo, and have a limited effect on the planform around the mouth of Mescal Arroyo. Anthropogenic constraints have a greater effect on the planform of the river channel around the arroyo mouth.

Flows on the Rio Grande in this reach have been controlled by the operation of Elephant Butte Dam since 1916. The channel downstream of Elephant Butte Dam has also been channelized to preserve the conveyance capacity of the channel for delivery of irrigation water downstream and to protect adjacent infrastructure from damage due to high flows. Continuous river maintenance work is performed through the channelized portion of the river downstream of Elephant Butte Dam to maintain the authorized 5,000 cfs channel capacity per the congressional Flood Control Acts of 1948 and 1950.

As is common in ephemeral channels, the slope of the arroyo is greater than that of the river channel. Figure 1 contains two profiles from surveyed data that illustrates the difference in slopes between the arroyo and the river channel, in this case they are an order of magnitude different.

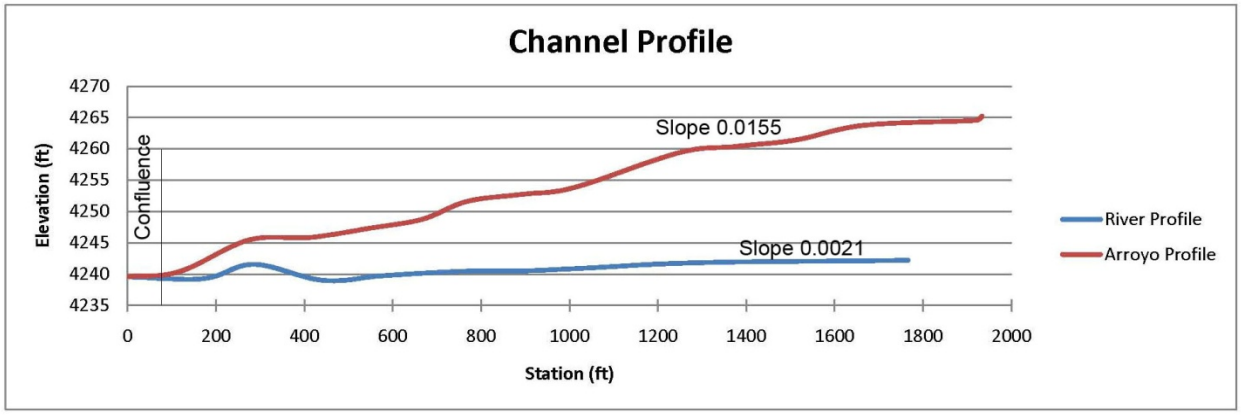

Figure 1 Comparison of Rio Grande Channel slope and Mescal Arroyo slope.

A combination of high runoff potential of the soils and sparse surface vegetation in the upper Mescal Arroyo watershed, high slope of the Arroyo, and a monsoon dominated hydrology, with its periods of intense rainfall result in high rates of sediment transport and deposition during these flashy events. High rates of sediment transport from Mescal Arroyo lead to alluvial fan deposition at the confluence with the Rio Grande that has on occasion both partially and fully blocked river flows, reducing the channel capacity of the Rio Grande below Elephant Butte Dam. The reduction of channel capacity reduces the ability of meeting downstream flow requirements. Deposition also creates a backwater area that impacts the operation of Elephant Butte Dam. Because of the importance of releasing and maintaining the flow downstream to Caballo Reservoir, an analysis of potential solutions to reduce the amount of sediment introduced to the Rio Grande from Mescal Arroyo or increase the sediment transport capacity of the Rio Grande in the vicinity of the arroyo needs to be pursued. Before potential solutions can be decided on it is important to have an understanding of the physical processes at work in the system and how they influence those problems. This geomorphic review presents an analysis of historic channel morphology of the Rio Grande at the confluence with Mescal Arroyo, and a rainfall runoff model to assess the morphological changes occurring in Mescal Arroyo and the effects of storms on the arroyo.

HISTORIC CHANNEL AND FLOODPLAIN ANALYSIS

Rio Grande Channel: The occurrence of high sediment runoff and deposition into the Rio Grande is not solely due to anthropogenic changes, this problem has existed prior to any man-made changes to the river channel. In the 1935 and 1957 aerial photographs shown in Figure 2, sediment deposition is evident at the arroyo's confluence with the river. The 1935 aerial photo was taken before the state road NM 51 was built on the north side of the river, in the photo the red arrow point toward an alluvial fan that has been created by flows from Mescal Arroyo. The blue arrow illustrates the response of the Rio Grande to the sediment influx, with the main channel shifting north. Because the channel is able to shift its location; as shown in the 1935 photo, the additional sediment from the arroyo doesn't impact water flow through the reach. In the 1957 photo, the road embankment and channelization constricted the river to the point where it could no longer alter its course in response to the sediment input from the arroyo. The red arrow on the 1957 aerial shows an alluvial fan that has constricted the channel further.

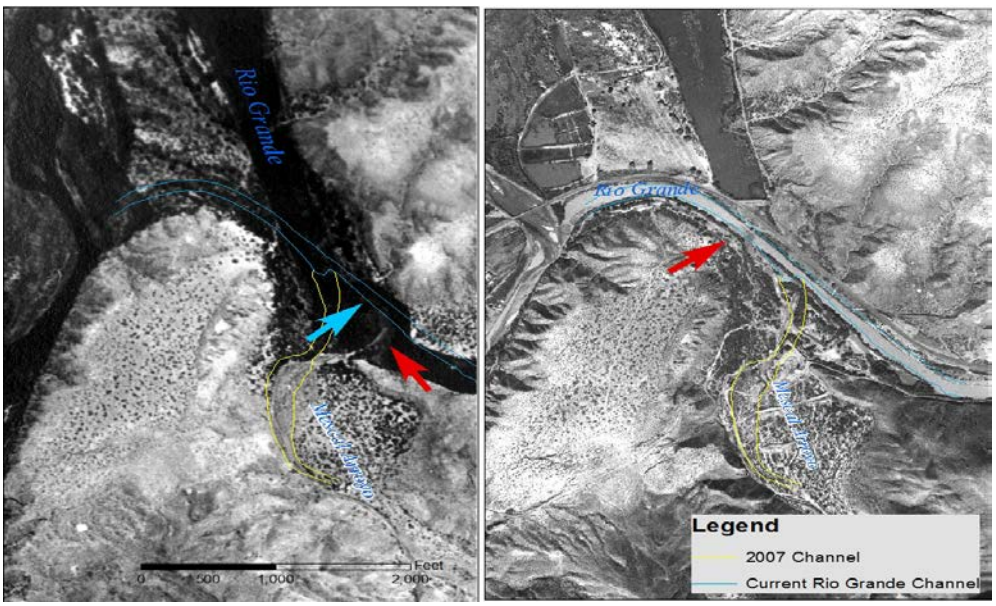

Figure 2 Left aerial photo 1935 and Right aerial photo 1957, blue line illustrates the river channel as of 2012 and yellow line illustrates the 2007 arroyo channel.

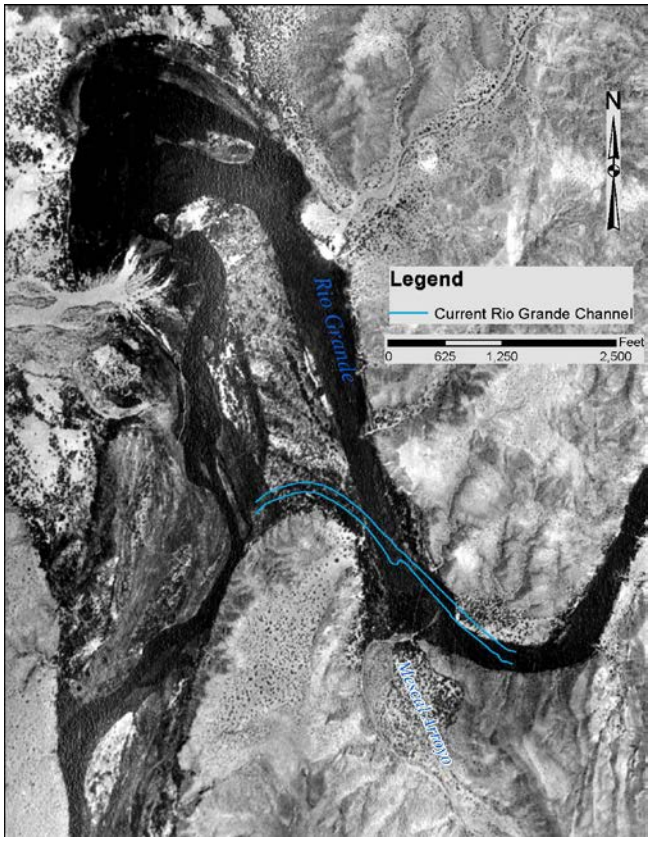

Figure 3 Channel morphology of the Rio Grande prior to anthropomorphic effects.

The Rio Grande was channelized to the location seen in the aerial photograph sometime between 1935 and 1956. Prior to channelization the Rio Grande was constrained by geologic formations to the sinuous planform seen in the 1935 aerial photography (Figure 3). The Rio Grande channel length; illustrated by the blue line in Figure 3 and measured from River Mile 25.2 to River Mile 24.5, was decreased from 8,700 feet in 1935 to 4,100 feet in 1956 through this reach. The active channel was also narrowed in width from an average of 169 feet in 1935 to an average of 98 feet in 1956. The river channel in 1935 also had a floodplain width of 402 feet, which is nonexistent in the 1956 channel. Channel length and widths were estimated using the georectified aerial photography from the corresponding years. The channelization resulted in an increase in the channel's slope by a factor of 1.9. A 1985 channel rehabilitation project was designed to meet the 5,000 cfs channel capacity requirement. The river channel was dredged and drop structures were installed downstream of Mescal Arroyo. (Drew Baird, pers. Comm.).

Post-channelization aerial photos from 1957 illustrate the sensitivity of the channel to the sediment input from Mescal Arroyo due to the loss of floodplain and channel areas for deposition; the red arrow seen on Figure 2 shows an alluvial fan created by the arroyo. Prior to channelization, the river had enough freedom to widen and shift in response to flow and sediment regimes. Both channelization and narrowing efforts led the channel to be more sensitive to sediment input from the arroyo by reducing the width of the river channel. The reduced channel width and the bank protection on the opposite bank has created a situation where the water from the arroyo is deflected and slowed by the highway embankment. The deflection of the western bankline and the river backwater effects on the sediment laden arroyo flow allows for the larger sediment to deposit creating an alluvial fan at the confluence of the river and arroyo. The highway embankment also prevents the river from shifting its course to the west to adjust to additional sediment. Any sediment introduced to the main channel needs to be mobilized by the flows of the Rio Grande, rather than the Rio Grande altering its course in response to the additional sediment.

Figure 4 Left photo taken 7/10/08 and right photo taken 9/10/08

The photos in Figure 4 were taken during one of the rainfall runoff events in the 2008 monsoon season. The line of bubbles; as shown by the red arrows, at the edge of the Rio Grande seen in the leftmost figure delineates the leading edge of the developing fan. The rightmost photo was taken at the same location on 9/10/08 after the monsoon season. Resulting alluvial fan

development has progressed further into the channel where it has constricted the mainstem Rio Grande flow, raising the water surface elevation and creating a backwater condition upstream.

Mescal Arroyo: Anthropomorphic changes at the lower portion of Mescal Arroyo to its confluence with the Rio Grande have altered the way runoff flows move through the arroyo affecting sediment deposition patterns at the confluence. Sometime between 1935 and 1957, the lower portion of Mescal Arroyo was channelized by sediment control embankments on both sides. Prior to the installation of these embankments, storm runoff flows flowed in more of the dendritic pattern exhibited by alluvial fans. These small migrating channels transport runoff water across the alluvial fan. The embankments were likely installed to reduce flow across the alluvial fan to protect the arroyo road crossing. As a result of channelization and flow regulation on the Rio Grande, the alluvial fan of the arroyo extended north (Figure 2) creating a larger alluvial area increasing the arroyo channel length and decreasing the arroyo slope; measured from the 2012 arroyo road crossing location to the river channel, the length of the arroyo increased from 542 ft in 1935 to 1626 ft in 1957. Some of that decrease in slope and increase in arroyo channel length can be attributed to the different location of the Rio Grande channel and the location of the confluence. From 1957 to 2012, the lower arroyo channel was shortened from the 1626 ft to 1199 ft in 2012, due to the relocation of the arroyo's confluence. The current spoil area west of the arroyo mouth existed as a vegetated bar prior to 1956. Currently, the arroyo is constricted near the upper end of the spoil location where rip-rap was installed in 2001 and has mostly been washed away by arroyo flows (Brent Tanzy, Pers. Comm.). Two Wolman pebble counts were performed across the channel in two locations, one cross section further into the arroyo and the second close to the spoil area. The D_{50} for the upstream location was in the range of 6mm or fine gravel and for the downstream location the D_{50} was in the range of 10mm or fine gravel. The coarser downstream size distribution is likely due to the location of the thalweg of the arroyo. At the upper cross section, the active channel was wider and less confined than the downstream cross section. The lower cross section is located below the road crossing and had a more defined active channel consisting of finer material. At the lower cross section there was a bar dominated by coarser sediments likely deposited at higher flows.

Elephant Butte Dam Operations: The operation of the dam and powerplant influences the discharge in the Rio Grande below the dam. Flow releases from the dam are established by the El Paso office in conjunction with the downstream irrigation district's demand (Ben Kalminson, pers. Comm.). Because dam releases are demand driven, there are times where there are no flow releases at all, at these times there is minimal seepage flows in the Rio Grande at the confluence with Mescal Arroyo.

Precipitation/Evaporation: Daily rainfall data from a National Climatic Data Center gauge in Truth or Consequences (35 year record) shows a mean annual rainfall amount of 9.43 inches. Most of the rainfall each year tends to come in the late summer months as short duration but high intensity monsoon storms. Figure 7 consists of average monthly rainfall data for the 35 years of record at the T or C gage and illustrates the meteorology of the monsoon storms. Plotted against the average monthly releases from Elephant Butte, the supply and demand dynamic can be seen. Demand for releases is reduced during monsoon season.

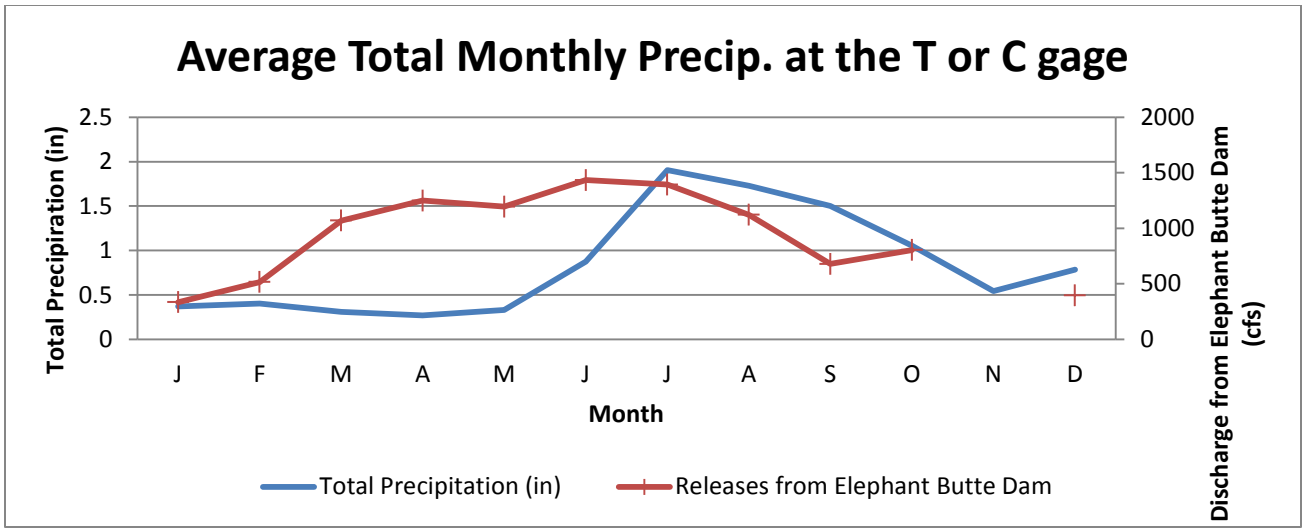

Figure 5 Average Total Monthly Precipitation for all years of record at the NCDC Truth or Consequences gauge compared to average monthly releases from Elephant Butte Dam.

HYDROLOGIC MODEL DEVELOPMENT

Data for the model was processed using the Hec-GeoHMS toolset for ArcGIS 9.3. This toolset aids in the development of model parameters by taking advantage of data published in GIS format. The HEC-GeoHMS toolset takes portions of GIS formatted data and creates model parameters from the data. This model used the 2005 New Mexico Geospatial Data Acquisition Coordination Committee (GDACC) 10 meter enhanced DEM to derive; sub-basin delineation, slopes within the sub-basin, basin centroid, flow path lengths, and channel slopes, for use in modeling the topography of the basin. Once the physical data has been processed through Hec-GeoHMS, the information can be exported to Hec-HMS where additional input values are chosen to describe and make assumptions about the basin model. The additional input values included in the model included soil data, geologic data, estimated evaporation rates and rainfall gage data for Mescal Arroyo. These include the type of basin and meteorologic model, and any specific precipitation gage data that may be available.

HYDROLOGIC MODELING RESULTS

The Mescal Arroyo Hec-HMS model was run for each of the six storm event models representing the different ARIs. Each of the resulting synthetic hydrographs seen in Figure 10 shows a sharp rise in runoff early in the simulation due to the nature of the NOAA precipitation estimates. The attenuation time and peak discharge from the simulations vary as a function of the data used and assumptions made in putting the model together.

Assumptions include:

- The DEM accurately represents the actual ground surface.
- The actual vegetation condition closely matches the assumptions made for the model.
- The precipitation estimates are accurate for the watershed.
- Runoff modeling accurately represents actual runoff in the watershed.

- The precipitation rate closely follows the rainfall curve used in the model.
- Precipitation is distributed equally across the entire watershed.
- Estimated evaporation loss rates are accurate for the watershed.

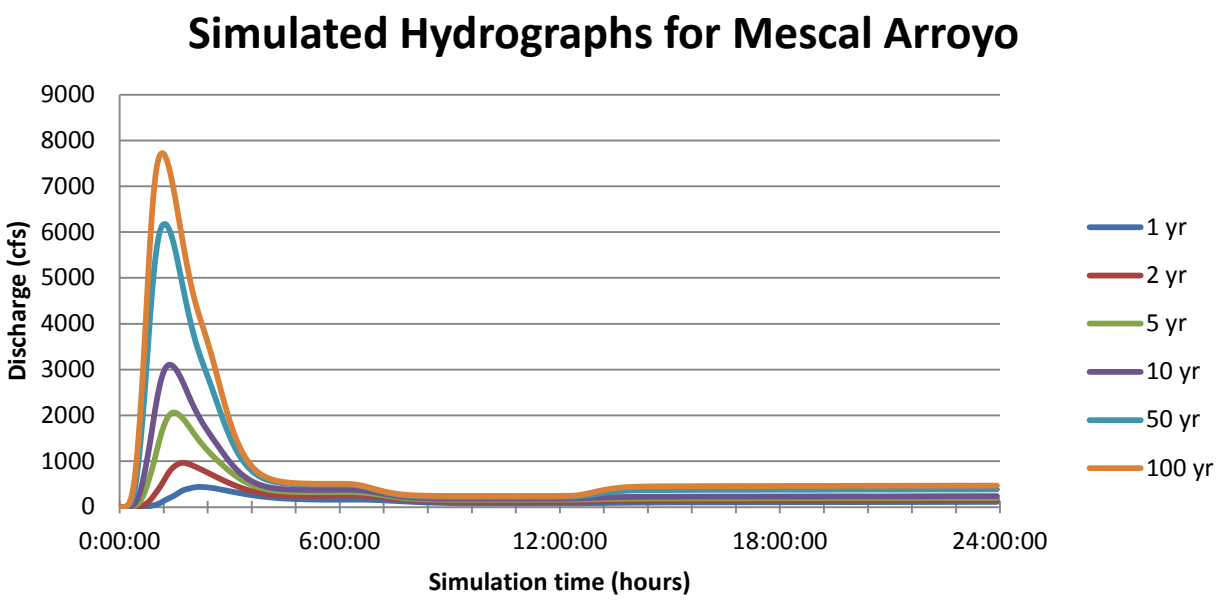

Figure 6 Simulated hydrograph results from the HEC-HMS model

Table 1 Estimated peak discharge and total event runoff for 24 hr return interval storm events.

Return Interval	Estimated Peak Discharge (cfs)	Estimated Event Runoff (ac-ft)
1 yr	450	263
2 yr	975	423
5 yr	2000	657
10 yr	3100	863
50 yr	6100	1458
100 yr	7700	1775

Model results presented in Figure 10 and Table 3, illustrate the high runoff potential in the Mescal Arroyo watershed. The high runoff and the soil types in the watershed have the potential to produce large amounts of sediment runoff. Table 4 provides visual quantity estimates and precipitation data showing the high sediment transport potential of the arroyo.

Table 2 Comparison of sediment removed from the mouth of the arroyo, rainfall through the monsoon season and yearly rainfall data from the Truth or Consequences gage over the yearly period

Estimated Sediment volume removed from Mescal Arroyo and Precipitation data from the T or C gage			
Year	Quantity Removed (cubic yards)	Total Precip for July through September	Total Yearly Precip
2001-2002	3500	3.65	5.48
2002-2003	2200	2.6	5.08
2003-2004	1000	2.85	5.38
2004-2005	5000	5.56	11.19
2005-2006	5000	0.53	3.81
2006-2007	15460	3.56	13.05
2007-2008	1200	3.98	5.42
2008-2009	8400	10.8	11.97
2009-2010	3000	5.44	9.86
2010-2011	3472	8.32	12.36

Table 4 lists an estimate of material removed at the confluence of the arroyo and the mainstem of the Rio Grande by the crew at Elephant Butte compared to the monsoon season precipitation and the total yearly precipitation for that year. Generally, the years with higher precipitation are also years with more sediment removed from the confluence. Aside from water years 2005 and 2006 where the majority of the precipitation occurred in the months January and February for 2005 and in October for 2006, most of the rainfall comes during monsoon season. These two outliers illustrate how variable weather in the arid southwest is. For the Mescal Arroyo model, the precipitation is distributed equally over the entire watershed, this assumption differs from storms in the real world that may be localized and only cover portions of the watershed. This may be one of the sources of poor correlation between yearly rainfall and sediment removed, since a storm of a certain magnitude focused higher in the watershed may yield less channel flow than a storm of the same magnitude closer to the confluence of the arroyo and river.

A PSIAC (Pacific Southwest Inter-Agency Committee) Sediment Yield calculation was performed to gain an idea of the amount of sediment that the arroyo is able to produce. The PSIAC method estimates yearly sediment discharge using a system to rate the arroyo conditions based on a number of parameters including; surface geology, soils, runoff, and land management types. For Mescal Arroyo, there were 9 ratings broken down by soil units. The calculations yielded an estimate of 3.4 ac-ft per square mile per year. Table 5 lists the PSIAC estimate of sediment volume produced by the corresponding geologic soil formation group.

Table 3 Estimates of sediment volume transported through Mescal Arroyo using the PSIAC method.

PSIAC Sediment Yield Estimates			
Unit number	Geomorphic association	Estimated sediment yield (yd^3/ sq-mi/yr)	Estmated sediment yield (AF/sq-mi/yr)
4	Akela	322.67	0.2
21	Bluepoint	387.20	0.24
28	Courthouse rock outcrop	968.00	0.60
30	Delnorte-Cave-Tencee complex	290.40	0.18
34	Albutte- Courthouse complex	806.67	0.50
37	Glendale-Gila complex	403.33	0.25
52	Lozier rock outcrop	371.07	0.23
64	Nickel-Tencee-Delnorte complex	451.73	0.28
71	Courthouse rock outcrop	1484.26	0.92
	Total estimated sediment yield	5485.32	3.4

CONCLUSIONS AND RECOMMENDATIONS

A historic geomorphic assessment of Mescal Arroyo and its confluence with the Rio Grande was done to provide information regarding its condition and history, as well as to illustrate the link between high-intensity rainfall events and the potential for sediment transport through the watershed. At times the arroyo sediment deposition tends to block or partially block flow in the mainstem Rio Grande, disrupting the continuity of flow downstream to Caballo Reservoir. The mainstem Rio Grande channel has been modified for flood control to effectively pass 5,000 cfs and also to meet delivery requirements downstream. Channel location has also been modified for the same reasons plus modification from road and embankment establishment. In addition, dam operations control the Rio Grande releases below Elephant Butte primarily for power and irrigation demand. The combination of these factors creates a situation where the Rio Grande is unable to adjust laterally to sediment input, nor is it able to mobilize most of the sediment deposits at the arroyo outfall with current flow releases.

This geomorphic review presents an analysis of historic channel morphology of the Rio Grande at the confluence with Mescal Arroyo, and a rainfall runoff model to assess the morphological changes occurring in Mescal Arroyo and the effects of storms on the arroyo. The results of the hydrologic analysis and the geomorphic assessment show:

- The alignment of the Rio Grande channel has been channelized to its current location, where it has been narrowed, channel length shortened and excavated to pass the required 5000 cfs. The channel is also restricted from meandering to adjust to sediment inputs.
- Flow regulation due to the dam has disrupted the natural flow regime of the Rio Grande.
- Anthropogenic modifications in the mouth of Mescal Arroyo have channelized the flow into a single channel coming out of the arroyo. The area chosen to spoil material excavated from the Rio Grande channel has further channelized and shortened the arroyo channel.

- The geology of the arroyo consists primarily of sedimentary formations, and geologic processes have left steep slopes within the watershed.
- Soils in the watershed are generally well drained and shallow, with a mostly impermeable substrate. Which have a high runoff potential.
- Monsoon storm meteorology dominates the yearly rainfall amounts in the arroyo. Monsoon storms drop large amounts of rainfall in a short period of time.
- The region is an arid region so vegetation consists of hardy drought tolerant plants.
- A rainfall runoff model was developed for the watershed using existing data for inputs. The results of the model provide an idea of the discharges that are possible from the watershed.
- PSIAC calculations were made to estimate the amount of sediment runoff that can be produced by the arroyo. Estimated total sediment yield is 74 ac-ft of sediment per year over the entire 14,000 acres of Mescal Arroyo.

Addressing the sediment transport problems associated with the arroyo and its confluence will be a continual maintenance concern. Because there are a number of land owners within the area of the arroyo any solution that requires work to be completed in the arroyo will have to consider land ownership issues. The arroyo is an extremely dynamic system any possible solution will have to be designed so that it can withstand the variable flows as well as minimize maintenance. Alternatives should be defined to be designed to withstand the 10 yr flow or about 3000 cfs. Finally, the design alternatives should have no impact on the delivery of water from Elephant Butte downstream. The following is a list of possible solutions to pursue related to sediment management of the arroyo:

- Alteration of dam operations – Operations of the dam could be altered to increase the amount of water in the Rio Grande below Elephant Butte Dam. The idea behind this is that increasing the water flow in the river in response to a rainfall event would be enough to keep the additional sediment mobile, helping to transport excess sediment downstream. This would require rapid response to rainfall events.
- Installation of sediment control structures in lower portion of Mescal Arroyo– Sediment control structures would decrease the amount of sediment introduced to the river. These structures would have to be robust enough that they can withstand the large variations in flow and would require periodic sediment removal. Control structures could include Gabion Baskets, Check Structures and grade control structures. It is important to note that any work in the arroyo is outside of Reclamation's authority under the Middle Rio Grande Project.
- Provide stable transition channel with continued need to remove sediment at confluence – Realignment of the arroyo channel would change the confluence of the arroyo and river to reduce the angle at which the arroyo meets the river. This concept assumes the reduced angle, the additional sediment would most likely be deposited in a location that wouldn't constrain the river channel as much. In addition to the new deposition location, the water velocities at the confluence should be high enough to keep the sediment mobile. Any structures associated with this would have to be robust and periodic removal of deposited sediment would be performed.

REFERENCES

Beven, Keith J., 2001 Rainfall-runoff Modeling: The Primer, New York NY: John Wiley & Sons, Inc,

Bonnin, Geoffrey M., Martin, Deborah, Lin, Bingzhang, Parzybok, Tye, Yekta, Michael, and Riley, David, 2006, Precipitation-Frequency Atlas of the United States: Volume 1 Version 4.0: Semiarid Southwest (Arizona, Southeast California, Nevada, New Mexico, Utah) , Silver Spring MA: US Department of Commerce.

Green, Gregory N. and Jones, Glen E.1997 The Digital Geologic Map of New Mexico in ARC/INFO Format, Open-File Report OF-97-52, http://greenwood.cr.usgs.gov/openf-file-reports/ofr-97-0052/1:500,000

Hornberger, George M, Raffensperger, Jeffrey P., Wiberg, Patricia L., and Eshleman, Keith N., 1998, Elements of Physical Hydrology, Baltimore MA: The Johns Hopkins University Press,

Institute for Transportation, 2009 Iowa Stormwater Management Manual, Iowa State University Institute for Transportation 2C-10

Lacy, Stephen, Geology and Pacific Southwest Inter-Agency Committee (PSIAC) Sediment Yield Evaluation for Mescal Canyon, Sierra County, New Mexico, NRCS Report 22 pgs.

_____ 1986, Urban Hydrology for Small Watersheds: Natural Resources Conservation Service Technical Release 55

United States Department of Agriculture Natural Resources Conservation Service 2011 Custom Soil Resource Report for Sierra County Area, New Mexico, NRCS Report http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm