Española Valley, Rio Grande and Tributaries, New Mexico

General Investigation Report - Draft Appendix A

Hydrology and Hydraulics

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On the cover (Photo Credit: Austin Kuhlman*)*

EXECUTIVE SUMMARY

The Española Valley General Investigation quantifies the residual flood risk from previous channelization and flood risk management projects, examines whether there is a Federal interest in further flood risk management in the Española Valley, identifies ways to remediate the worst of the channel instabilities still in the system, and examines opportunities to mitigate the senescence loss of the bosque riparian forests. The hydrologic and hydraulic analyses conducted for the Española Valley General Investigation study are described in this appendix.

1. Study Information

   The U.S. Geologic Survey (USGS) installed river gages along the Rio Grande at Embudo in 1889 and down river at Otowi Bridge in 1895. The first gage for the Rio Chamita was installed in 1912. Other gages the basin have been installed for a variety of reasons, including gages upriver and downriver of the three reservoirs on the Rio Chama.

   Both the U.S. Army Corps of Engineers (USACE) and the U.S. Bureau of Reclamation (USBR) have a long history of dam construction and river engineering for the Rio Grande basin. Much of this engineering was possible because of the long history of river gage measurements. The USBR has maintenance responsibilities for the Rio Grande. Consequently, after the Rio Grande was channelized in the 1950s and 1960s, the Bureau established range lines along the river, which have been routinely surveyed to monitor for any major channel instabilities.

   Following the construction of Abiquiu Dam, USACE became concerned with the stability of the Rio Chama. In response to changes in the Rio Chama channel following dam closure, a Reconnaissance Study was commissioned to evaluate the changes (U.S. Army Corps of Engineers, 1996b). This study used a series of color orthophotos and the 1973 stereoscopic topography data to determine whether the channel had come to a relatively stable condition after dam construction or whether deterioration was inevitable that would require remediation. The conclusions of this study included a determination that the channel had reached a stable condition with only minor changes in dam release rates necessary to prevent significant channel erosion or residual flooding risks.

   In 2007, color orthophotos and LiDAR topography were obtained for the Española Valley General Investigation. In addition, sediment samples and cross section surveys were also undertaken. This information, along with publically-obtained GIS data and current USGS gage data, was used to generate new hydrologic analyses of the Española Valley, followed by hydraulic analyses of the floodplain. Flood risk maps were generated from this work.

2. Problem

   The watersheds in the Southwest, in general, can be easily destabilized by land use changes and climate change. Concurrent with the arrival of the Railroad in the 1880s, the demand for timber soared, and livestock stocking rates increased dramatically. The deforestation and extensive sheep and cattle overgrazing led to extensive soil erosion with overwhelming release of sediments into the floodplain of the Rio Grande. The steep tributaries in the Española Valley were competent enough to transport these sediments to the valley margins; however once reaching the broad Rio Grande floodplain these sediments dropped out of suspension and splayed in large deposits over the floodplain.

The depositing sediment increased the extents of alluvial fans up these tributary valleys and expanded the alluvial fan toes towards the Rio Grande. Concurrently the depositing sediment filled the Rio Grande channel, causing the river to braid across the floodplain, and retarding drainage from irrigated farm fields. The period from the 1870s to 1940s is also known for the frequent large floods that devastated communities along the Rio Grande and its tributaries. The severity of these floods was acerbated by the loss of conveyance in the Rio Grande channel, constrictions in the Rio Grande floodplain caused by alluvial fan toes, and the lack of competent channels on these tributary alluvial fans.

In the 1940s the US Army Corps of Engineers proposed to build flood control dams that also trapped sediment along the Rio Grande and several tributaries. Many of the tributary alluvial fans were actively channelized with adjacent spoil piles built to function like levees. The drought of the 1950s lent urgency to the effort to straighten the Rio Grande through the Española Valley to reduce flooding, improve drainage and to more efficiently convey water downstream to meet the Rio Grande Compact water deliveries to Texas. In the late 1950s and 1960s, the watersheds partially recovered due to a period with frequent gently rains that promoted vegetation growth across the Southwest. Hill slope soil erosion was dramatically reduced, tributary headcuts slowed and tributary channel banks restabilized. The recently straightened Rio Grande channel with a steeper gradient and reduced sediment load rejuvenated its channel bed erosion. The dredged channel bottom however lacked any natural stabilizing bed features. Consequently the sand fraction of the bed mobilized and winnowed out until the cobble fraction armored the channel bed and the mobile gravel fraction sorted into new riffle bedforms. Because of the lost of so much alluvial sediments, the bottom of the Rio Grande channel bed dropped in elevation. The increased height differential of the floodplain meant that the Rio Grande had become significantly incised in the Española Valley.

This channel incision had the negative effect of lowering of the groundwater table, which adversely affected the bosque riparian forests and adjacent agriculture. This incision also led to problems getting water into diversion canals and caused destabilization of channel banks. The destabilized channel banks were addressed by installing Kelner jetty jacks and cabled tree boles. This incision increased channel conveyance such that flood risks declined. However the residual flood risk associated with this channel incision was not examined in detail until this General Investigation study.

3. Plans Considered

The preliminary mapping of the flood risks in the lower Española Valley for the Rio Grande and five tributaries has been completed. This mapping is available for the affected communities for use in their community planning efforts. This mapping was also used to screen flood risk measures, channel stability measures, and ecosystem restoration measures.

4. Tentatively Selected Plan

Flood risk management measures were screened but none were retained in the tentatively selected plan (TSP). The details of this screening are contained in Appendices B and I.

Ecosystem restoration measures were screened and were retained in the recommended plan. Terrace lowering along channels and construction of high flow channels are proposed along the lower Rio Chama, and the middle and upper reaches of the Rio Grande in the study area which will have a direct impact on channel stability.

The grade restoration facilities (GRFs) measure was screened and retained. GRFs are recommended on the Rio Grande just below and just above its confluence with the Rio Chama; and also on the Rio Chama at a midpoint between the confluence with the Rio Grande and the Salazar Diversion.

5. Project Impacts

Should the TSP go forward, detailed site surveys, additional sediment sampling of the affected channels and soil borings where large structures are proposed will need to be undertaken. Such efforts will significantly improve the density and accuracy of cross sections in the associated hydraulic models. The with- or without-project hydraulic analyses will be significantly improved.

Currently under USACE guidance (ECB 2014-10), a qualitative assessment of climate change impacts is required for non-coastal projects (U.S. Army Corps of Engineers, 2014b). However this guidance includes a warning that quantitative analysis will be required in the future for proposed projects when the quantitative analysis methods are developed and approved. Currently qualitative analysis has been completed for the Cochiti Dam and Reservoir (U.S. Bureau of Reclamation, 2013; U.S. Army Corps of Engineers, 2012a). See Appendix G for project specific information on past and potential further climate change impacts.

The two proposed GRFs for ecosystem restoration measures are both primarily intended to improve the ground water hydrology of the bosque and nearby wetlands. In addition to groundwater improvements, both the terrace lowering and high flow channel measures will have small individual improvement to the stability of the adjacent channel and probably a significant cumulative improvement at the reach scale. These two ecosystem restoration measures will also have a small benefit for reducing local flood risks, primarily for the more frequently occurring events.

The proposed GRFs are intended to have individual and a cumulative positive impact on the stability of the Rio Grande near the confluence with the Rio Chama. The GRF on the Rio Chama is solely provided for the diversion of water for ecosystem restoration. The unfortunate consequence of GRFs is that they do act like the run-of-the-river diversion dams that are common in the Española Valley. Normally dams that do not have flood retention pools cause rises in flood stages. To prevent the GRFs from causing significant increases in residual flood risks, a feature similar to the terrace lowering measure will be built with each GRF. In addition, a terrace lowering measure may be built in between GRFs. Any remaining residual flood risk is planned to be mitigated with the addition of parallel high flow channels on one or both channel banks. As a final resort, spoil piles that serve no useful function could be removed from the floodplain to increase local conveyance which will also lower flood stages.

A Navigation Report and Navigation Servitude are not required for this project.

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LIST OF ACRONYMS AND DEFINITIONS

Abbreviation	Definition	
1-D	One Dimensional (use to describe modeling software)	
2-D	Two Dimensional (use to describe modeling software)	
ACE	Annual Chance Exceedance (inverse of flow frequency)	
	0.2% ACE	500-year flood flow frequency
	0.5% ACE	200-year flood flow frequency
	1% ACE	100-year flood flow frequency
	2% ACE	50-year flood flow frequency
	5% ACE	20-year flood flow frequency
	10% ACE	10-year flood flow frequency
	20% ACE	5-year flood flow frequency
	50% ACE	2-year flood flow frequency
AGFD	Arroyo Guachupangue Flood Depth	
ArcGIS	Arc Geographic Information System (ESRI software)	
ASCE	American Society of Civil Engineers, Inc.	
BAER	Burned Area Emergency Response	
cfs	Cubic Feet per Second (flow rate of water)	
CPD	Computer Program Document	
DSS	Data Storage System	
ECB	Engineering and Construction Bulletins	
EFM	Environmental Features Modeling	
ER	Engineer Regulations	
ERDC	Engineer Research and Development Center	
ESRI	Environmental Systems Research Institute, Inc.	
FEMA	Federal Emergency Management Agency	
FIRM	Flood Insurance Rate Maps	
FRM	Flood Risk Measures	
ft	Feet	

ft/s	Feet per Second
ft/s/s	Feet per Second per Second
GIS	Geographic Information System
GRF	Grade Restoration Facility
HEC-2	Hydrologic Engineering Center – hydraulic modeling software
HEC-6T	Hydrologic Engineering Center – sediment transport software
HEC-DSSVue	Hydrologic Engineering Center – DSS Visual Utilities
HEC-EFM	Hydrologic Engineering Center – Environmental Feature Model
HEC-GeoEFM	Hydrologic Engineering Center - Geographic Environmental Feature Model
HEC-GeoHMS	Hydrologic Engineering Center - Geographic Hydrologic Modeling System
HEC-GeoRAS	Hydrologic Engineering Center – Geographic River Analysis System
HEC-HMS	Hydrologic Engineering Center – Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center – River Analysis System
HEC-SSP	Hydrologic Engineering Center – Statistical Software Package
h:v	Horizontal to Vertical
LiDAR	Light Detection And Ranging
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
NM	New Mexico
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
pcf	Pounds per Cubic Foot
RCFD	Rio Chama Flood Depth
RGFD	Rio Grande Flood Depth
RPFD	Rio Pojoaque Flood Depth
SCCFD	Santa Clara Creek Flood Depth
SCRFD	Santa Cruz River Flood Depth
SMART	Specific, Measurable, Achievable, Realistic and Time-related (goals)
TSP	Tentatively Selected Plan
UNET	**U**nsteady flow through a full **NET**work of Open Channels software
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey
WSE	Water Surface Elevation
WY	Water Year

REGIONAL TERMS

Term	Definition
Acequia	A community-operated watercourse used in former Spanish colonies in the Americas for irrigation. In the southwestern United States many of these watercourses were hand dug and clay lined by Native Americans prior to Spanish colonization.
Arroyo	A stream channel located in the southwestern United State that has eroded down through its alluvial floodplain leaving a deep incised channel with almost vertical banks.
Bosque	The name for areas of gallery riparian forest found along the floodplains of rivers and streams in the southwestern United States. It derives its name from the Spanish word for woodlands. This gallery riparian forest is normally dominated by Cottonwood trees.
Española Valley	Originally referred to as *La Vega de los Vigiles (Vigile's Meadow)*, it is a valley in northern New Mexico bounded to the west by the Jemez Mountains and to the east by the Sandre de Cristo Mountain range. Near its center are the confluences of the Rio Grande with the Rio Chama and the Santa Cruz River. This valley is confined to the north by the Rio Grande Gorge and to the south by the White Rock Canyon.
Pueblo	As a proper noun, a political subdivision of States (e.g. Pueblo, Colorado) or a sovereign Indian Nation that was originally a Spanish organized Indian Reservation. The Treaty of Guadalupe Hidalgo with Mexico gave these Indian Pueblos status as village centers. Overt time these village center Pueblos have expanded their boundaries considerably. As a common noun, a pueblo can be any village or small settlement in the southwestern United States.
Spoil banks	A term used along the Rio Grande where drainage districts excavate drains near the river and then deliberately place the excavated spoil riverward to form an earthen levee.
Spoil piles	A term used when a river is straightened by mechanical dredging and the removed material is placed to cut off the former river meander, or when the excavated spoil is left in nearby piles that are not continuous, not uniform or otherwise, do not adequately function like earthen levees.

1 - INTRODUCTION

1.1 Española Historical Problems and Solutions

The Rio Grande valley over the 19th and 20th centuries had significant problems in its floodplains. Heavy tributary delivery of sediments overwhelmed the Rio Grande channel, which lead to waterlogged farm fields and floodplain communities. Once or twice a decade, severe flooding occurred, causing extreme damage to agriculture, communities, and infrastructure. Severe flooding occurred as late as 1942.

Initially, New Mexico state and local resources struggled with each flood and attempted to recover their farm communities. The USBR, and later USACE, started building dams for water supply, sediment control, and flood risk reduction. USACE built four large dams upriver of Albuquerque, including one on the Rio Chama that directly mitigated the flooding problems in the Española Valley. Because channel aggradation due to sedimentation was viewed as causing many of the flood risk management, ground saturation, and water supply problems along the Rio Grande, straightening the channel was viewed as the solution: a straighter channel has a higher rate of flow, and therefore is capable of scouring sediment from its bed.

Acequia associations, the Middle Rio Grande Conservancy District, the State of New Mexico, and other organizations also constructed water supply reservoirs, river diversions, irrigation ditches, and drainage ditches. Eventually the Rio Grande and many of its tributaries were straitened with mechanized dredging leaving lines of dredge spoils along their channels. The USACE and USBR straitened the Rio Grande in the 1950s and 1960s. With relatively stable channel alignments, new bridges over these channels were then constructed.

1.2 Consequences of this Historical Recovery Effort

The recovery effort for the Rio Grande valley was occurring at the same time that the climate was moving from one cycling pattern to another. The last large flood in 1942 was followed by a lengthy drought that eventually turned into the worst drought in New Mexico history. This drought ended in the mid1950s and was followed by cooler period with more frequent gentler rains. This atmospheric cooling has been attributed to the World War II industrialization and the post war economic boom pumping particulates into the atmosphere. This led to a reduction of hill slope erosion and sediment delivery into tributaries just as several dams were being built to trap sediments.

With a sudden change in the supply of sediment and the reduction of large storm events to move these sediments, there were changes in tributary channels and the Rio Grande. The channelized, and thus steepened, river beds winnowed of their fines and became incised at lower elevations. This incision causes the channel banks to destabilize due to their height, with the USBR tasked to stabilize them. This incision drained down the water table adversely affecting riparian habitat, which is still a major problem.

The mining of the channel beds, where it occurred, was recognized too late as adverse to the stability of these channels. This caused a series of head cuts to form and then migrate upriver threatening infrastructure. These head cuts also further increased bank heights and further lowered the water table. Headcuts are particularly problematic for acequia associations that rely on small, rock-filled diversion dams. These dams wash out as the channel bottom drops. The diversion dams cannot be replaced in-kind and the diversions were forced to extend upstream. Since 1973, the entrance to the Vigiles Ditch has moved 800 feet upstream utilizing concrete rubble until it has reached into the confluence of the Rio Chama with the Rio Grande as shown in Figure 1.

Figure 1 Damaged concrete rubble water diversion below the confluence of the Rio Chama and Rio Grande (Source: Alan Schlindwein).

The river channelization, excavation of drainage ditches, and the construction of diversion canals resulted in alluvial spoil being wasted into heterogeneous spoil piles that lack stability and continuity. These spoil piles cut off the floodplains from their river channels, created isolated wetlands in old channel scrolls, and led to an incorrect cultural impression that they provided secure and safe flood protection.

1.3 Current 21st Century Problems

Some of the potential problems currently facing the sponsors, which are being considered in this study, include:

1) Lack of appreciation of the risks of river and tributary flooding from historical and current weather patterns:
   a) The spoil piles in their current locations are aggravating infrequent flooding more often than preventing it.
   b) Channels downstream of dams have reduced in size, increasing residual flood risks.
   c) Several western tributaries to the Rio Chama and Rio Grande are currently producing higher than normal sediment loads due to forest fires, but this will only temporarily halt or reverse channel degradation in some reaches while these burned areas reforest.
2) Incision and head cutting, along with bank erosion threatening:
   a) Infrastructure: bridges, diversion dams, the existing grade control structure, acequias.
   b) Culture: Tribal resources, and archaeological and historic sites
   c) Communities: residential, agricultural and commercial development.
   d) Riparian: bosque, wetlands, and channel fringes.
3) Lack of understanding of the consequences of potential future climate change and severe fires on:
   a) Hydrology of the basin.
   b) Geomorphology of the channels, alluvial fans, deltas and floodplain.
   c) Watershed forestry, rangeland, agriculture and riparian bosque.

1.4 H&H Study Goals

The goals of these hydrologic and hydraulic analyses in this appendix are to:

- Quantify and map flood risk.
- Eliminate potential head cut migration towards infrastructure and riparian habitat.
- Mitigate for the adverse effects of channel incision on habitat and infrastructure.

This Appendix begins by describing existing hydrologic and hydraulic conditions analyses, including floodplain mapping. Next, future changes in hydrology and hydraulics without the implementation of USACE's tentatively selected plan (TSP) are projected. Finally, the hydraulic design of the TSP is developed and this plan's potential consequences on hydrology and hydraulics are analyzed. Because this project is occurring in an alluvial valley, sections on geomorphology and sediment transport are included such that existing condition observations and future predictions can be made. The results of these analyses are a critical first step for the further engineering analysis of the proposed project by other disciplines and the generation of the plan's economic benefits. The study area for the Española Valley is shown on Figure 2.

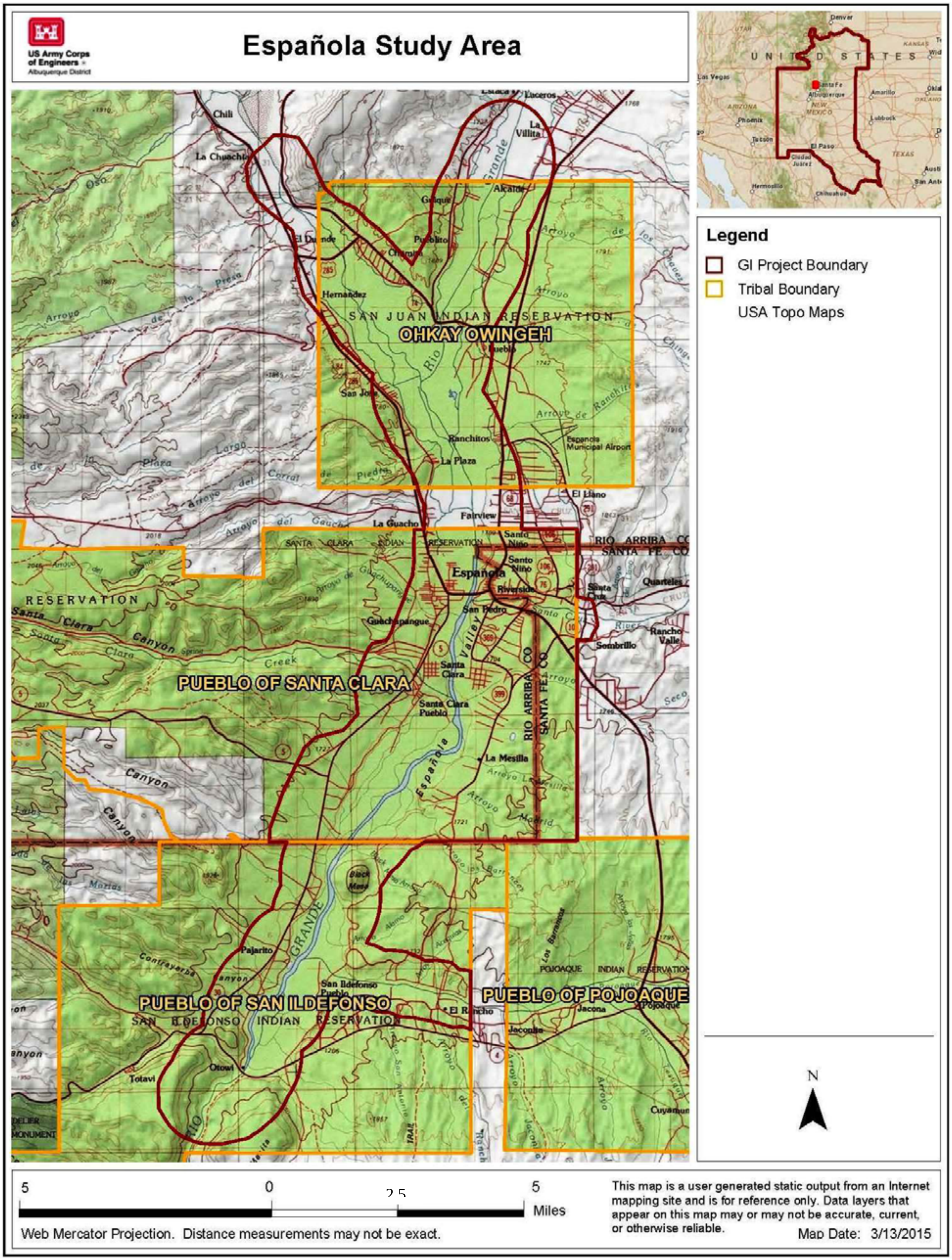

Figure 2 Vicinity and study area.

2 - EXISTING CONDITION HYDROLOGY

The purpose of this assessment is to determine the existing peak flood flows for the following eight events on the Rio Grande, Rio Chama, and four Rio Grande tributaries in the Española Valley: 50%, 20%, 10%, 4%, 2%, 1%, 0.5% and 0.2% Annual Chance Exceedance (ACE)[1] floods (U.S. Army Corps of Engineers, 2015). The detailed hydrologic assessment is located in Attachment 1. Flows on the Rio Grande and the Rio Chama were estimated based on assessing measured peak flow data at three long-term gages. Peak flows on the four tributaries, Arroyo Guachupangue, Santa Cruz River, Santa Clara Creek, and Rio Pojoaque, were estimated by creating watershed hydrologic computer models.

An additional assessment of the Rio Grande, Rio Chama and Santa Cruz River is to determine the existing flows associated with the natural germination and survival of willow and cottonwood species. These flows are used to screen potential ecosystem restoration locations.

2.1 Rio Grande and Rio Chama Flow Frequency Hydrology

Three long-term gages (Figure 3) are located on the Rio Grande and the Rio Chama in the Española Valley: Rio Grande near Embudo, NM #08279500 (peaks recorded 1889-present), Rio Grande at Otowi Bridge, NM #08313000 (peaks recorded 1895-present) and the Rio Chama near Chamita, NM #0829000 (peaks recorded 1915-present). A review of these gage data found that many of the annual peak flood events were combination events, in which high snowmelt runoff was augmented by local spring rain storms. However each gage had a different peak flow character for their top ten floods. On the Rio Grande at Embudo, snowmelt runoff dominated the record and only one of the top ten events occurred as a rain-only event. Normally snowmelt events are generated by very large portion of the watershed having deep snowpacks, resulting in a relatively long flood event. Rain-only events normally involve a very intense rain event over a much smaller portion of the contributing watershed, resulting in relatively short (sometimes flash) flood events.

[1] The annual chance exceedence (ACE) values of 50%, 20%, 10%, 4%, 2%, 1%, 0.5% and 0.2% refer to the probability of a particular flow event being exceeded in any single year. Therefore, the previous nomenclature of the "100-year flood" is properly defined as a flood flow having a 1 percent chance of being exceeded in any one year (or 1% ACE). See page x for a complete table of comparisons.

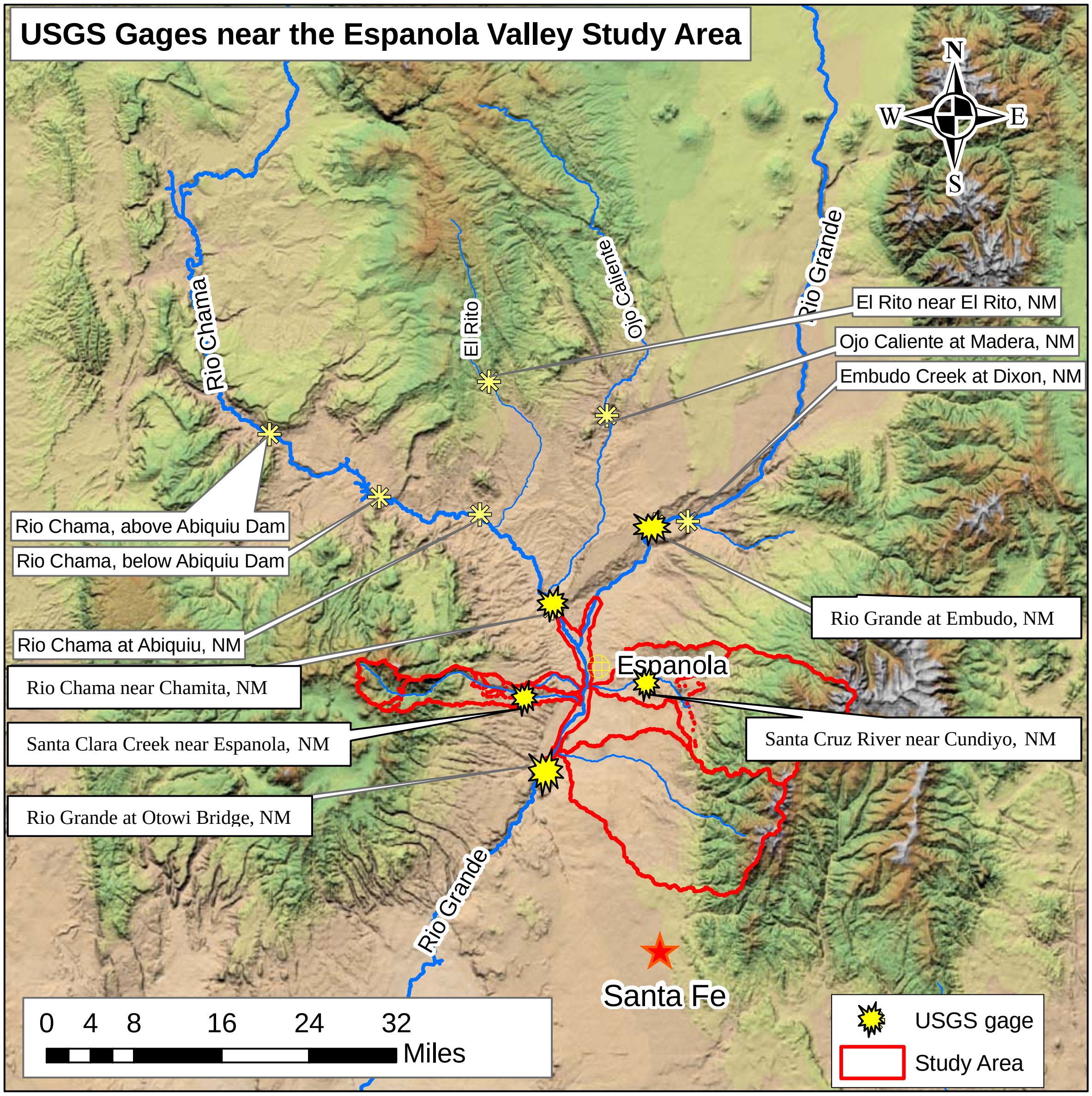

Figure 3 Map of long-term USGS gage locations in relationship to the study area, and to the Rio Grande and Rio Chama.

The Rio Chama has a much smaller watershed than the Rio Grande above Embudo, consequently because of its small watershed area; it can be dominated by rain-only events more often. The Rio Chama gage record showed only one of the top ten events as exclusively a snowmelt runoff event. The gage record for the Rio Grande at Otowi Bridge gage, located downstream from the Rio Chama confluence, showed an almost equal distribution of snowmelt, rain-only, and combination events. The increased importance of the combination events comes from coincidental floods on the Rio Chama and the Rio Grande above Embudo, but also on the contributions of the Rio Grande watershed between the Embudo and Otowi Bridge gages. This lower watershed is dominated by high mountains and steep piedmonts. A large rain event on a snowpack would produce a very short flash flood on these narrow tributaries that would quickly confluence with and be attenuated by the broad Rio Grande floodplain. This attenuation is reflected in Table 1 where the Rio Grande at Otowi Bridge has a 0.2% ACE event of 33,200 cfs; whereas in Table 2, the Rio Pojoaque has a 0.2% ACE event of 37,800 cfs. Consequently a long duration snowmelt-only flood passing the Embudo gage will frequently coincide with downriver tributary rain driven flood events.

Since 1911, a series of dams and reservoirs have been constructed on the Rio Grande and its tributaries upstream from the study area. On the Rio Chama, the most recent and largest structure, Abiquiu Dam, was authorized for flood risk management and began operations in 1963. As a consequence, the gage record for the Rio Chama near Chamita, NM, was truncated at 1963 for this study, and only post-1963 data were used to assess flow frequencies (Table 1). Therefore the flow frequencies for the Rio Chama are completely independent of the Rio Grande. On the Rio Grande above Embudo, although some small dams and reservoirs were emplaced in the headwaters, the structures do not have a significant influence on the flow frequencies. Therefore the flow frequencies for the Rio Grande above the confluence with the Rio Chama are based on the Rio Grande at Embudo gage and are completely independent of the Rio Chama (Table 1).

The USGS gage for the Rio Grande at Otowi Bridge has a very long flow record in the Española Valley. A significant number of large annual peak flows occurred before the closure of the Abiquiu Dam, such that a post-1963 assessment of flow frequencies would not adequately represent the risks of infrequent events. Many of these annual peak flows were minimally affected by flows from the watershed above the Abiquiu Dam. While including pre-1963 gage data will skew the flow frequency analysis slightly between the two rivers, the additional number of years will reduce the error bands for the overall range of flow frequencies for the Rio Grande. The long gage record for the Rio Grande at Otowi Bridge was used to assess flow frequency below the confluence with the Rio Chama (Table 1).

Table 1 Annual chance exceedence events for the Rio Chama and the Rio Grande.

Median ACE results in cubic feet per second (cfs) for gage data on the Rio Chama and Rio Grande. Results computed for the Rio Chama near Chamita, NM, gage regulates the time period of 1964 – 2006, while the results for both gages on the Rio Grande utilized all available gage data.

ACE	50%	20%	10%	4%	2%	1%	0.5%	0.2%
Rio Chama near Chamita, NM	3,025	4,300	5,300	6,400	8,000	9,400	10,900	13,300
Rio Grande at Embudo, NM	4,000	7,300	9,700	12,100	15,400	17,900	20,400	23,700
Rio Grande at Otowi Bridge, NM	7,200	11,600	14,800	17,900	22,100	25,400	28,700	33,200

In addition to the frequency flow assessment, peak hydrographs were routed throughout the Rio Grande and the Rio Chama in support of the floodplain delineation assessment. These routings defined the amount of flood attenuation expected to occur as flows are transported downstream. On the Rio Grande, the snowmelt-dominated peak flows attenuated very little due to the high volume of water being routed; however, on the Rio Chama, the rainfall-dominated peaks attenuated quickly from the USGS gage downstream to the confluence with the Rio Grande. Given that the Abiquiu reservoir was sized to hold twice the PMP, there are insignificant flow contributions from above the dam for all flood events, therefore historic snowmelt events on the upper Rio Chama are no longer relevant for hydrology. Consequently, high flows originating upstream from Española, NM on the Rio Grande are more likely to create flood flows than flows originating from the heavily regulated Rio Chama watershed.

2.2 Tributaries Flow Frequency Hydrology

Hydrologic models were created for each of the four tributaries using HEC-HMS (U.S. Army Corps of Engineers, 2006a), a USACE software application designed to create flood hydrographs for watersheds based on rainfall frequency-runoff calculations. Except for Arroyo Guachupangue, which is exclusively a low elevation watershed, these tributaries convey waters from high elevations in the mountains down to the Rio Grande floodplain, a relatively low elevation landscape. Although a small snowpack often accumulates in the high elevation areas, the largest flow for each of these tributaries occurs in the summer months as a result of high-intensity rain events.

Comparisons between the four tributaries show that, generally, the largest watershed has the highest flows while the smallest watershed has the smallest flows. Although the Santa Cruz River and the Rio Pojoaque watersheds are similar in size, their peak flow values are significantly different, especially at the lower frequency events modeled (Table 2). This difference is attributed to several flood protection structures within the Santa Cruz River watershed.

Table 2 Peak discharge for annual chance exceedence events for the four tributaries in the study area.

Summary of estimated annual chance exceedence event (cfs) values for the four tributaries in the study area.									
Drainage Area (mi^2)		**50%**	**20%**	**10%**	**4%**	**2%**	**1%**	**0.5%**	**0.2%**
Arroyo Guachupangue	4.9	250	820	1,240	1,830	2,300	2,800	3,300	3,900
Santa Clara Creek	50	200	840	1,580	2,700	3,600	5,200	9,300	15,900
Santa Cruz River	183	550	1,920	3,200	4,800	6,100	8,000	10,500	16,000
Rio Pojoaque	195	250	4,300	8,070	12,500	16,900	22,200	28,200	37,800

2.3 Flood Flow Hydrologic Conclusions

Two distinctive flows are of concern for flooding in the Española Valley:

- Spring floods from snowmelt are high runoff volume, long duration events as shown on hydrographs in Attachment 1 on Figures 41 and 46.
- Flash floods are rapidly transported through the valley in the summer and early fall months. Examples of flash flood hydrographs on tributaries of different watershed areas are shown in Attachment 1 on Figures 13, 19, 25, 29 and 37.

While both spring flows or the rainfall runoff can cause flooding, the highest peak flows on record were caused by local spring rains in combination with high base flows. These high volume flows fill the Rio Grande's floodplain, preventing peak attenuation and posing the greatest threat for flooding.

Summer peak flows on the Rio Grande originate from local tributaries delivering rain-only flows. The larger tributaries are most likely to produce high flows that could cause flooding on the Rio Grande, such as the Rio Pojoaque tributary. Model estimates indicate that peak flows greater than the 1% ACE event from the Rio Pojoaque (Table 2) are similar to or within the confidence intervals of the frequency values determined from the Rio Grande at Otowi Bridge, NM, gage data (Table 1).

Historically, floods from the Rio Chama likely occurred often; however, with the construction of Abiquiu Dam, snowmelt runoff is retained from a large watershed, removing the threat of large peak flows from snowmelt floods and greatly reducing the threat from combination rainfall-snowmelt events on the unregulated watershed. Although relatively high peaks are still possible from rain storms, those flows attenuate quickly below the contributing tributaries on the Rio Chama and then as these flows route downstream on the Rio Grande they attenuate further. This doesn't imply that damaging floods are no longer occurring along the Rio Chama, as evidence by the local flood of September of 2013, just that the frequency of large events has been reduced.

2.4 Environmental Restoration Hydrology

The Ecosystem Functions Model (EFM) is an analysis tool to support the planning, implementation and monitoring of flood damage reduction and environmental restoration measures. It is composed of a computer program, HEC-EFM version 3.0 (U.S. Army Corps of Engineers, 2013b), and an insert toolbar for ArcMap 10.1 (ESRI, 2012) called HEC-GeoEFM version 1.0 (U.S. Army Corps of Engineers, 2013c). The model also relies on HEC-DSSVue 2.0.1 (U.S. Army Corps of Engineers, 2013a) and a plug-in USGS Data Retrieval module version 5.1 to obtain gage data for the initial analysis. Only this initial analysis was performed on this project. The initial hydrological analysis is based on parameters of the target species discussed in Section 2.4.2 HEC-EFM analyzed the gage data to find the critical life-cycle stream flows that can then be used in project planning.

2.4.1 River Gages

Ecosystem restoration measures were proposed along the Rio Grande, Rio Chama and Santa Cruz River. Therefore the USGS stream gages at Chamita, NM; Embudo, NM; Otowi Bridge, NM; and Santa Cruz River near Cundiyo, NM #082910000 were downloaded by DSSVue and turned into DSS files. The DSS file format is a long standing database system for transferring information between HEC computer programs. The entire gage record was downloaded for each USGS gage site. For analysis on the Rio Grande and Rio Chama, the record was segregated into two periods: pre-Abiquiu Dam construction and post-Abiquiu Dam construction. The period of records used in the following analysis was October 1, 1963 to April 6, 2014; with the exception being Cundiyo that was October 1, 1963 to April 14, 2014.

2.4.2 Target Species

The intent of the ecosystem restoration measures is to establish bosque species that will be represented in the model by willow (*Salix exigua*) and cottonwood (*Populus fremontii*). Willow is normally found in wetter locations than cottonwood and both are adapted to colonize disturbed areas. However along many of the rivers in the project, great efforts have been undertaken to stabilize the channel banks and prevent the channels from migrating. Therefore the natural colonization habitat for cottonwood establishment has become quite scarce.

Cottonwood trees start flowering before they leaf-out in the spring. Seed production starts in mid-April and last until July, with the seeds viable for a month. For the EFM, the entire seeding seasons was set to April 15 to July 4 for cottonwoods. The peak seeding seasons was set April 22 to July 7 for cottonwoods. Seedling root growth for cottonwoods is 4 cm/day. In EFM, the rate of stage recession was analyzed at 0.92 feet over 7 days for cottonwoods. Cottonwood seedlings can withstand 45 days of inundation and in EFM the season of this analysis was set for April 15 to October 30. (Hink & Ohmart, 1984; Dellorusso, 2014)

Willow will leaf-out first and then flower. Seed production starts in May and lasts until October. For the EFM, the entire seeding seasons was set to May 1 to October 1 for willows. The peak seeding seasons was set to May 7 to July 15 for willows. Seedling root growth for willows is 2 cm/day. In EFM, the rate of stage recession was analyzed at 0.46 feet over 7 days for willows. Willow seedlings can withstand 60 days of inundation and in EFM the season of this analysis was set for May 15 to October 30. (Hink & Ohmart, 1984; Dellorusso, 2014)

2.4.3 Analysis Method

EFM analyzes the USGS gage data for the associated growing seasons of the target species, for the period of years after the Abiquiu Dam was constructed. This produces stochastic results for flows that have EFM percent exceedance flows of 10%, 25%, 33%, 50% or 77% (U.S. Army Corps of Engineers, 2014a). For this analysis the EFM percent exceedance is not an annual exceedence, but approximates percent exceedance for the growing season of each species.

The flows for the 10% EFM exceedance were approximately equal to the 20% ACE event, while the 50% EFM exceedance flows were approximately equal to the 50% ACE event. Selecting which annual exceedance that will be used for screening sites and in final design was based on field observations, hydrologic characterization of the subject rivers, and the success of previous nearby projects.

Seeding and recruitment success of willows and cottonwoods is tied closely to growing season stream flows when the seeds are released and during growth after germination. Both species will drop a few seeds through the growing season with peak releases in both the spring and fall. Field observations of cottonwood seedlings indicate an approximate every-other year germination success rate. It was assumed that the 33% EFM exceedance would apply to cottonwoods on the Rio Grande. Since willows survive in a wetter hydrological condition, the EFM 50% exceedance was assumed for willows on the Rio Grande (Table 3 and Table 4).

Both the peak seeding season and entire growing season were analyzed and reported below:

Table 3 Embudo gage peak seeding season survival.

Embudo Gage	**Exceedance** (percent)	**Willow** Flow (cfs)	**Cottonwood** Flow (cfs)
Peak Seeding Season Survival	77%	735	871
	50%	2420	2485
	33%	3511	3511
	25%	5188	5188
	10%	7167	7167

Table 4 Otowi Bridge gage peak seeding season survival.

Otowi Bridge Gage	**Exceedance** (percent)	**Willow** Flow (cfs)	**Cottonwood** Flow (cfs)
Peak Seeding Season Survival	77%	1920	1941
	50%	4065	3955
	33%	5890	5890
	25%	7883	7883
	10%	8938	8938

Given that flows on the Rio Chama are heavily regulated by dam regulation with specific water supply releases, a higher exceedance seemed appropriate for screening sites. It was assumed that the 50% EFM exceedance would apply to cottonwoods on the Rio Chama. Since willows survive a wetter hydrological condition, the 77% EFM exceedance was assumed for willows on the Rio Chama (Table 5). Because of the water supply releases, there may be additional restrictions on available flows that will reduce the frequency of successful germination and seedling survival.

Table 5 Chamita gage peak seeding season survival.

Chamita Gage	**Exceedance** (percent)	**Willow** Flow (cfs)	**Cottonwood** Flow (cfs)
Peak Seeding Season Survival	77%	1245	1407
	50%	2005	2250
	33%	2370	2480
	25%	2545	2635
	10%	3178	3178

Since the Santa Cruz River is a smaller, flashy river system, a lower exceedance seemed appropriate for construction purposes. It was assumed that the 25% EFM exceedance would apply to cottonwoods on the Santa Cruz River. Since willows survive in a wetter hydrological condition, the 33% EFM exceedance was assumed for willows on the Santa Cruz River (Table 6).

Table 6 Cundiyo gage peak seeding season survival. Yellow highlights the selected EFM flows.

Cundiyo Gage	**Exceedance**	**Willow**	**Cottonwood**
Peak Seeding Season Survival	(percent)	Flow (cfs)	Flow (cfs)
	77%	60	51
	50%	111	112
	33%	196	192
	25%	248	235
	10%	348	348

Unlike the peak seeding season analysis, the growing season analysis appeared to produce reasonable results at the 33% EFM exceedance level for all species and gage locations (Table 7 through Table 10). This reasonable relationship also translated well into profiles and mapping (see Section 8.2).

Table 7 Embudo gage growing season submergence. Yellow highlights the selected EFM flows.

Embudo Gage	**Exceedance**	**Willow**	**Cottonwood**
Growing Season Submergence.	(percent	Flow (cfs)	Flow (cfs)
	77%	345	432
	50%	782	1050
	33%	1197	1570
	25%	1418	1750
	10%	2211	3002

Table 8 Otowi Bridge gage growing season submergence. Yellow highlights the selected EFM flows.

Otowi Bridge Gage	**Exceedance**	**Willow**	**Cottonwood**
Growing Season Submergence.	(percent	Flow (cfs)	Flow (cfs)
	77%	727	1006
	50%	1120	2035
	33%	2300	3130
	25%	2810	3423
	10%	3875	4424

Table 9 Chamita gage growing season submergence. Yellow highlights the selected EFM flows.

Chamita Gage	**Exceedance**	**Willow**	**Cottonwood**
Growing Season Submergence.	(percent	Flow (cfs)	Flow (cfs)
	77%	156	361
	50%	332	795
	33%	616	1020
	25%	762	1295
	10%	1454	1885

Table 10 Cundiyo gage growing season submergence. Yellow highlights the selected EFM flows.

Cundiyo Gage	Exceedance	Willow	Cottonwood
Growing Season Submergence.	(percent	Flow (cfs)	Flow (cfs)
	77%	14	23
	50%	29	55
	33%	48	74
	25%	55	90
	10%	81	136

The EFM analysis produces four EFM flows (highlighted in yellow for each USGS gage station location on Table 3 through Table 10) representing a peak seeding survival flow and a limiting growing season submergence flow for each species at each gage.

For the screening process these four EFM flows need to be modeled in HEC-RAS and flow inundation maps produced. These maps indicate areas next to the channel that could readily be used for terrace lowering and areas into the floodplain were water could potentially reach if connected by high flow channels. Because the HEC-RAS models start at river mile locations that are not coincidental with the river gages, the flows are translated from the gage site based on the techniques discussed in Section 2.2 . These gage translation ratios have already been determined during the hydrologic flood flow analysis for the project (Attachment 1). Therefore the exact translation ratios used for the 50% ACE event was used to translated the USGS gage station EFM flows as shown in Table 11. This ACE flow was used because it was within the range of the four EFM flows.

On the left of Table 11 are the values for the 50% ACE events from the HEC-RAS models or from the Hydrologic Report (Attachment 1). Because of the complexity of the hydrology at the confluence of the Rio Chama and Rio Grande, there are actually three peak flow models. One peak flow model for the Rio Chama with corresponding flows on the Rio Grande. The second model for the peak flows on Rio Grande above the Rio Chama confluence and a third model for peak flows on the Rio Grande below this confluence. The flows used for scaling are shown with a yellow highlight. The four EFM flows were then scaled with these 50% ACE events, the scaling results are highlighted in orange on the right side of Table 11. The Santa Cruz River proved to be independent of the Rio Grande and could use a simpler scaling technique.

Table 11 Translation of EFM flows at USGS Gages to HEC-RAS locations. Yellow highlights the original flood hydrology translation. Orange highlights the dependant EFM translation.

			upstream peaks	downstream peaks		Lower Rio Chama EFM Flows Translated					Upper Rio Grande EFM Flows Translated					Lower Rio Grande EFM Flows Translated				
		50% ACE	50% ACE	50% ACE		Willow		Cottonwood			Willow		Cottonwood			Willow		Cottonwood		
RAS XS	location	Rio Chama	Rio Grande	Rio Grande		Low	High	Low	High		Low	High	Low	High		Low	High	Low	High	
		cfs	cfs	cfs		cfs	cfs	cfs	cfs		cfs	cfs	cfs	cfs		cfs	cfs	cfs	cfs	
28075.65	US 285 Bridge	2993	1925	3604	RAS	644	1301	1066	2351		579	1170	759	1698		1164	2058	1584	2981	RAS
		1.045041899	0.48354685	0.50618																
21570.12	Hernandez Dam																			
17010.09	Chamita Gage	2864	RAS			616	1245	1020	2250	EFM										
12387.1	Salazar Dam																			
	Embudo Gage		3981	Hydrology Report							1197	2420	1570	3511	EFM					
105695	Alcalde Dam	2370	3588	3588	RAS	510	1030	844	1862		1079	2181	1415	3164		1159	2048	1577	2968	RAS
		0.827513966	0.90128109	0.503933																
89565.54	Ohkay Owingeh border																			
82450.43	Confluence w/ Chama	4929	5500	7180	RAS	1060	2143	1755	3872		1654	3343	2169	4851		2319	4099	3156	5940	RAS
		1.721019553	1.38156242	1.008427																
	Otowi Bridge Gage			7120	RAS											2300	4065	3130	5890	EFM

location	Santa Cruz River		Santa Cruz River Translated				
	cfs						
Cundiyo Gage	300	Hydrology Report	48	196	74	235	EFM
Confluence Rio Grande	550	RAS	88	359	136	431	RAS
	1.83333333						

3 - HISTORICAL GEOMORPHOLOGY

The primary objectives were to:

- Describe the historic and existing channel and riparian conditions.
- Identify changes in the channel planform, cross-sectional and longitudinal profiles, sedimentology, and connectivity with the floodplains.
- Document the causes of the identified changes.
- Identify trends in the geomorphic characteristics of the Rio Grande, Rio Chama, and the major tributaries within the project boundaries.

Based on the results of these investigations, the potential for channel and floodplain/terrace restoration and appropriate restoration methods were evaluated. The detailed geomorphic analysis is found in Attachment 2.

By the 1930s, increases in sediment from the watershed, in conjunction with reduced flows from irrigation activities, led to aggradation and braiding of the Rio Grande in the Española Valley. The increased frequency of flooding, punctuated by the floods of 1941 and 1942, were the impetus for subsequent flood-control activities by the State of New Mexico and Federal agencies. The Rio Grande was channelized and straightened, with spoil piles placed in the floodplain in the 1950s countering floods; while maintenance activities such as bank protection continued into the 1980s. Sand and gravel mining within the Rio Grande in the 1980s caused significant incision along the river, with incision measuring as much as 10 feet in the lower part of Ohkay Owingeh Pueblo. The mining activities on the Rio Grande likely caused incision on the tributaries as well. Repeat surveys on the Rio Grande, compared with 2007 data, indicate that the current bed elevation is now stable, with temporary aggradation at tributary confluences and also degradation associated with channel bed mining.

Starting in 1963, peak flows and sediment supply from the Rio Chama decreased as Abiquiu Dam began operations. Although historically a large supplier of sandy sediment to the Rio Grande, storage within Abiquiu Reservoir has reduced the Rio Chama’s supply by 50%. In combination with the channel incision, reduced peak flows have disconnected the Rio Chama from its floodplains and influenced the geomorphology of the Rio Grande.

The Rio Grande carries a mix of sand, gravel, and cobbles. Although the sediment deposits along this section of the Rio Grande were historically gravel and cobbles, recent sample data indicate that some places reflect a coarsening of deposits, while other locations have deposits of sand. The current sand patches are not thought to be long-term deposits. Historically, the Rio Chama carried primarily sand to the Rio Grande. The smaller tributaries also deliver sand; however, their sediment contributions are now a mixture of sand and gravel. (U.S. Army Corps of Engineers, 2009)

Reconnection of the incised rivers to their floodplains will require system manipulation because the floodplains in the project area are rarely connected with the common flood 50% ACE event. Preliminary HEC-EFM version 3.0 modeling (U.S. Army Corps of Engineers, 2013b) was used to screen potential side-channel reconnection opportunity sites that were identified along the Rio Chama, Santa Cruz River, and the Rio Grande (see Section 8.2.3). Many of these sites were identified in previous studies (Attachment 6).

4 - EXISTING CONDITION HYDRAULICS

A new set of hydraulic models were created using the HEC-RAS application and new 2007 topographic data; the detailed assessments and mapping of their reaches are located in Attachment 3. Both field collected survey cross section data and cross section data extracted from the 2-foot LiDAR data were used to create the models. Two models were created on the Rio Grande, with the division at the Rio Chama confluence. An individual model was created for each tributary: Rio Chama, Santa Cruz River, Arroyo Guachupangue, Santa Clara Creek and Rio Pojoaque. The resulting flood inundation maps are located in Attachment 5.

4.1 Rio Grande and Rio Chama Floodplain Delineation

Hydraulic models were developed for the approximately 20-mile reach of the Rio Grande and 5.3-mile reach of the Rio Chama within the study area using the USACE HEC-RAS computer software (U.S. Army Corps of Engineers, 2008). The main channel geometry of the model was based on topographic and bathymetric survey data collected in 2007 specifically for this study supplemented with cross-section data previously collected by USBR and its contractors. Model geometry in the overbanks was developed from 2-foot contour resolution, LiDAR-derived 2007 topographic mapping. Hydraulic roughness coefficients used in the model were based on field observations, bed-material characteristics, and features visible in the 2007 aerial color orthophotography.

4.1.1 Original Floodplain Mapping

The hydraulic model was calibrated by varying the main channel roughness coefficients until the predicted water-surface elevations matched measured data within reasonable tolerances. Results from the calibrated model are in good agreement with the rating curves at the USGS Rio Grande at Otowi Bridge and Rio Chama near Chamita gages; measured water-surface elevations at the relatively low flows at the time of the cross-section surveys (490 to 510 cfs at Otowi Bridge and ~50 cfs at Chamita); and water-surface profiles developed from the LiDAR mapping, the data for which was collected at flows of 1,200 to 1,270 cfs at Otowi Bridge and 330 to 340 cfs at Chamita.

The hydrograph routings for the 50%, 20%, 10%, 4%, 2%, 1%, 0.5% and 0.2% Annual Chance Exceedance (ACE)[2] events (U.S. Army Corps of Engineers, 2015) were developed as part of the hydrologic assessment (Attachment 1); these hydrographs provided the resulting steady-state peak flows for use in determining the flood inundation boundaries. The routings were performed separately for the Rio Grande upstream from the Rio Chama, the Rio Grande downstream from the Rio Chama, and the Rio Chama.

[2] The annual chance exceedence (ACE) values of 50%, 20%, 10%, 4%, 2%, 1%, 0.5% and 0.2% refer to the probability of a particular flow event being exceeded in any single year. Therefore, the previous nomenclature of the "100-year flood" is properly defined as a flood flow having a 1 percent chance of being exceeded in any one year. See page x for a complete table of comparisons.

Results from the hydraulic models indicate that the main channel hydraulic conditions vary considerably along the project reach due to the effects of hydraulic structures, variability in geomorphic conditions, and other anthropogenic effects on channel geometry. The model results also show significant backwater upstream from bridges and constrictions in the bounding terraces, particularly at the higher flows.

The computed water-surface profiles were used to delineate the inundated area for each of the modeled flows using HEC-GeoRAS (U.S. Army Corps of Engineers, 2005) in conjunction with ArcGIS Version 9.2 (ESRI, 2006). The floodplain mapping indicates that the earthen levees in the vicinity of the City of Española generally contain flows up to and including the 10% ACE event and significant flooding occurs at flows that equal or exceed the 2% ACE event (Attachment 5, Section 1, Maps RGFD Sheets 3-5). The most significantly wide area of flooding occurs in the reach of the Rio Grande between Santa Clara Creek and the Santa Clara/San Ildefonso Pueblo boundary (Attachment 5, Section 1, Map RGFD Sheet 5) as the floodplain reaches its greatest width after flowing between several constricting alluvial fans.

Significant flooding at the higher peak flows also occurs upstream from the NM Highway 74 Bridge (Attachment 5, Section 1, Map RGFD Sheet 2), through the City of Española (Attachment 5, Section 1, Maps RGFD Sheets 3-4), and downstream from the Rio Pojoaque (Attachment 5, Section 1, Map RGFD Sheet 6). As expected, the least amount of overbank flooding occurs in the canyon-bound reach below Otowi Bridge (Attachment 5, Section 1, Map FGFD Sheet 7). In the Rio Chama, the largest amount of flooding occurs between the Sawyer Diversion and the abandoned Chili Railroad Line due to the flat channel gradient in this area that is associated with an alluvial fan (Attachment 5, Section 1, Map RCFD Sheets 1-2). In both the Rio Grande and Rio Chama, very little overbank flooding is indicated at the 50% ACE event, and relatively minor flooding occurs at the 20% ACE event. Large scale flooding generally occurs at flows exceeding the 2% ACE event.

4.1.2 Floodplain Amendment

The existing condition hydraulic model in HEC-RAS underwent extensive internal review and approval. In general this model was only to be altered during the analysis of potential levees, grade restoration facilities, and ecosystem restoration measures to determine future conditions. However when major errors occur in this modeling, the model needs to be corrected and the existing condition floodplain remapped. This is important because FEMA has not had a program for mapping floodplains on Indian reservations until recently. Therefore the USACE produced floodplain maps usually are the first flood risk assessments based on detailed hydraulic modeling to be received by the Pueblos.

4.1.2.1 San Juan Elementary School

Three proposed levee alignments were analyzed that went around the San Juan Elementary School, with each additional alignment including more adjacent buildings and residences. The results of the HEC-RAS model indicate that the most inclusive levee would result in a greater than a 1-foot rise in the 1% ACE stage. FEMA generally limits the 1% ACE event stage increases to 1-foot or less, under the concept of protecting a critical floodway and limiting changes to the Flood Insurance Rate Maps.

A routine second step in this levee analysis was to remove any existing spoil piles from the river bank, under the practice that this dirt would be sieved and recycled into the proposed levee. This practice could significantly reduce the cost of importing earth to the construction site. However this second step in this hydraulic analysis did not mitigate for the increased flood stage resulting from the most constrictive levee alignment.

Figure 4 Old New Mexico Route 74 bridge (Source: Alan Schlindwein).

4.1.2.2 New Mexico Route 74 Bridge Mitigation

The San Juan Elementary School is just north of New Mexico Route 74 on the eastern fringe of the floodplain. NM 74 crosses the Rio Grande on the western fringe of the floodplain. Because the school is on the upriver side of the highway embankment, it experiences the higher levels of flooding caused by the two restrictive bridges over the Rio Grande and the elevated approach roadway. If there was a way to improve the hydraulic efficiency of these bridge crossings, this could mitigate for the adverse stage increase of the proposed upriver levee. The operational highway bridge is a broad spanning structure located just upstream from the historic highway bridge, which is still used for pedestrian traffic. This smaller bridge has some obvious hydraulic issues that make it inefficient and a promising candidate for potential flood stage mitigation.

However when mitigation measures were considered, the geometry of the old bridge in the HEC-RAS model could not be reconciled with LiDAR-based topography. The model had a three span bridge with 55 foot long spans. Ground based photography showed a four span bridge at this location (Figure 4). Because the bents in the old bridge extended beyond the bridge deck, they could be easily measured in Google Earth Pro at 102 feet for the two mid bridge spans and 101 feet at the two abutments. A 406 foot long bridge adequately matched the LiDAR based topography.

Consequently the old bridge was corrected in the HEC-RAS model and this correction eliminated the “greater than 1-foot flood stage increase” observed in earlier model runs. This correction was documented in all of the hydraulic models being used for analysis and the affected floodplain was remapped.

4.2 Floodplain Delineation for Santa Cruz River

A hydraulic model of the Santa Cruz River within the project boundaries was developed using the HEC-RAS computer software (U.S. Army Corps of Engineers, 2008). The cross-sectional geometry of the model was developed using the 2007 LiDAR-derived mapping data. Hydraulic roughness is accounted for in the model through the use of Manning’s *n* roughness coefficients. Main-channel *n*-values were set at 0.035 to account for the grain and form roughness in the primarily gravel-bed channel. Overbank *n*-values ranged from 0.040 for areas with no vegetation and relatively low form roughness to 0.10 for areas with very dense vegetation and high form roughness, and were input into the model using the horizontal variation in roughness option. The downstream boundary condition was established using normal depth with an energy slope of 0.006, consistent with the average bed slope in the downstream portion of the study reach. Ineffective flow areas were used where appropriate, and all hydraulic structures (i.e., bridges) were coded into the model.

As with the mainstem Rio Grande, hydrographs for all 8 flow frequencies were developed in the hydrologic assessment (Attachment 1). Results from the model runs indicate that the hydraulic conditions vary significantly along the project reach due to road crossings, variations in the main channel and floodplain widths, and changes in channel gradient. Computed water-surface profiles show significant backwater effects at the higher flows upstream from the US Highway 285 and NM Highway 106 bridges (Attachment 5, Section 1, Map SCCFD Sheet 1). Less significant backwater occurs upstream from areas that have a narrower floodplain or are constricted by levees and berms.

4.3 Floodplain Delineation for Arroyo Guachupangue

A hydraulic model of Arroyo Guachupangue within the project boundaries was developed using the HEC-RAS computer software (U.S. Army Corps of Engineers, 2008). This model is built with a “Y” shape geometry. The Arroyo Guachupangue and the South Branch are two nearly equal sized channels that confluence west of the Town of Española and then pass through town to the east to confluence with the Rio Grande. The cross-sectional geometry of the model was developed using the 2007 LiDAR-derived mapping data. Hydraulic roughness is accounted for in the model through the use of Manning’s *n* roughness coefficients. Main-channel *n*-values were set at 0.035 to account for the grain and form roughness in the mixed sand- and gravel-bed channel. Overbank *n*-values ranged from 0.038 for areas with no vegetation and relatively low form roughness to 0.08 for areas with very dense vegetation and high form roughness, and were input into the model using the horizontal variation in roughness option. The downstream boundary condition was established using normal depth with an energy slope of 0.012, consistent with the average bed slope in the downstream portion of the study reach. Ineffective flow areas were used where appropriate, and all hydraulic structures (i.e., culvert crossings) were coded into the model.

As with the mainstem Rio Grande, hydrographs for all 8 flow frequencies were developed in the hydrologic assessment (Attachment 1). Results from the model runs indicate that the hydraulic conditions vary significantly along the project reach due to road crossings, variations in the main channel and floodplain widths, and changes in channel gradient. Computed water surface profiles show significant backwater effects at higher flows upstream from the NM Highway 30 culverts and at constrictions in the bounding flood terraces upstream from the confluence with the South Branch.

4.4 Floodplain Delineation for Santa Clara Creek

A hydraulic model of Santa Clara Creek within the project boundaries was developed using the HEC-RAS computer model (U.S. Army Corps of Engineers, 2008). The cross-sectional geometry of the model was developed using the 2007 LiDAR-derived mapping data. Hydraulic roughness is accounted for in the model through the use of Manning’s *n* roughness coefficients. Main channel *n*-values were set at 0.035 to account for the grain and form roughness in the mixed sand- and gravel-bed channel. Overbank *n*-values ranged from 0.040 for areas with no vegetation and relatively low form roughness to 0.10 for areas with very dense vegetation and high form roughness, and were input into the model using the horizontal variation in roughness option. The downstream boundary condition was established using normal depth with an energy slope of 0.013, consistent with the average bed slope in the downstream portion of the study reach. Ineffective flow areas were used where appropriate, and all hydraulic structures (i.e. culvert crossings) were coded into the computer model.

Figure 5 Santa Clara Creek upstream of Highway 30, May 2007.

As with the mainstem Rio Grande, hydrographs for all flow frequencies were developed in the hydrologic assessment (Attachment 1). Results from the model runs indicate that the hydraulic conditions vary significantly along the project reach due to road crossings, variations in the main channel and floodplain widths, and changes in channel gradient. Computed water surface profiles show significant backwater effects at the higher flows upstream from the New Mexico Highway 30 (Figure 5) and Kee Street Bridges (Attachment 5, Section 1, Map RGFD 4). Less significant backwater occurs upstream from areas that have a narrower floodplain or are constricted by levees and berms.

4.5 Floodplain Delineation for Rio Pojoaque

A hydraulic model of the Rio Pojoaque within the project boundaries was developed using the HEC-RAS computer software (U.S. Army Corps of Engineers, 2008) producing flood extents (Attachment 5, Section 1, Map FDRP Sheet 1). The cross-sectional geometry of the model was developed using 2007 LiDAR-derived mapping data. Hydraulic roughness is accounted for in the model through the use of Manning's *n* roughness coefficients. Main-channel *n*-values were set at 0.035 to account for the grain and form roughness in the mixed sand- and gravel-bed channel. Overbank *n*-values ranged from 0.035 for areas with no vegetation and relatively low form roughness to 0.85 for areas with very dense vegetation and high form roughness, input to the model using the horizontal variation in roughness option. Because using a normal depth downstream boundary condition (with an energy slope equal to the average bed slope near the mouth) resulted in unreasonable downstream water surface elevations, the hydraulic model of the Rio Grande was used to estimate water-surface profiles near the mouth. The computed stage from the Rio Grande model for the 10% mean daily exceedance discharge plus the peak flow from the Rio Pojoaque was used for the downstream boundary condition in the Rio Pojoaque model for the lower flows (the 50% and 20% ACE events), while the computed stage for the 50% mean daily exceedance discharge (plus the peak flows in the Rio Pojoaque) was used for the higher flows. Ineffective flow areas were used where appropriate, and all hydraulic structures (i.e., bridges) were coded into the model.

As with the mainstem Rio Grande, hydrographs for all 8 flow frequencies were developed in the hydrologic assessment (Attachment 1). Results from the model runs indicate that the hydraulic conditions vary significantly along the project reach due to road crossings, variations in the main channel and floodplain widths, and changes in channel gradient. Computed water-surface profiles show significant backwater effects at higher flows upstream from the Black Mesa Road and Arriba County Road 101D Bridges. Less significant backwater occurs upstream from areas that have a narrower floodplain or are constricted by spoil levees.

4.6 Existing Condition Inundation Areas

Attachment 3 contains summaries for each river, broken down by reaches, of the inundated area by flood event. For the upstream Rio Grande, downstream Rio Grande and Rio Chama in the study area the total inundated acreage is shown on Figure 6 for each flood event.

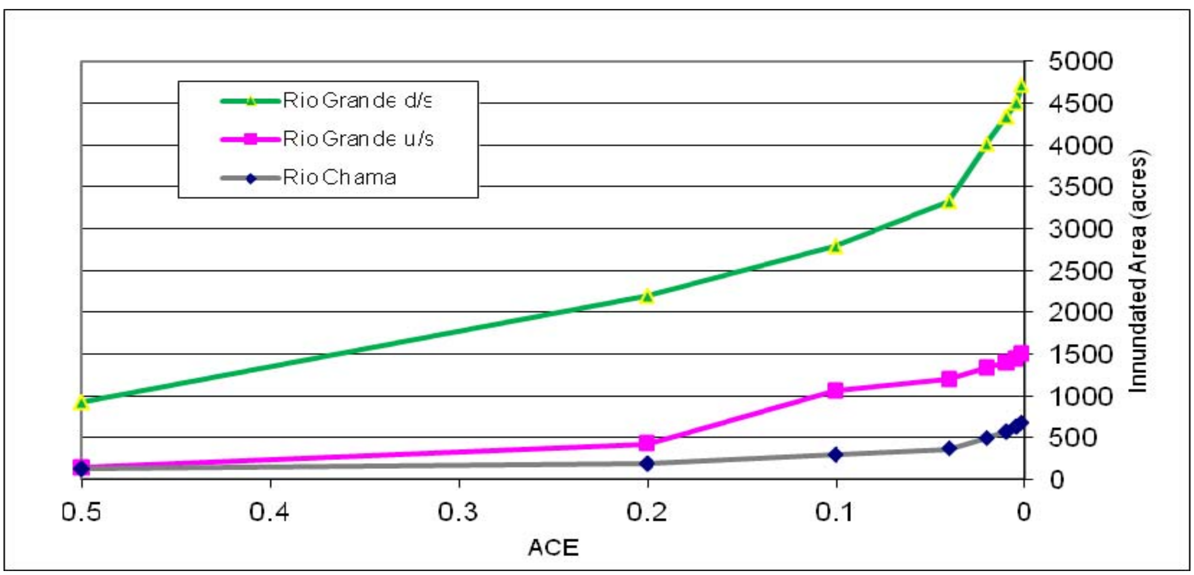

Figure 6 Total Inundation Acreage for three River Reaches in Study Area.

5 - SEDIMENT TRANSPORT ANALYSIS

Mobile boundary sediment transport computer models of the tributaries in this study were developed using the HEC-RAS version 4.0 computer model (U.S. Army Corps of Engineers, 2008). The channel geometry from the hydraulic models developed for the floodplain delineation mapping was used. Bed material input was based on sediment samples collected during the October 2007 field reconnaissance.

Upstream sediment supplies for each reach were estimated using the equilibrium load option that computes the transport capacity of the upstream cross section of the modeled reach, and uses these capacities as the supply. For all models, the geomorphic top of bank was used to designate the cross-sectional limits of erosion, and the vertical erosion limits (i.e., depth of the bed sediment reservoir) were set at 10 feet below the existing bed to allow for the possibility of large vertical adjustments. Exceptions to this method occurred at known stable points such as diversion weirs or concrete sills; in these locations, the bed was not allowed to degrade.

For these tributaries, the model results were validated, at least qualitatively, by comparing the estimated annual bed material sediment yield with estimates from other Rio Grande tributaries in New Mexico. The detailed analysis for each tributary can be found in Attachment 4.

5.1 Sediment Transport Analysis for Arroyo Guachupangue

Sediment transport methods followed the general methods outlined above. There was insufficient riverine flow data on Arroyo Guachupangue for the hydrologic input to the sediment transport model; a sequence of eight flood hydrographs were created using the precipitation patterns (1980-2005) in the City of Española with the HEC-HMS computer model used to predict stream flows on this arroyo (Figure 7).

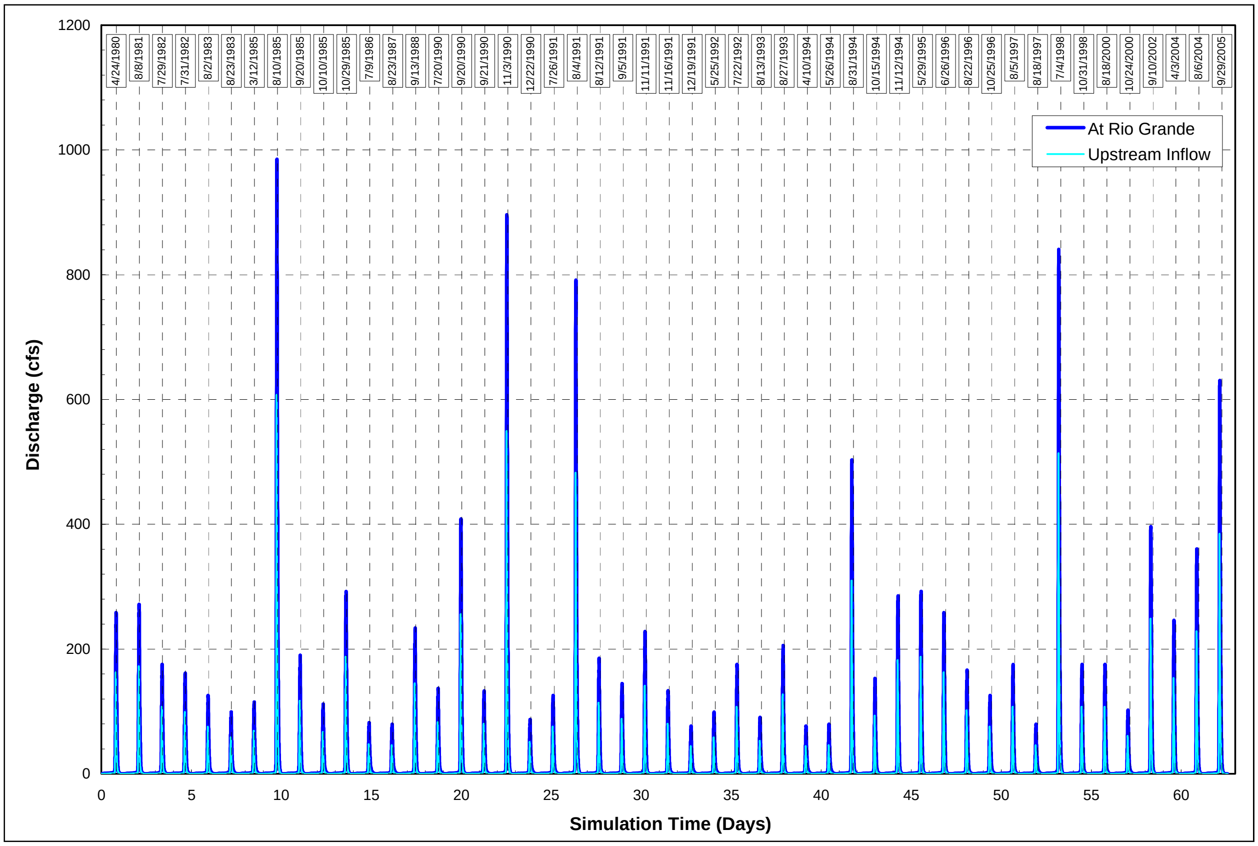

Figure 7 Estimated hydrograph series for the Arroyo Guachupangue simulation between WY1980 and WY2005.

Results from the model indicated that there is the potential for notable aggradation on the mainstem just upstream from the South Branch confluence (Figure 8). Other than this one location, the remainder of the mainstem is slightly degradational to relatively stable.

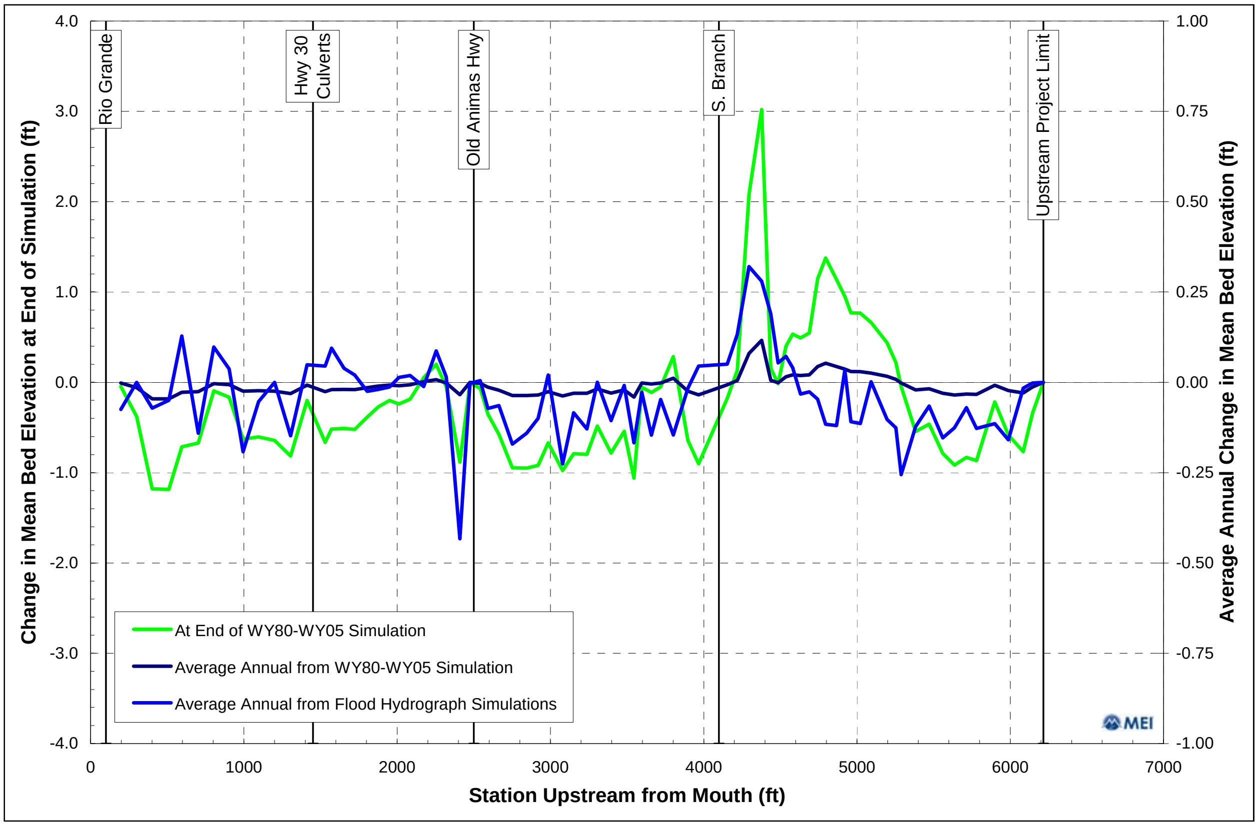

Figure 8 Predicted change in mean bed elevation at the end of simulation and the estimated average annual change in the Arroyo Guachupangue. Also shown is the estimated average annual change in mean bed elevation.

5.2 Sediment Transport Analysis for Rio Pojoaque

Sediment transport methods followed the general methods outlined above. As with the Arroyo Guachupangue, there was insufficient riverine flow data on the Rio Pojoaque for the hydrologic input to the sediment transport model. Similar to the assessment for the Arroyo Guachupangue, a sequence of eight flood hydrographs were created using the precipitation patterns (WY 1980-2005) in the City of Española with the Rio Pojoaque HEC-HMS model to predict river flows on the river (Figure 9).

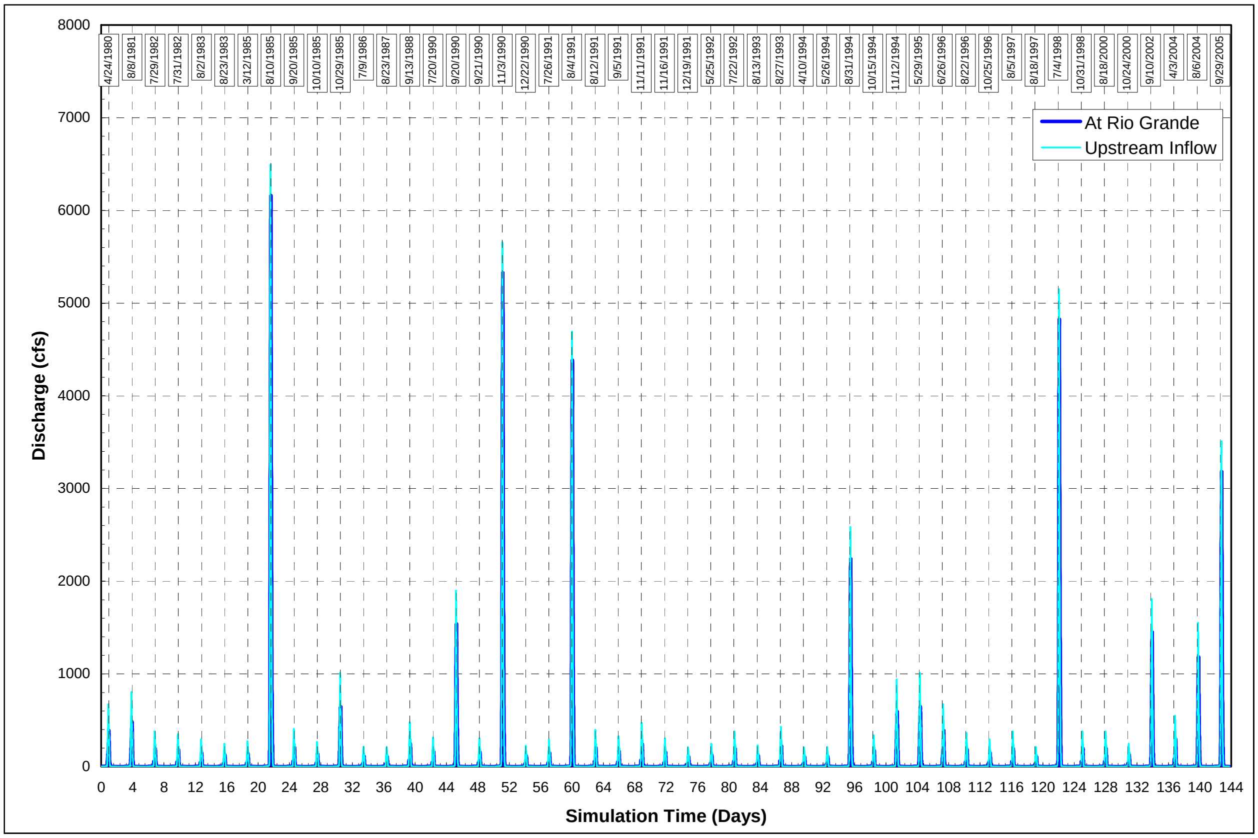

Figure 9 Estimated hydrograph series for the Rio Pojoaque simulation between WY1980 and WY2005.

The most significant amount of change in the Rio Pojoaque occurs in the 1,000-foot long backwater zone upstream from the Road 101D Bridge, where up to 3.2 feet of aggradation is indicated at the end of the simulation (Figure 10). The sediment-trapping effects of the bridge result in degradation downstream from the bridge. Degradation depths of up to 0.8 feet are indicated in the relatively narrow reach upstream from the confluence with Jacona Ranch Arroyo. The remainder of the study reach appears relatively stable.

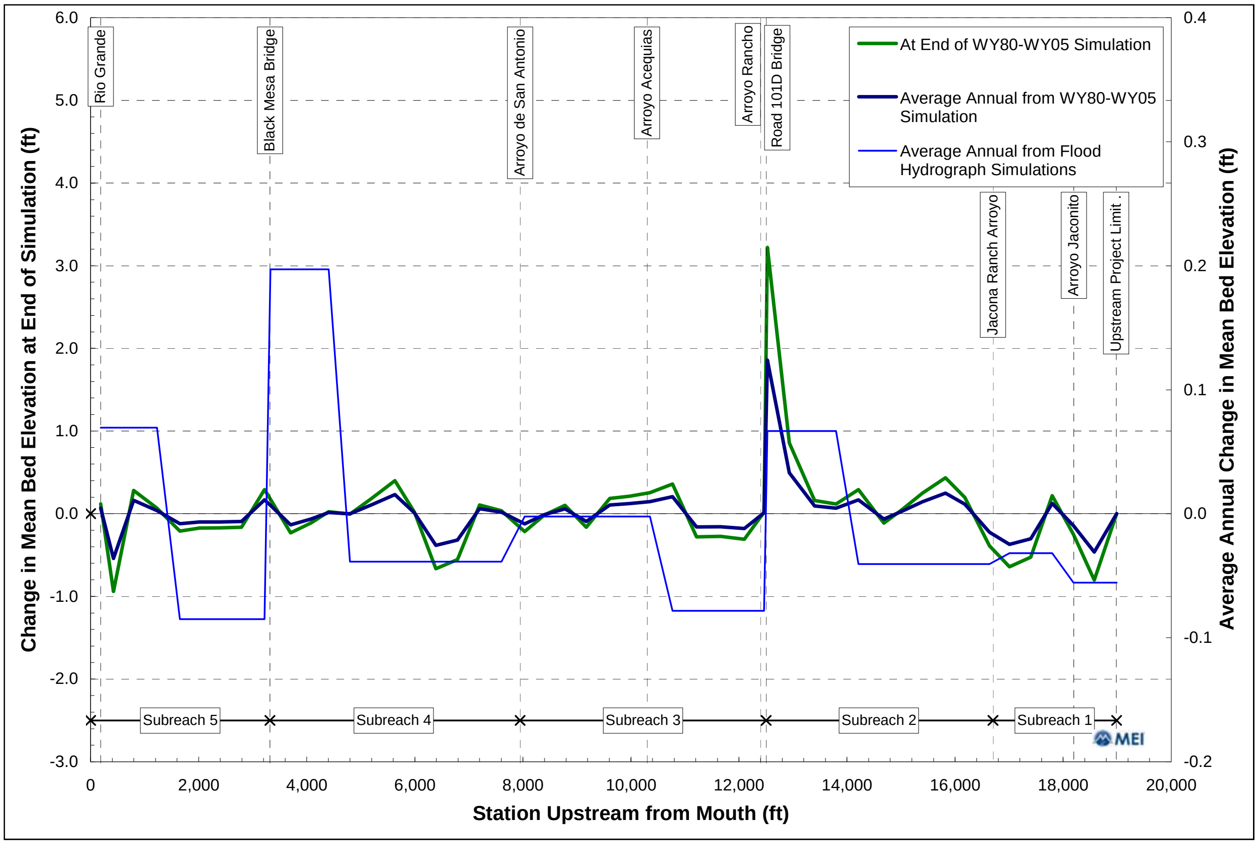

Figure 10 Predicted change in mean bed elevation at the end of simulation and the estimated average annual change in the Rio Pojoaque. Also shown is the estimated average annual change in mean bed elevation.

5.3 Sediment Transport Modeling on Gravel-Sand Bedded Channels

The sediment transport reports for the Arroyo Guachupangue and Rio Pojoaque were performed with a valid sediment transport function in the HEC-RAS version 4.1 hydraulic computer model running the mobile boundary routine. These reports are included in Attachment 3.

5.3.1 Future Conditions Considerations

However, the sediment transport studies of the Rio Grande, Rio Chama, Santa Cruz River, and post-fire Santa Clara Creek were performed with a sediment transport function that was incorrectly coded in the HEC-RAS computer model. As a result, HEC-RAS significantly under-predicts sediment transport. This incorrectly coded function is found in HEC-RAS version 4.0; version 4.1; and the alpha and first beta releases of version 4.2; there is no simple work around for this problem (Gibson, 2014). This error in the Wilcock-Crowe sediment transport function was corrected in the second beta(sediment)/alpha(2D) release of HEC-RAS 4.2 dated August 2013. The Hydrologic Engineering Center in Davis California has since abandoned the release of version 4.2 and is moving forward with a major release of HEC-RAS version 5.0; a beta version is currently available for testing purposes only.

The surface based sediment transport function (Wilcock & Crowe, 2003) has been verified in field studies (Haschenburger & Wilcock, 2003) and is appropriate for gravel-cobble bed river channels with high sand content. It is a surface-based sediment transport function originally proposed by Parker (1990). In the HEC-RAS version 4.0 release, the Wilcock-Crowe function was incorrectly identified and was confused with a different method (Wilcock, 1998; Wilcock & Kenworthy, 2002). To implement the Wilcock-Crowe function properly, a new two layer channel bed had to be coded into HEC-RAS. This two layer routine also had a reported coding error (U.S. Army Corps of Engineers, 2013d). The input of the surface layer and sub-layer of the channel is necessary for the Wilcock-Crowe function to be correctly used in mobile bed modeling. This two layer approach requires a specific bed sampling protocol (Parker & Sutherland, 1990).

The HEC-RAS computer model's mobile boundary routine also needs a sediment supply to be delivered at the upstream end of the modeled reach. This sediment information consists of a mass rate sediment feed and a sediment gradation of this feed. Appropriate methods for this sediment feed are detailed in Parker & Wilcock (1993) and were originally implemented correctly in HEC-6T (the precursor to HEC-RAS 4.0) and by Tetra Tech on the Santa Clara Creek (U.S. Army Corps of Engineers, 2013d). One of the sediment feed impossibilities for the Wilcock-Crowe function is to use the bed surface gradation as the gradation of the sediment feed. HEC-RAS does not test for this inappropriate condition and thus doesn't produce an error message. However armored channel bed conditions do not exist in arroyos (Varyo, 2012) where the gradation of the sediment feed and the surface layer should be the same. For the sediment transport modeling of these arroyos, the Wilcock-Crowe function should not be used. In general, any channel that develops sand dunes at any stage of flow is unsuitable for the Wilcock-Crowe function (Haschenburger & Wilcock, 2003).

The intended use of the HEC-RAS mobile bed routine (on only the Rio Chama and Rio Grande) was to simulate channel evolution 52 years into the future. Because the mobile bed model is computationally overwhelming for long reaches and long time series, a 26 year synthetic hydrograph was created by the compression of actual USGS gage data. Based on sediment transport thresholds, all flows that were not competent to move sediment were removed from the USGS data to create a much shorter synthetic hydrograph to improve the speed of the computer runs and reduce the size of the output files. Because of the output file size limitation; the compressed synthetic hydrograph had to be run twice to reach the duration of the study time line. At the end of the first run, the resulting channel geometry was copied into a second computer model. This second model was run to reach the end of the study timeline. The final end state condition of the (Rio Chama and Rio Grande) channel geometry was exported and used as the future conditions channel geometry in a third computer model. The eight flood flows were then modeled in this third HEC-RAS model to determine whether there would be any significant changes in future flood risks.

It is uncertain whether the sediment transport threshold was originally computed correctly in HEC-RAS, such that the compressed synthetic hydrograph is representative of the flows with geomorphically significant sediment transport. The limitations of HEC-RAS version 5.0 have yet to be explored to determine if a synthetic hydrograph is needed for future modeling efforts. All past modeling efforts that used the miscoded Wilcock-Crowe sediment transport function had to be discarded as they were scientifically invalid. As a consequence, the future conditions of the affected rivers could not be determined. This should not be a major study risks for two reasons. First, future changes in hydrology were not anticipated for the Española Valley (Attachment 1). Second, the geomorphology study (Attachment 2) concluded that the river systems monitored by the Bureau of Reclamation had in the past few decades become quite stable.

5.3.2 Engineering During Design Considerations

These computer modeling difficulties are particularly common for the American Southwest where channels of widely varying geometry, channel gradients, and bed/bank composition are encountered. The Southwest is also noted for slope changes that produce alluvial fans, complex confluences that can produce deltas, extremes of climate that change sediment delivery from hill slopes, and the transient influence of hurricanes, El Niño events, and forest fires. Consequently simulating future hydrology and sediment delivery is fraught with uncertainty.

The hydraulic computer modeling of alluvial fans and deltas is difficult even for a surveyed existing condition. The exercise of predicting sediment transport and channel change into the future and then modeling alluvial fans is an order of magnitude more difficult. The flood risk analysis of alluvial fans using classical methods is problematic and newer, more relevant procedures are being investigated (FEMA, 1995; National Research Council, 1996; Cazanacli, Paola, & Parker, 2002). The modeling of alluvial fans commonly requires two-dimensional (2-D) hydraulic computer models.

One recent discovery of sediment transport mechanics is particularly relevant to canyons and alluvial fans. It was noticed that channels with gradients steeper than 2% have significantly different sediment sorting characteristics than channels with gradients shallower than 2% (Solari & Parker, 2000). Normally, channels have a tendency to develop finer bed gradations in the downstream direction; but when over 2% in slope, these channels are actually more capable of moving larger particles and will become coarser on the channel bed in the downstream direction. This partially explains why large boulders are capable of moving down canyons and being deposited on alluvial fans. When these boulders are combined with debris flows, the upper third of alluvial fans are particularly prone to avulsion, bifurcation, and channel migration that rework the flow paths on alluvial fans and dramatically change flood risks (Cazanacli, Paola, & Parker, 2002).

The effects of this 2% slope threshold also lead to instabilities for engineered works, such that the design of the grade restoration facilities (GRF) needed to avoid this curious sorting mechanism. The design slope of the GRFs on the Rio Grande is 1.0% and for the Rio Chama, it is 1.2% to maintain normal stability and sediment transport characteristics (see Section 8.2.3). This 2% slope effect also partially explains why headcuts are so destructive and so difficult to model. The face of headcuts is always greater than 2% and these headcuts will then migrate upriver until this face is stretched to below 2% in slope. At that point the former headcut will develop into a steep run, and then possibly transition into a more stable riffle-run depending on channel planform. However the steeper the average gradient of the river channel, the harder it is for a headcut to naturally stabilize. In the Southwest, as mainstem headcuts transition to steeper tributaries, these tributary headcuts have the maddening characteristic of continuing upstream almost to the watershed divides.

One of the other difficulties in modeling channels in the Southwest is that the typical channel bed gradations were neither well studied, nor understood until recently. The earliest studies in sediment transport concentrated on big sandy rivers or small gravely mountain streams. For the Southwest channels to be adequately modeled, studies needed to concentrate on gravel channels with high sand concentrations and also on sand channels with high gravel concentrations. The study of the former produced empirical results (Andrews, 1983) and theoretical explanations (Parker & Klingeman, 1982; Andrews & Parker, 1987). The limitation of Andrews' empirical equation was that it was only applicable to particles below the D_{50} size. A strategy to eliminate this limitation was proposed (Parker, 1990) with the solution (Wilcock & Crowe, 2003) being misunderstood and incorrectly coded into HEC-RAS. The studies of the later, sand channels with high gravel content are ongoing (Blom, Ribberink, & Parker, 2008) with research computer models that only partially explain the unique gravel transport characteristics of sand bed-form channels.

The final limitation of HEC-RAS is that it is the compilation of one-dimensional (1-D) hydraulic model codes from HEC-2 and UNET along with 1-D sediment transport code from HEC-6T. For the theoretical sediment transport models currently being developed, it is necessary for the 2-D version of UNET and a bank stability model to be incorporated into HEC-RAS. The bank stability model and several 2-D routines are proposed with the beta release of HEC-RAS version 5.0, which also will incorporate several new capabilities beyond sediment transport and mobile bed modeling. Once all of the software bugs in the beta release are corrected, HEC-RAS version 5.0 will be significantly improved for the hydraulic and mobile boundary modeling of Southwestern rivers and streams. This version 5.0 should be available for the design of the selected plan.

6 - EXPECTED FUTURE CONDITIONS HYDROLOGY

6.1 Introduction for Changes in Hydrology

The hydrological response of the Upper Rio Grande watershed in the future depends on changes in land use and changes in climate. This hydrologic response then leads to changes in vegetation and ultimately in sediment delivery to tributaries, arroyos and rivers. The stability of streams and rivers is a balance between the delivery of runoff and the delivery of sediment. Once these interrelated factors are considered for the future without-project condition, then the expected future hydrologic effects on the proposed project measures can be evaluated.

6.1.1 Land Use Changes

The existing Rio Grande watershed is primarily used for agriculture, rangelands, forestry, recreation, and to lesser extents (area wise) mining, homesteads, villages, industry, research, and urban areas. Federal lands are essentially fully-developed with little potential for growth. Agriculture is dependent on water resources, either rainfall or diverted irrigation water, with little potential for growth in area or intensity. Both range use and forestry are very dependent on the annual weather.

When compared to the total watershed, the expected future impacts of all land development is low and slight when compared to the areas of the watershed that produce the most runoff and snowmelt (U.S. Army Corps of Engineers, 2009).

7 - EXPECTED FUTURE WITHOUT-PROJECT HYDRAULIC CONDITIONS

The future condition of the Española Valley floodplain without a USCE project (expected future without-project condition) is developed as a baseline for comparison with future conditions if the TSP is constructed (expected future with-project condition, see next chapter). Changes in the flood stages can be produced by changes in watershed flood flows, changes in the channels, or changes in the floodplain geometry or roughness. The watershed is not expected to change significantly so both the future hydrology and the future condition of the floodplain are not expected to change. Sediment transport modeling with a mobile bed routine was completed to determine whether the major waterways in the Española Valley are expected to evolve a new geometry.

7.1 Expected Future Without-Project Condition Hydraulic Models

Due to issues with the computer models (detailed in Section 5.3), only the Arroyo Guachupangue and Rio Pojoaque produced changes in their channels under expected future without-project conditions. These expected future without-project condition analyses are found in Attachment 3. However, the TSP does not include any proposed measures along these two water courses.

7.2 Expected Future Without-Project Condition Floodplains

The expected future without-project condition floodplains for the Arroyo Guachupangue and Rio Pojoaque are found in Attachment 5, Section 4, Maps FDT.2 and FDT.4 respectively. The expected changes in the two channels were minor, whether due to aggradation or degradation; consequently the expected changes in the floodplain are also very minor.

7.3 Risk-Based Recommendations for Expected Future Without-Project Condition Modeling

The geomorphology report found in Attachment 2 concludes that the river channels monitored by the USBR have significantly stabilized in the last few decades. This conclusion is largely base on the LiDAR coverage from 2007 with range lines and other cross section surveys also collected in 2007. Therefore, the risk of finding significant changed conditions during the design of an authorized project is very small.

Before the design of any location, a detailed survey will still be required so at a minimum, an accurate set of plans and cost-estimates can be developed. Should any site be significantly different from the 2007 LiDAR, this site should be analyzed to determine the cause of such change. At the time of project design, there should be at least 10 years of potential channel change available for accurate analyses. Should the determined cause of any channel change be significant and there be a dynamic hydraulic computer model capable of simulating such change, then the modeling of the future condition should be reconsidered.

In addition, there is a possibility over the next few years that predictions of climate change may produce detailed results for daily flow series hydrology. If such a series also adequately predicts infrequent floods or low flows that affect ecosystem restoration; then additional channel bed sediment sampling may be considered along with this new flow series in an addition future conditions modeling effort.

8 - EXPECTED FUTURE WITH-PROJECT HYDRAULIC CONDITIONS

The expected future with-project condition of the Española Valley floodplain, in which the TSP is constructed, was also modeled for comparison with the baseline condition. Changes in the flood stages can be produced by changing the surface condition of the floodplain or by physically altering the geometry of the flow channels and/or floodplain in the study area. Because all of the proposed measures will produce geometry changes and some will produce surface changes, these measures must be hydraulically evaluated to determine if the project goals are being attained and to mitigate any residual flood risk associated with the development of the TSP.

The TSP can be qualitatively assessed for the ecosystem restoration measure based on previous construction of said measure along the Rio Grande south of Albuquerque. The GRFs have already been sited during the alternatives screening process. Those sites with great potential for channel stability and habitat improvements have been preliminarily designed and therefore can be quantitatively assessed with a hydraulic model.

8.1 Flood Risk Management

At the request of the sponsor Pueblos, the Albuquerque District conducted a flood risk analysis with a following flood risk management study. The individual flood risk analyses can be found in Attachment 3 and the resulting flood risk mapping can be found in Attachment 5. Usually the flood risk management study is based upon an existing assessment of homes, businesses, and public buildings and infrastructure that are known to be at flood risk based on existing Federal Emergency Management Agency's (FEMA) Flood Insurance Rate Maps (FIRM). However, in the past FEMA was not performing detailed hydraulic studies on Indian Reservations and did not produce until recently FIRM maps that covered these Indian Reservations even when FEMA approved, detailed models were available.

The attached USACE flood risk analysis was not conducted for the purpose of meeting FEMA mapping standards such that FIRM panels cannot be produced from this effort. The USACE study was conducted to conservatively determine the location of the structures at risk on the sponsor Pueblos so that a flood risk management study would be inclusive. Initially, the flood risk mapping only showed the extents of flood inundation; based on these extents, the distribution of structures at risk was determined for each Pueblo. Once the distribution of structures within flood boundaries was determined, then proposed measures could be characterized that would protect individual structures, local groups of structures, or reaches of rivers and streams.

8.1.1 Inundation Depth Mapping for Flood Risk Screening

To screen flood risk reduction measures, two critical pieces of information are needed: the type of structures involved and the depth of flooding on these structures. The structures were typed from windshield surveys and the depth of flood inundation was produced from the existing HEC-

RAS models. Information from the HEC-RAS models was produced in two different steps: gridding the map of flood extent and then using this to estimate depth of flooding at each grid square based on the elevation difference between the modeled water surface elevation and the average ground surface elevation based on the 2007 LiDAR data. Grid squares used in this analysis measured 25 feet on a side. For the area coverage of these inundation depth maps, see Attachment 5. Based upon this colored grid map, the flood risk reduction measures were screened for applicability.

8.1.2 Levee Screening and Mitigation

The alignments of potential levees were selected based upon the initial inundation depth mapping, such that the proposed alignments found shallow depths to reduce the height of the required levees around the areas to potentially be protected. These alignments are found in Appendix J, Exhibit B along with typical levee cross sections. These potential levee alignments, should they be built, will cause the depth of flooding to increase in the channel reach adjacent to the proposed levee and for a distance upstream. For the purpose of levee screening, additional inundation depth estimates are needed to evaluate these raised water surfaces.

To determine these surfaces, the proposed levee alignment was inserted into the HEC-RAS model as a simple wall tall enough to contain the 0.2% ACE event. The hydraulic model was then run to determine the additional depth of flooding for each flood exceedance frequency event along the proposed levee. In addition, the distance of additional flooding for each flood exceedance frequency event was discerned upstream of the proposed levee.

As a routine step in these hydraulic analyses, the spoil piles riverward of the proposed levee alignment were removed from the hydraulic model. This is done for several reasons, as removing the spoil piles:

- Establishes a floodway with the proposed USACE levee as one boundary.
- Reconnects the floodplain with the river channel, improving riparian habitat.
- Reduces flood stages for most exceedance frequencies along the proposed levee.
- Reduces the upstream flood stage impacts from the proposed levee.
- The material from the spoil piles is screened into usable size fractions and then recycled into the proposed levee.

Generally, because proposed USACE levees will raise some flood stages, some sort of mitigation must be provided to landowners on the opposite side of the channel and upstream of these proposed levees. Removing spoil piles from the floodplain is the most efficient method for providing this mitigation. Other mitigation strategies are to:

- Improve the entrances and exits of bridges, or
- Build ecosystem measures that lower the channel banks or create side channels in the floodplain, or
- To set back an existing levee that is too close to the channel.

8.1.3 Further Analysis

The economic analysis of FRM locations screened out all but one potential levee alignment. The one remaining levee had real estate and residual flooding issues along Arroyo Guachupangue. The local sponsor, Santa Clara Pueblo, decided to not pursue this alignment. Had any of the proposed levee alignment proceeded, the further analysis would be guided by a risk-based Flood Management study. Although levees are not part of the TSP, the hydraulic modeling contributes important insights relevant to future development in the region in relation to the remaining residual flood risk:

- Alluvial fans should be avoided by all future development activities. For the alluvial fans that extend into the Rio Grande floodplain and have been eroded by past floods, these escarpments should be systematically abandoned.
- Existing development on alluvial fans is generally concentrated on its lower reaches. Therefore existing features to protect this development from flooding are also concentrated on the lower end of alluvial fans. However, on alluvial fans, the upper third is prone to avulsions and channel migration, which is where the existing flood protection measures are commonly lacking.
- Acequias are usually accompanied on the river side by access roads that are some of the most effective flood risk reduction measures found in the Española Valley. The access roads with the greatest potential to act as flood risk reduction measures come from out of the tributaries and then parallel the main channel. The simple raising or leveling of these acequia roads so that they match the slope of the flood profiles would be very effective at providing a uniform level of protection.
- The existing spoil piles are not consistently continuous, not properly leveled, and not capable of holding back flood water. In addition, they interfere with floodways and are not properly connected to bridge approach roads. At several locations these spoil piles are the cause of increased flood risks. Removing or moving portions of these spoil piles would improve the floodways in the Española Valley. The practice of excavating drainage ditches with a drag line or track hoe, then turning 180 degrees and depositing this spoil for a spoil bank levee, should never be used. The practice of setting a drag line or track hoe on top of a spoil bank levee then excavating below either slope toe and depositing the spoil on top of the levee should never be used. Both excavation practices increase the rate of flow of seepage through the levee, increasing the risk of embankment breaching due to piping and slope collapsing.

8.2 Ecosystem Restoration Measures

The hydrological analysis in Section 2.4 produced four flow values for each of the HEC-RAS models: two flows that would best support the establishment of willow and cottonwoods and two flows that would best represent the drowning of the seedlings of these two species. These flows from Table 11 were entered into HEC-RAS version 4.1 to determine the four river profiles corresponding to the four flow values for the upper and lower Rio Grande, the lower Rio Chama and the Santa Cruz River. The river profiles were then entered into HEC-GeoRAS version 10.1 to map the extents of these flows as shown on Figure 11 to Figure 14. Flow depth and extent maps were used to evaluate prospective locations of ecosystem restoration measures. For each reach with potential ecosystem restorations measures, one ArcGIS map was created for the willows and one map for the cottonwoods. These maps are found in Attachment 5.

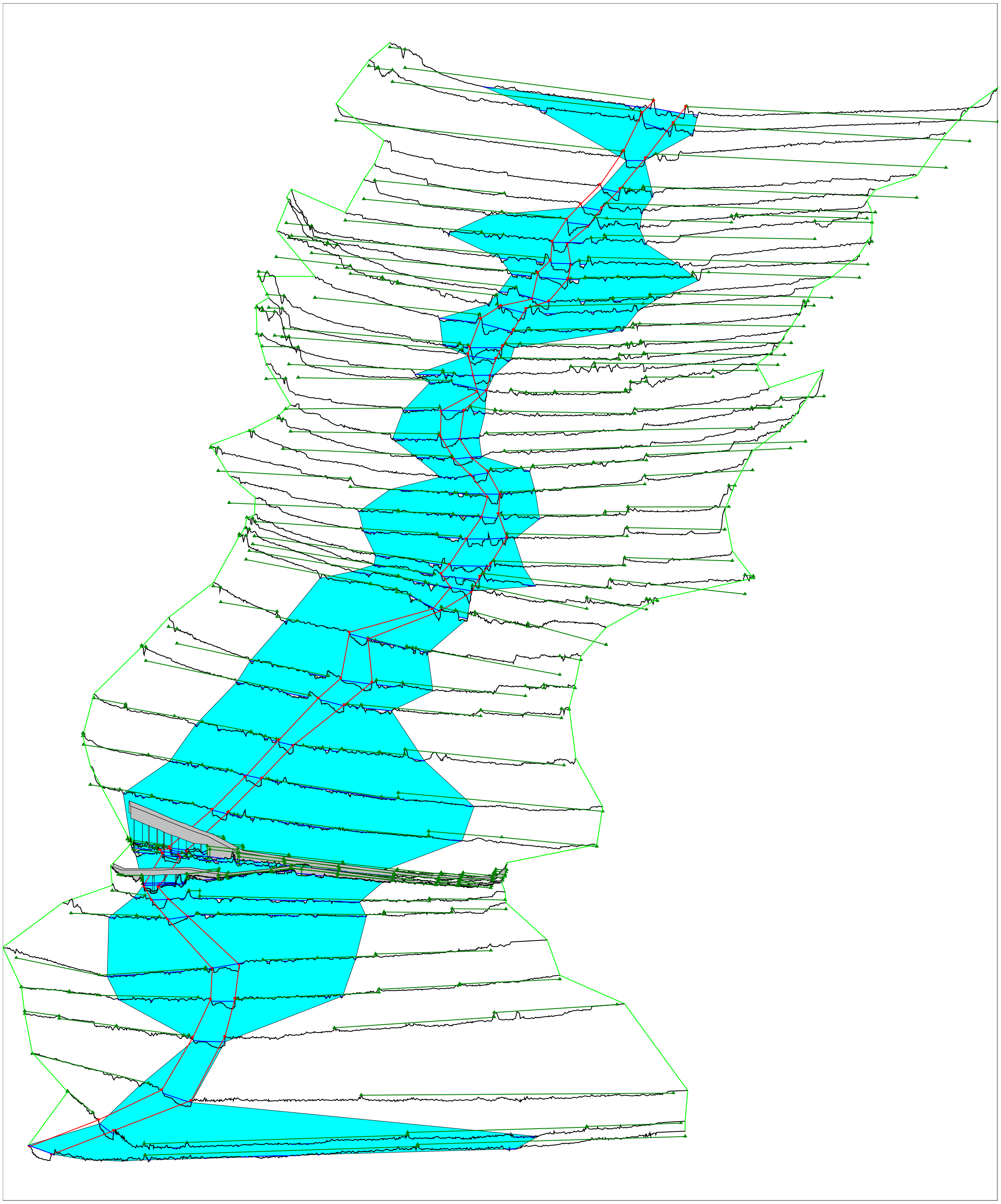

Figure 11 EFM Cottonwood flow extents along upper Rio Grande in study area.

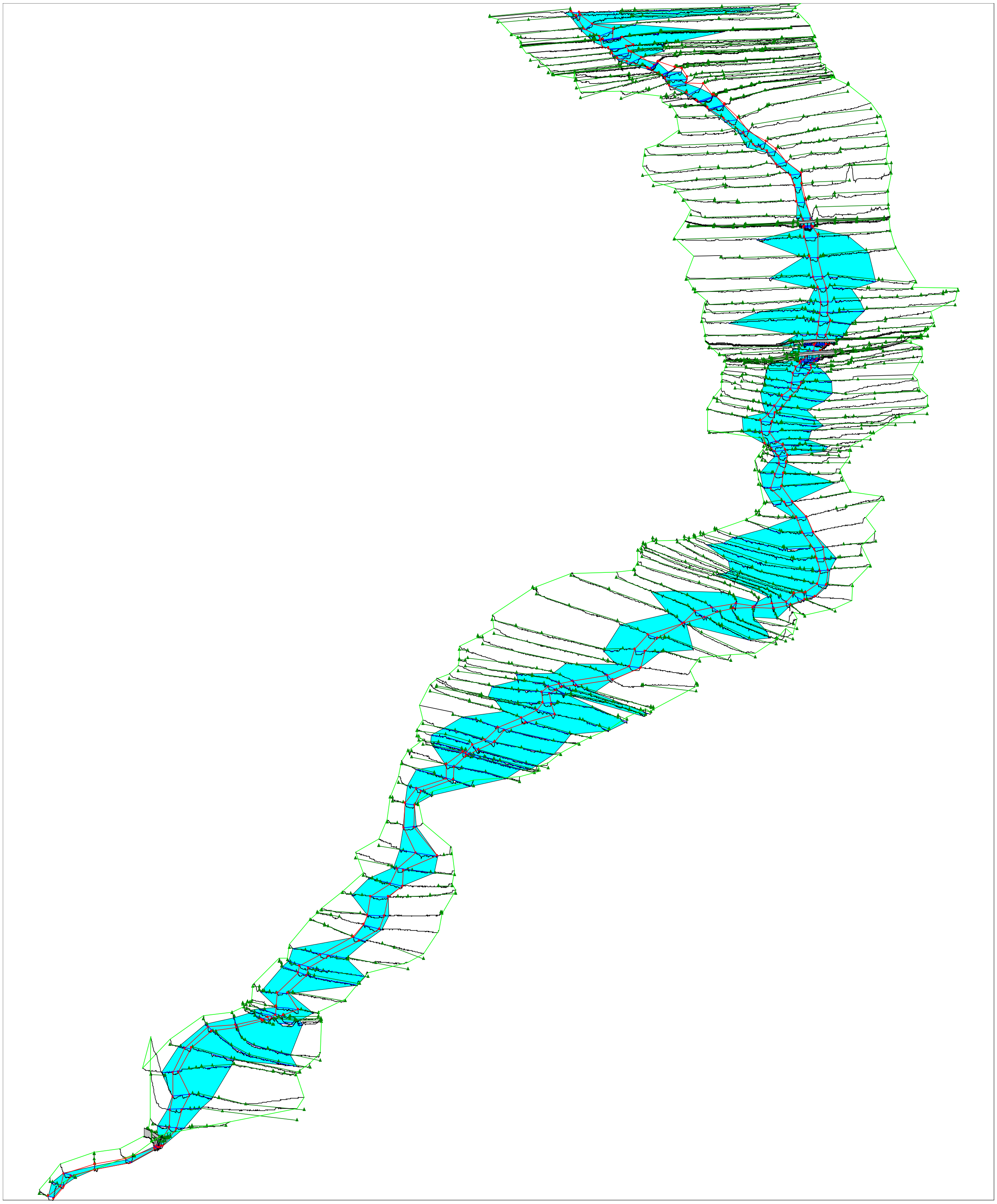

Figure 12 EFM Cottonwood flow extents along lower Rio Grande in study area.

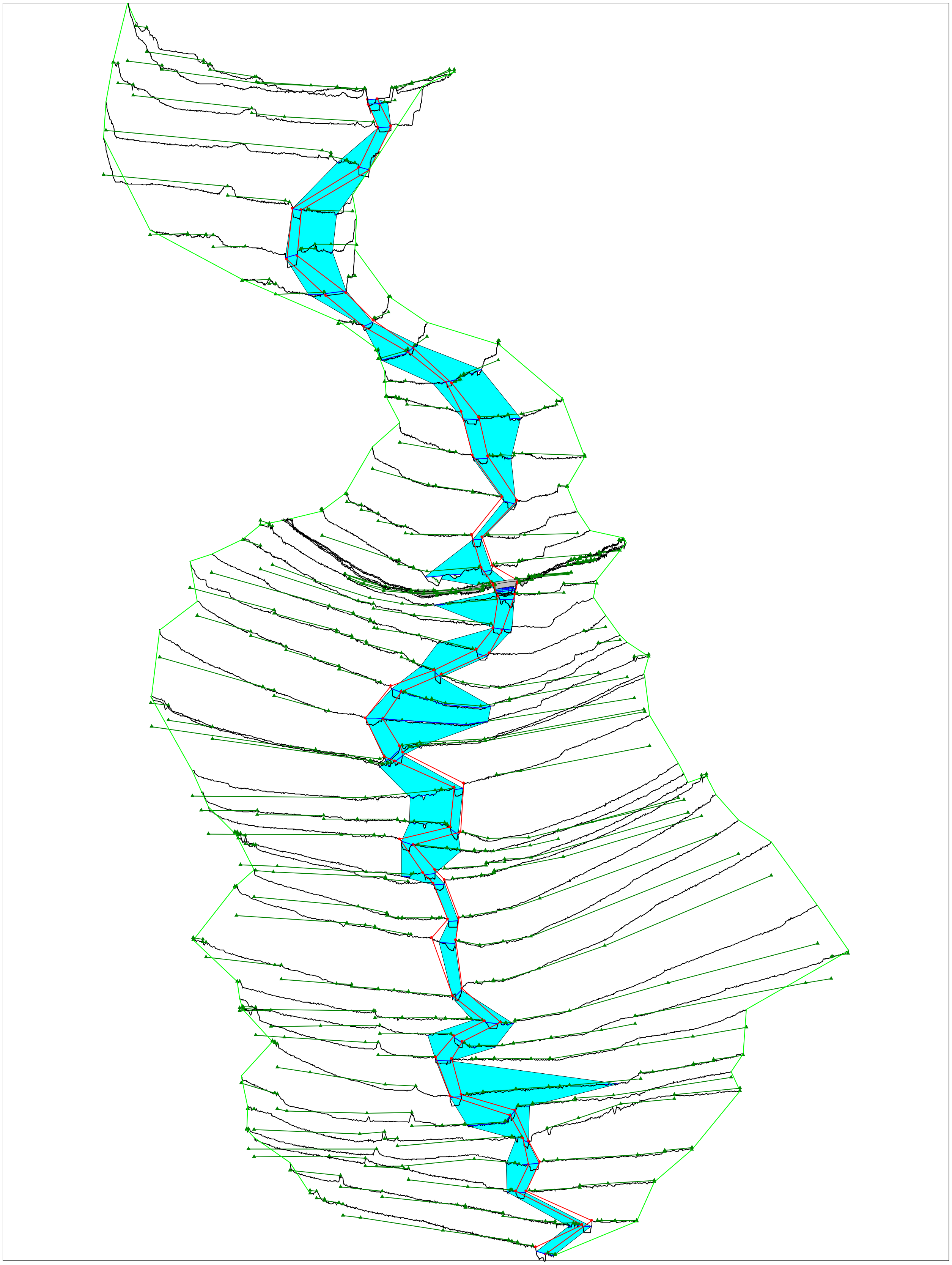

Figure 13 EFM Cottonwood flow extents along Rio Chama in study area.

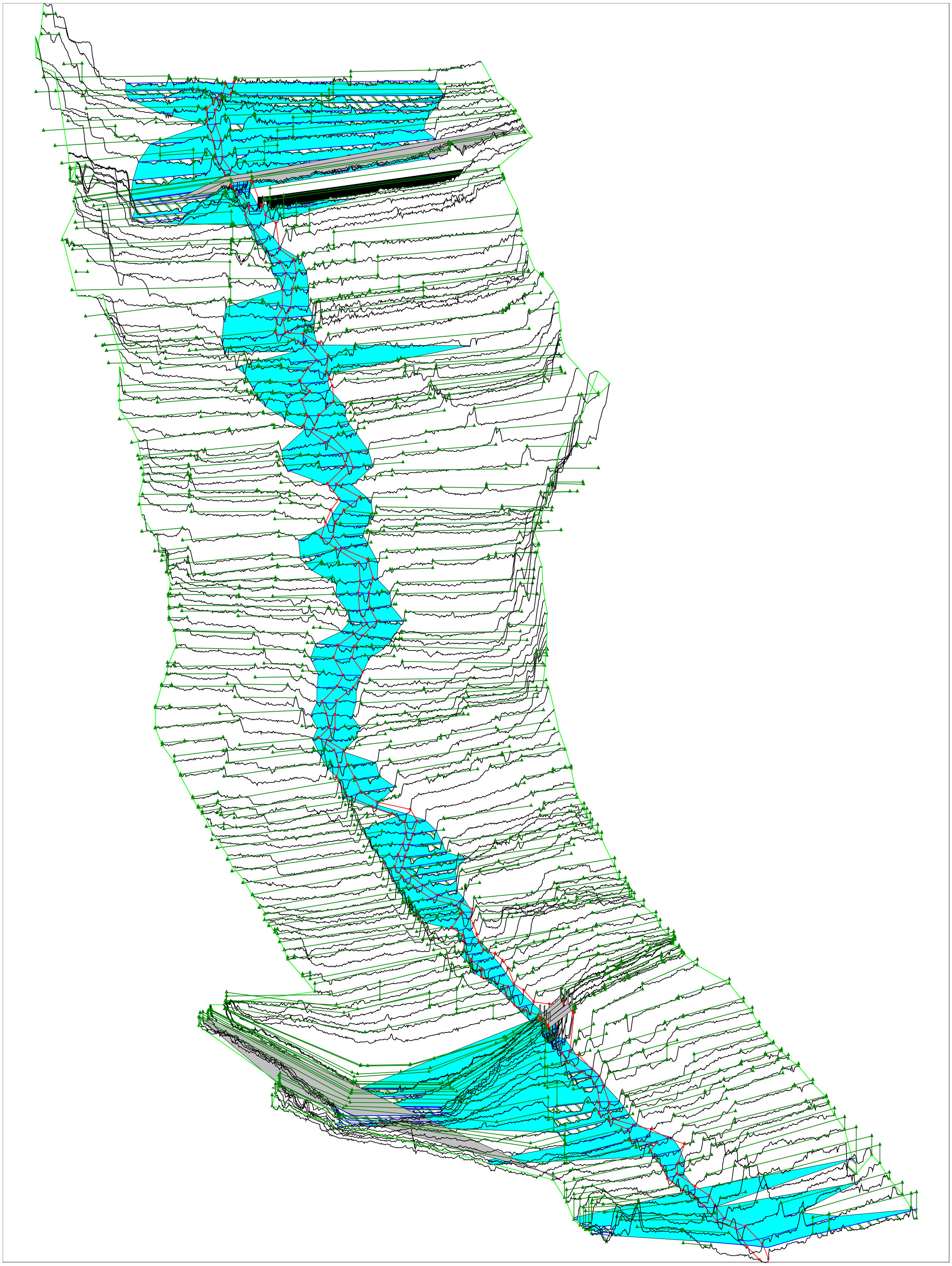

Figure 14 EFM Cottonwood flow extents along Santa Cruz River in study area.

Potential sites for ecosystem restoration measures have been repeatedly examined, with two reports found in Attachment 6. The final selection of viable measures was accomplished with the economic analysis found in Appendix B. The locations of ecosystem restoration measures for the tentatively selected plan are found in Appendix J, Exhibit A. These measures are discussed in depth in Appendix C, Chapter 2: the Biological Assessment.

8.2.1 Expected Hydraulic Effects of Ecosystem Restoration Measures

Upon close examination, these maps show a significant limitation in the current HEC-RAS hydraulic models. These models have cross sections with large spacing, primarily to utilize range lines repeatedly resurveyed by the USBR. Because of this large spacing, additional cross sections were surveyed in the field in 2007 so that an adequate computer model could be created to model flood flows. However even this reduced spacing is too far apart to adequately represent the channel bottom for the relatively small flows associated with ecosystem restoration. Consequently at several locations the local riffles and some bars that were missed in the modeling appear as islands or bare channel bottoms in the mapping.

As a result there is not enough detail in the current HEC-RAS model to produce quantitative hydraulic results for the ecosystem restoration measures. Based upon experience with similar restoration efforts by USACE, a qualitative description for these measures is possible. These proposed measures will have an immediate effect on the hydraulics of the adjacent channel, while also having a long term effect on the geomorphology of these channels.

The immediate effects of terrace lowering include increasing the channel cross sectional area and also increasing the channel wetted perimeter. This will slightly change the flow stages for any event that inundates the lowered terrace. If the bank lowering is above the natural elevation of the floodplain, determined by effective discharge analysis (Wolman & Miller, 1960; Emmett & Wolman, 2001), then the channel will become more stable but there should not be a long term adjustment in the channel geometry. If the bank lowering goes below the natural elevation of the floodplain, there should be a reduction in the depth of the adjacent channel by aggradation, which will also make the channel more stable. Lowering the terrace for just cottonwoods would most likely lead to the former result, while lowering the terrace for willows would most likely lead to the latter result.

Creating high flow channels in the floodplain will create a parallel flow channel with its own cross sectional area and wetted perimeter. This too will alter the flow stage for any flow event entering the side channel. If the channel entrance is above the natural elevation of the floodplain, it will help stabilize the main channel. If the channel entrance is below the elevation of the natural floodplain, it can lead to a reduction in the depth of the adjacent main channel bed by aggradation that also helps to stabilize the main channel. Creating a side channel for just cottonwoods would most likely lead to the former result, while creating a channel for willows would most likely lead to the latter result.

Both terrace lowering and high flow channels will lower channel velocities and shear stress for those flows that enter these features. For features that divert flow below the elevation of the natural floodplain, the reduced flow in the original channel will cause sediments to initially drop to the bed and slowly aggrade the channel until equilibrium is reestablished. This will reduce the height of the channel banks, which will increase their slope stability. A combination of more stabile slopes and lower erosion rates could lead to revegetation and sediment depositing against these banks. Such bank redevelopment would slightly deepen the adjacent channel until a new equilibrium is established. The general consequences of these adjustments would make these banks less prone to migrate which would increase the lateral stability of the channel. However the created high flow channels could be deliberately designed to migrate such that disturbed conditions appropriate for willow or cottonwood establishment could be provided over time. As long as the cross sectional area of their entrances can be controlled, these high flow channels will not be prone to avulsions.

The prime seedling establishment seasons are the wet spring and the North American monsoon. Consequently the flows generated by HEC-EFM modeling mirror the conditions of these two wet seasons. However the long flow releases associated with irrigation and municipal supply will drown these seedlings; consequently HEC-EFM modeling inherently avoids these flows. As a result, the proposed ecosystem restoration measures will capture the peaks of freshets for the purpose of regenerating the natural bosque habitat. These peaks will soak into the floodplain and raise the water table. Storing water in a water table will reduce evaporation losses and make this water available for stream flow during the dry season. A higher water table will preferentially support native bosque habitat. The transpiration losses of the riparian habitat will essentially be the same, whether the habitat is native species or invasive exotics.

8.2.2 Uncertainty for Determining Flow-Stage Relationships for Ecosystem Measures

To provide insights into the uncertainties associated with the proposed measures, sensitivity analyses of selected area were completed for low flows at Embudo and for high flows at Española. The measured low flows and associated stages for the USGS Embudo gage site are shown in Figure 15.

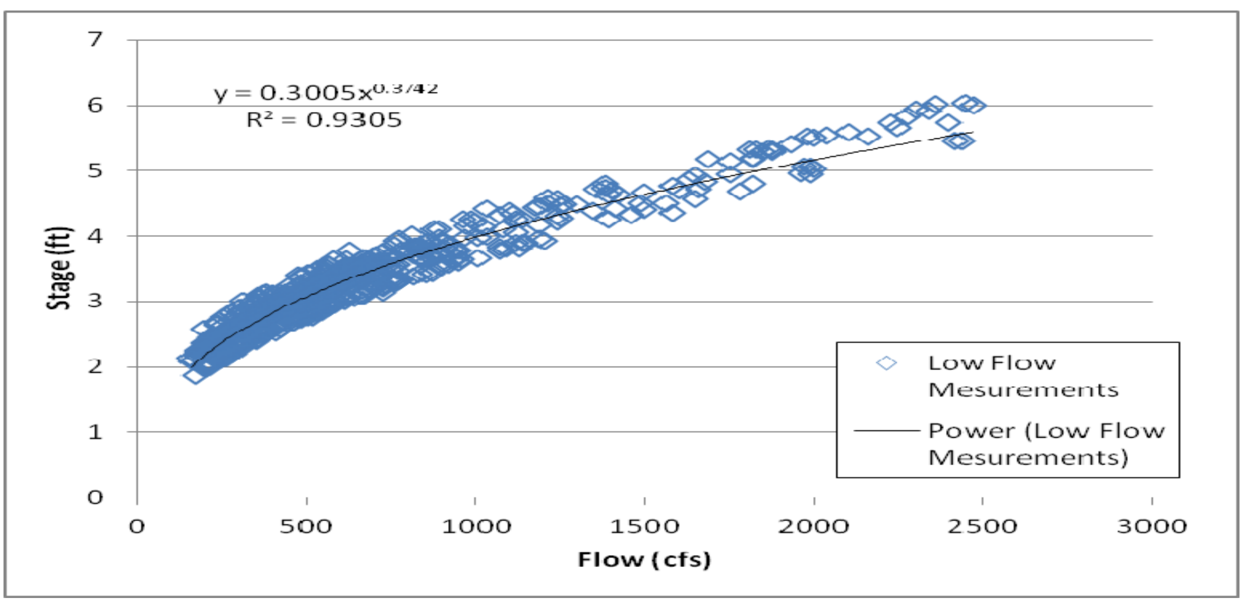

Figure 15 Sensitivity Analysis of Embudo Gage for Low Flow verses Stage.

The purpose of this flow-stage analysis was to determine the natural variability for flows below 2500 cfs on the Rio Grande such that the uncertainty with design elevation could be quantified. The fitted power function was then evaluated with the actual measurements with a resulting standard deviation of 0.2 feet. There is approximately 0.8-foot of natural stage variability associated with any flow chosen for ecosystem restoration. This natural variability will also affect the design of GRFs. However for these facilities, this variability only effects the downriver transitions and not the crests of these structures.

For final design, all of the USGS gages in the project areas will undergo a more detailed analysis of flow-state uncertainty. Combining this analysis with more detailed channel geometry surveys will improve the long-term functionality of the proposed ecosystem measures. In urban areas the concern is that the ecosystem restoration measures could affect flood stages which could be difficult to model. An analysis of the sensitivity of roughness factors was conducted by Mussetter Engineering Incorporated in the reach of the Rio Grande that passes the City of Española. This analysis considered breaching several spoil piles adjacent to the Rio Grande which would approximate the proposed ecosystem restoration measures.

A sensitivity analysis of the hydraulic roughness coefficients (Manning's *n*-values) was carried out to determine the effects of using altered *n*-values on the computed stage. This analysis was carried out as follows:

- A with-breach conditions hydraulic model with reduced (low-estimate) *n*-values was developed by lowering the best-estimate *n*-values by 0.005 in the main channel and by 0.010 in the overbanks.
- A separate with-breach conditions hydraulic model with high-estimate *n*-values was developed by increasing the best-estimate *n*-values by 0.005 in the main channel and by 0.010 in the overbanks.
- The models were executed for only the 1% ACE steady-state peak flow event.
- The computed water-surface elevations were compared to determine the effects of the adjusted *n*-values.

For purposes of the analysis, the *n*-value adjustments were made throughout the entire Rio Grande model, under the assumption that uncertainty in the *n*-values would affect the entire reach rather than only the portion through Española, and the modified values in downstream portions of the model could affect the computed stages in the Española reach. A summary of the best-estimate and modified *n*-values is provided in Table 13**.**

Table 13 Sensitivity Analysis of Roughness Factors near the City of Española

Summary of best-estimate, low-estimate, and high-estimate *n*-values used in the hydraulic model of the Rio Grande.				
Location	Ground Cover Description	Best-Estimate *n*-value	Low-Estimate *n*-value	High-Estimate *n*-value
Main Channel	Channel Bed	0.038	0.033	0.043
Overbank	Channel outside of main channel with no vegetation	0.038	0.033	0.043
Overbank	Very sparse vegetation with minimal topographic irregularities	0.045	0.035	0.055
Overbank	Sparse vegetation with minimal topographic irregularities	0.050	0.040	0.060
Overbank	Sparse vegetation with moderate topographic irregularities	0.055	0.045	0.065
Overbank	Moderate brush and woody vegetation with minimal topographic irregularities	0.060	0.050	0.070
Overbank	Moderate brush and woody vegetation with topographic irregularities	0.065	0.055	0.075
Overbank	Mixed moderate/dense brush and woody vegetation with topographic irregularities	0.070	0.060	0.080
Overbank	Dense brush and woody vegetation with minimal topographic irregularities	0.075	0.065	0.085
Overbank	Dense brush and woody vegetation with topographic irregularities	0.080	0.070	0.090
Overbank	Very dense brush and woody vegetation with topographic irregularities	0.090	0.080	0.100
Overbank	Extremely dense brush and woody vegetation with topographic irregularities	0.100	0.090	0.110

Results from the analysis indicate that, as expected, the high-estimate *n*-values increase the computed stage, and the low-estimate *n*-values reduce the computed stage (Figure 16**,** Table 14). The average difference in computed water-surface elevation (compared to that using the best-estimate *n*-values) is about 0.4 feet for both the low- and high-estimate *n*-values, with the largest differences of up to 0.6 feet occurring at locations where downstream backwater effects are least significant (Figure 17, Table 14). Conversely, locations with significant downstream backwater effects show the smallest differences in computed stage. Because the water-surface elevations are significantly different using the adjusted *n*-values, the total top width is also significantly different (Figure 18, Table 14). Using the low-estimate *n*-values would result in an average reduction in top width of about 140 feet, with localized reductions of up to 500 feet downstream from Fairview Lane Bridge and between the U.S. Highway 285 and Española Bridges. If the high-estimate *n*-values were used, the average top width would increase by about 120 feet, with a maximum increase of about 500 feet downstream from Fairview Lane Bridge.

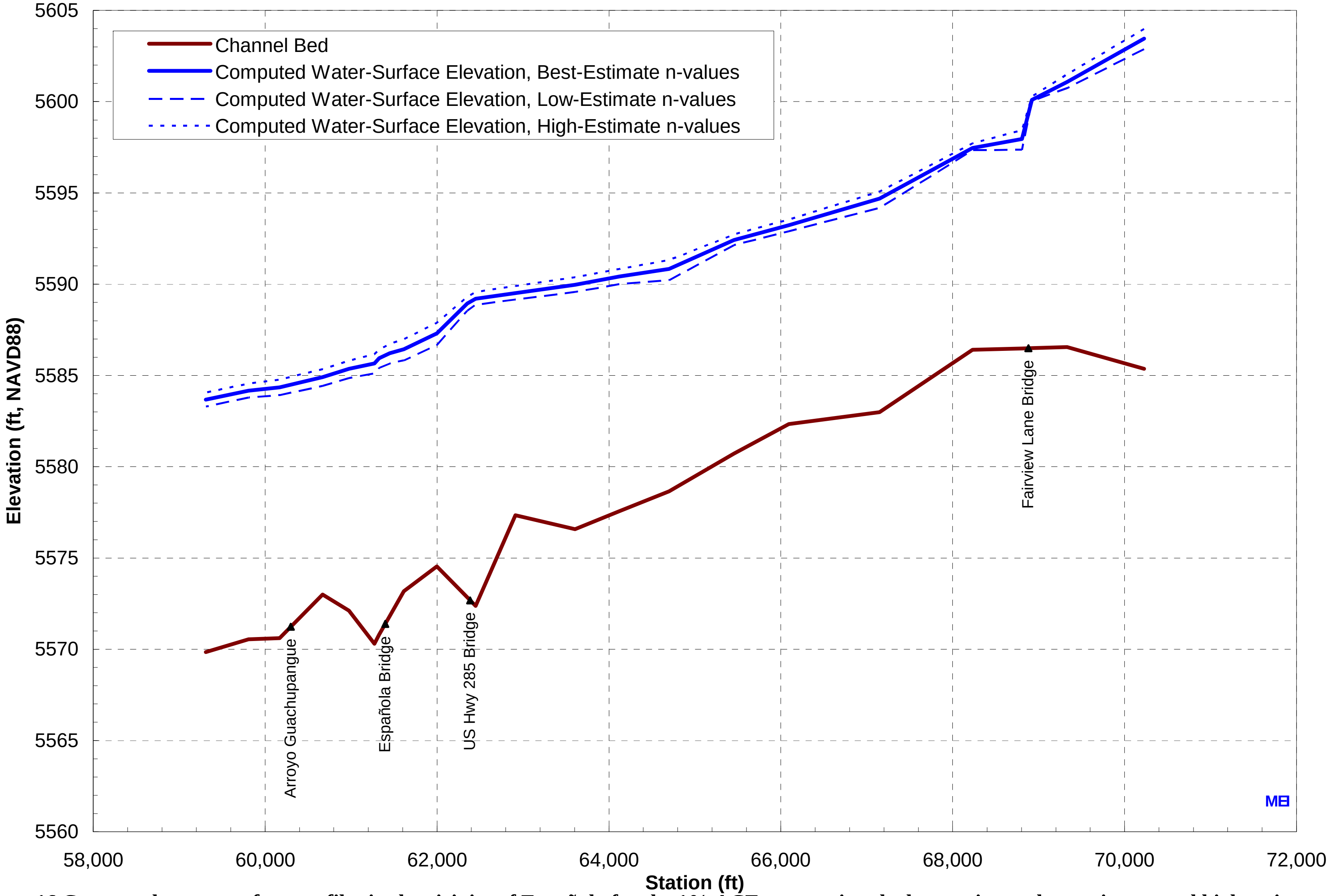

Figure 16 Computed water-surface profiles in the vicinity of Española for the 1% ACE event using the best-estimate, low-estimate, and high-estimate n-values.

Table 14 Summary of computed model results of 1% ACE event for the Manning's n-value sensitivity analysis.

River Station (ft)	Channel Bed Elevation (ft)	Water-Surface Elevation (ft)			Main Channel Velocity (ft/s)			Main Channel Hydraulic Depth (ft)			Total Top Width (ft)		
		Best Estimate *n*-value	Low Estimate *n*-value	High Estimate *n*-value	Best Estimate *n*-value	Low Estimate *n*-value	High Estimate *n*-value	Best Estimate *n*-value	Low Estimate *n*-value	High Estimate *n*-value	Best Estimate *n*-value	Low Estimate *n*-value	High Estimate *n*-value
70225	5585.4	5603.5	5602.9	5604.0	7.0	7.8	6.4	13.6	13.2	14.1	2510	2310	2660
69330	5586.6	5601.1	5600.7	5601.5	10.1	10.4	9.7	12.8	12.4	13.2	3240	2970	3510
68921	5586.5	5600.1	5600.0	5600.3	10.0	9.9	9.8	11.7	11.6	11.9	870	840	950
68807	5586.5	5598.0	5597.4	5598.4	12.8	13.9	12.0	8.2	7.6	8.7	630	550	690
68233	5586.4	5597.5	5597.4	5597.7	5.8	5.9	5.3	9.2	9.1	9.5	3700	3650	3860
67150	5583.0	5594.7	5594.2	5595.1	8.2	10.0	7.2	9.3	8.8	9.7	2970	2470	3470
66092	5582.3	5593.2	5592.9	5593.5	5.1	5.7	4.7	8.9	8.6	9.2	4450	4320	4670
65454	5580.7	5592.4	5592.2	5592.7	5.9	6.4	5.4	8.6	8.3	8.9	4450	4300	4540
64701	5578.7	5590.8	5590.2	5591.3	7.8	9.5	6.8	10.5	9.9	11.0	2850	2490	2990
64122	5577.6	5590.4	5590.0	5590.8	4.6	5.1	4.1	11.2	10.8	11.6	3820	3760	3920
63607	5576.6	5590.0	5589.6	5590.4	3.5	4.0	3.1	8.8	8.4	9.1	3700	3660	3790
62912	5577.4	5589.5	5589.2	5589.9	3.7	3.9	3.4	10.6	10.3	11.0	3630	3570	3670
62449	5572.4	5589.2	5588.9	5589.6	3.8	4.0	3.6	10.6	10.2	11.0	2430	2390	2460
62351	5572.8	5588.9	5588.6	5589.3	4.9	5.3	4.5	10.7	10.3	11.1	2270	2240	2310
61998	5574.5	5587.3	5586.7	5587.9	9.8	10.8	9.0	11.1	10.4	11.6	2980	2440	3210
61615	5573.2	5586.4	5585.8	5587.0	8.2	9.1	7.5	9.3	8.7	9.9	2690	2520	2800
61450	5571.8	5586.2	5585.7	5586.7	6.8	7.4	6.3	9.6	9.1	10.2	880	870	1030
61326	5570.8	5585.9	5585.4	5586.4	6.5	6.9	6.1	9.8	9.3	10.3	1380	1260	1490
61272	5570.3	5585.7	5585.1	5586.2	7.2	7.8	6.8	9.8	9.2	10.3	1520	1380	1640
60977	5572.1	5585.4	5584.9	5585.8	5.4	6.0	4.9	8.3	7.8	8.8	1790	1730	1840
60670	5573.0	5584.9	5584.4	5585.4	5.3	5.8	4.8	8.8	8.4	9.3	1950	1800	2000
60169	5570.6	5584.4	5583.9	5584.8	5.6	6.1	5.1	11.3	10.9	11.8	2350	2300	2380
59806	5570.6	5584.2	5583.8	5584.6	4.4	4.7	4.1	11.8	11.4	12.2	2370	2360	2410
59310	5569.8	5583.7	5583.3	5584.1	4.9	5.3	4.5	12.3	12.0	12.7	2490	2390	2580

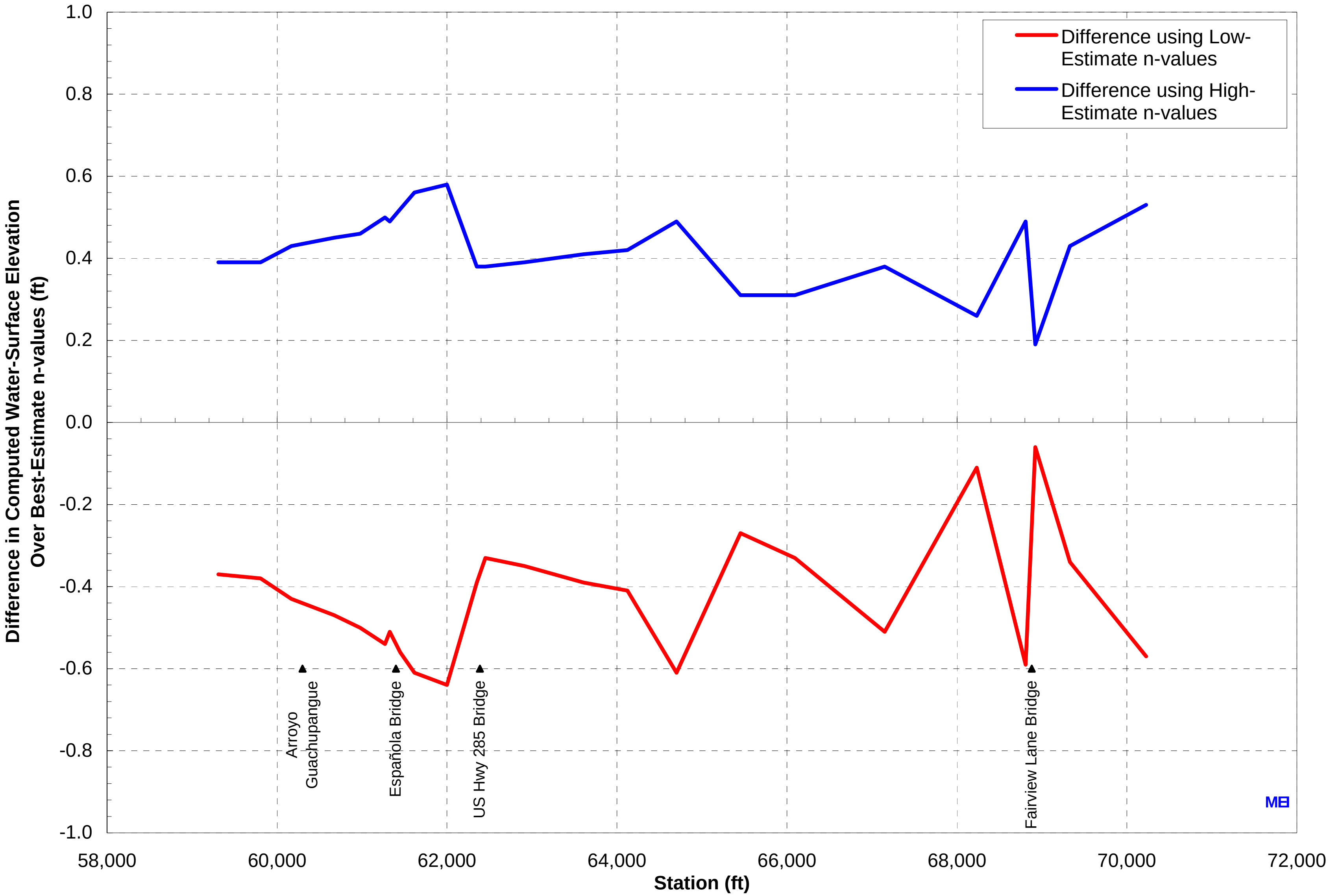

Figure 17 Computed difference in water-surface elevation for the 1% ACE event using the low-estimate and high-estimate n-values compared to the water-surface elevation using the best-estimate n-values.

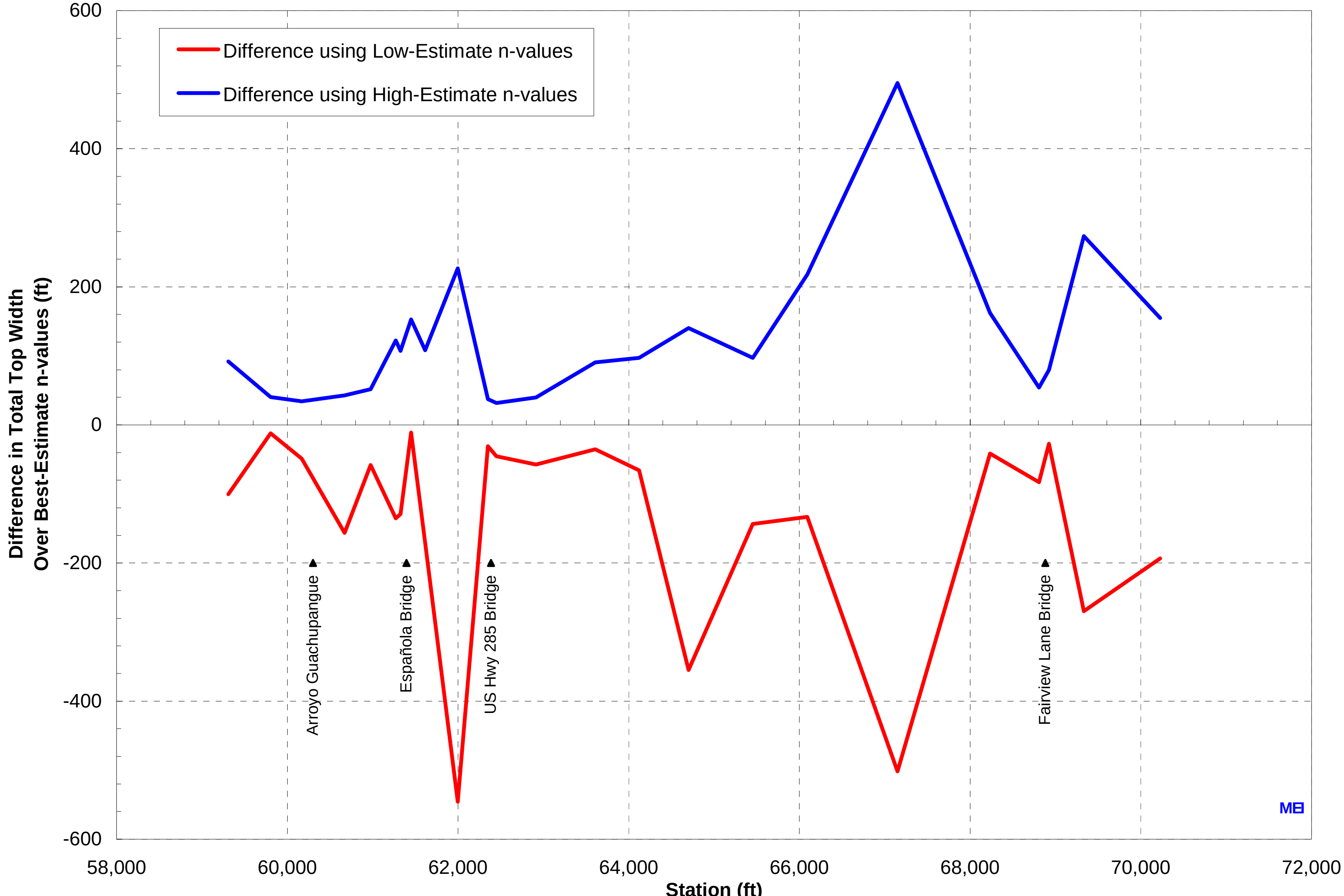

Figure 18 Computed difference in total top width for the 1% ACE event using the low-estimate and high-estimate n-values compared to the water-surface elevation using the best-estimate n-values.

8.2.3 Future Modeling of Ecosystem Restoration Measures

All of the proposed measures were assessed independently, unless there was a very define co-dependency. These independent assessments were necessary for the economic analysis and cost estimates. Many of the proposed ecosystem restoration measures are in close proximity to potential Grade Restoration Facilities (GRF) measures that are discussed in the next section. Should these GRFs not be built, several of the proposed ecosystem restoration measures may not be physically feasible, others may not be economically feasible, and the benefits of the remaining nearby measures may be reduced. Consequently, those GRFs that are retained will have to be hydraulically modeled based on future surveys, then utilizing a valid sediment transport model (HEC-RAS version 5.0 or later) the future equilibrium condition of the Rio Grande and/or Rio Chama channel profiles determined. Based on the immediate and future equilibrium condition of the river channels, then the entrance condition hydrology of the terrace lowering and high flow channels can be determined. A sensitivity analysis similar to the previous section can be repeated for the affected reaches (projected to be automated in HEC-RAS version 5.1) and a flow variation of the relevant USGS river gages repeated such that those measures affected by GRFs can be properly designed.

8.3 Grade Restoration Facilities

Grade restoration facilities (GRFs) are intended to reduce the gradient of the river channel in the upstream directions for two purposes. First, GRFs are being used to halt the migration of head cuts that are threatening the upstream channel on both the Rio Chama and Rio Grande as shown on Figure 1. On Figure 19 the mining activity site is shown in yellow. Over time these head cuts have moved up river with the current location of activity shown in red. Below the active headcuts the channel is expected to slowly aggrade in the reach shown in green. The Rio Chama from San Jose to Hernandez is slowly degrading in the reach shown in pink and could significantly collapse if the active headcut enter this tributary. This ongoing degrading condition is stopped at an irrigation dam near Hernandez where some upriver aggregation is shown in green on Figure 19.

On Figure 19 the Rio Grande from San Juan to Alcalde has another reach (also shown in pink) were slow degradation is occurring that could be accelerated if the active headcuts get past the confluence with the Rio Chama. This upstream migration could extend up to another irrigation dam near Alcalde. Halting the upriver migration of headcuts is accomplished by replacing the hydraulic drop that is associated with these head cuts with a series of stable structures of equal or greater hydraulic drop. If the stable structures have a higher hydraulic drop, then some degree of restoration of previous channel incision is possible.

Second, GRFs are used to mitigate for the adverse results associated with channel incision. This is accomplished by using a stable structure to raise the hydraulic grade line of the upstream channel until normal riparian function can be restored to the adjacent floodplain (Hogan, Peterson, Smith, & Valentine, 2000). The proposed locations of the GRFs are shown in Appendix J, Exhibit A. General sections of these GRFs are shown on Sheets 17 and 18 in Appendix J, Exhibit A. The rationale for locating and designing these structures follows.

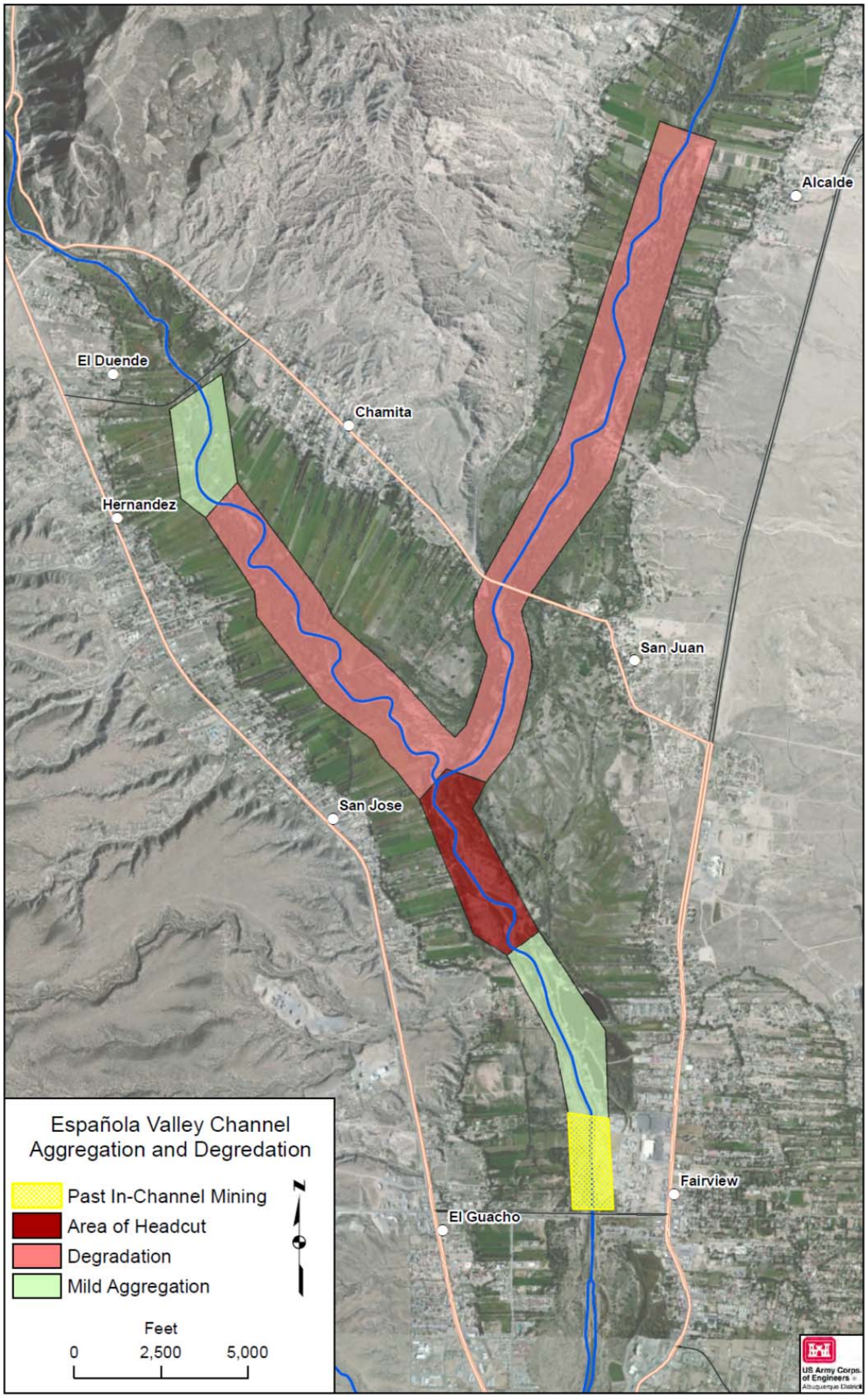

Figure 19 Ongoing channel changes near the confluence of the Rio Grande and Rio Chama.

8.3.1 Locating Structures

While the theory of grade control structures always begins with viewing the channel in profile to illustrate the location of these structures (U.S. Army Corps of Engineers, 2001); in practice it is best to start by locating suitable GRF sites on maps. GRFs for these optimal locations are then designed to maximize their potential to solve the problem at hand, before suboptimal locations are considered.

The optimal GRF placement is at the downstream end of a bend that has a long straight downstream reach. Natural alluvial channels to some degree are formed with a series of bends. In this series of bends a sequence of bedforms develops that produce features call riffles, runs, pools and glides. For a natural alluvial channel to be stabile, the pools need to be in bends and the riffles need to be in the transitions between bends. If riffles are found in bends and pools are found on straight reaches, then the channel is out-of-phase and unstable. By locating GRFs at the end of bends, this will deepen and enhance the function of the pool, while placing in-phase a hydraulic drop structure where a riffle should be.

Because a GRF has a significant hydraulic drop, this drop typically generates a great amount of local turbulence. The GRF needs to center this turbulence and send it downstream in the middle of the channel to avoid erosion of the channel banks. This alignment will allow the generated turbulence to dissipate primarily through water-on-water turbulent friction. It is important to avoid allowing this turbulence to dissipate on a channel bank, because an eroded downstream channel bank can lead to the collapse of the GRF's side slopes and cause a flanking failure of the GRF.

This GRF location strategy is called "working with the river continuum concept" (Vannote, Minshall, Cummins, Sedell, & Cushing, 1980). This theory includes the idea that rivers in balance will build bedforms in stable locations. By locating engineered structures in these naturally stable locations to enhance natural channel functions, these engineered structures will inherently be more durable and have a longer design life. Based on where GRF would most likely be located, the 2007 color orthophotos, HEC-RAS models, and the 2007 LiDAR topography were examined. The left and right banks were considered separately and the best locations were identified for further screening. The preliminary screening results are found in Attachment 6.

8.3.2 Limitations

Real estate ownership is the primary consideration for changing the location for a GRF. If a viable alternative location is available without a real estate issue, then the structure site should be moved.

8.3.3 Profile Slope Concerns

In general, GRFs with a high hydraulic drop will be harder to site and still be stable. Therefore a series of smaller structures with lower hydraulic drops is generally recommended (U.S. Army Corps of Engineers, 2001), which individually will be more stable. These structures will have a design slope, which not only must overcome the vertical problem of the system, but must also chase grade up the channel. So the length of the structure is attributed to both the vertical problem and chasing grade. Steepening the design slope will reduce the structure length, but at the same time make the structure harder to stabilize. Steeper structures may be shorter, but the consequences are that the riprap size used to build these structures must be larger, and the thickness of this rock placement will greater.

The confluence of the Rio Chama and Rio Grande is presented in Figure 20 where the Rio Chama approaching from the left is noticeably steeper than the Rio Grande that transitions the figure from right to left. Between Profile stations 65,000 and 80,000 there is a dip in the Rio Grande profile that resulted from mining activity that ended in the 1980s. The first head cut went as far as Profile station 84,000 before the USBR arrested its progress with a grade control structure as indicated on Figure 20. Two more head cuts are found below the confluence where the two middle GRFs are located. The two GRFs above the confluence are both for water diversions.

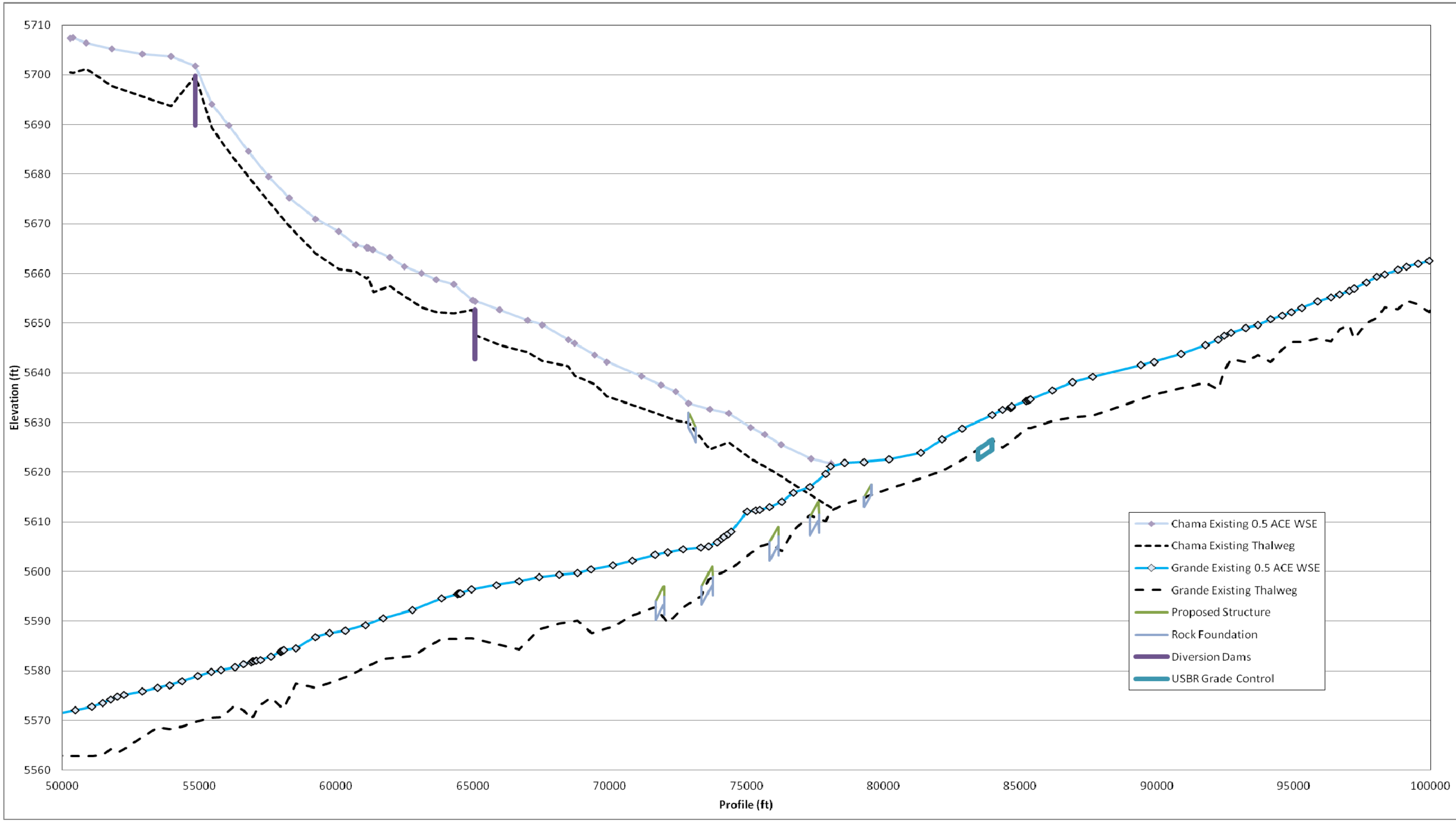

Figure 20 Profile of the confluence of the Rio Grande and Rio Chama.

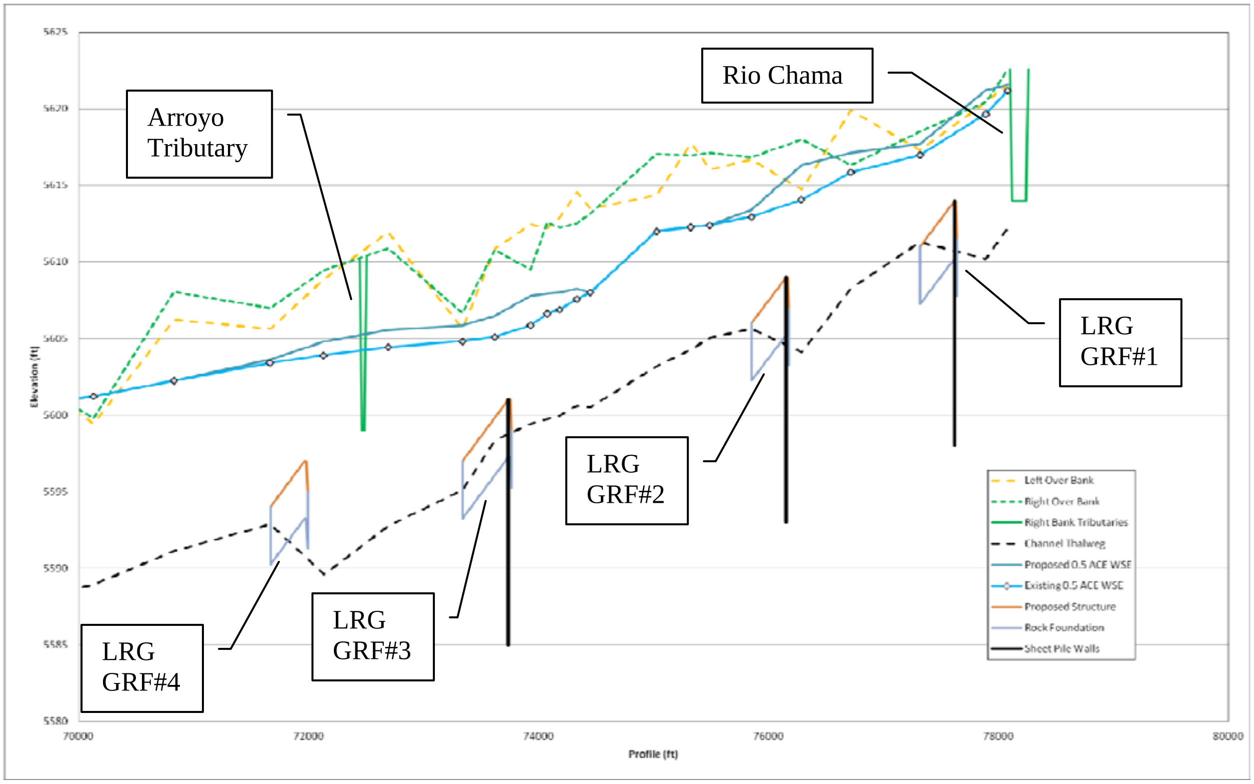

Figure 21 Profile of a series of GRFs on the Rio Grande.

A closer presentation of the reach with two head cuts is shown on Figure 21. The LRG GRF#4 at station 72,000 has the function of stabilizing the upstream structure and it has a small right bank arroyo tributary just upstream that will help feed the aggradation of the channel bed. The LRG GRF#3 at station 74,000 is located on top of a head cut and LRG GRF#2 at station 76,000 is located just below a head cut. LRG GRF#1 has the function of re-stabilizing the confluence at station 78,000. The left and right banks are indicated with dash lines and the 50% ACE water surface elevations indicated over 5 feet of incision along this reach. The success of this GRF strategy is to provide a stable increase in this 50% ACE WSE such that the 50% ACE WSE rises to the bank height at the confluence with the Rio Chama. On this profile both the location of sheet pile walls and the thicknesses of the GRFs are indicated.

In general, it is strongly recommended that a minimum thickness of the riprap be 15-inches to properly withstand debris impacts (U.S. Army Corps of Engineers, 1994). This means that the minimum design slope should be one that produces a 15-inch thick bed. However in the end, the design slope may not be dependent on structure stability but on environmental concerns.

8.3.4 Environmental Limitations for GRF Design Slope

River channel are habitats for mobile species that have limitations in their ability to swim fast, an associated endurance at this swimming speed, and their need for sufficient swimming depth. In general, large fish need deeper water to swim in and small fish have lower swimming speeds (Katopodis, 1996). Given these two constraints, it is difficult to steepen a GRF while maintaining both optimal depth and flow velocities. For a prismatic, trapezoidal channel these environmental concerns produces both a low design slope and a limiting length of the GRF.

A more practical approach is to have a “V” shape on the bottom of the channel to concentrate flow in mid channel and provide better depth for large fish. Simply using larger rock sizes will increase channel roughness and reduce flow velocities. However for the purpose of remediating active head cuts on a steep gradient, even a prismatic V channel made of large rocks may not provide a practical solution.

It is an observed phenomenon that a placed riprap bed will sort to a degree when large flows are re-introduced. Small rocks that by happenstance are on the surface will saltate (skip) off the structure and larger rocks that happen to be precariously balanced will flip over to a stable position usually against a nearby rock. On structures steeper than 2% in gradient, the large rocks once moved have a tendency to migrate to the bottom of structures (Solari & Parker, 2000) as noticeable in Figure 22. This sorting will produce a bed that is both better for fish passage and overall stability; however this sorted bed is hard to predict for the purpose of design. It is therefore practical to deliberately design a field of boulder clusters in a checkerboard pattern that will be highly exposed to flow in the overall placed riprap bed. (Acharya, Kells & Katopodis, 2000)

The GRFs on the Rio Grande including those shown on Figure 21 are all designed to a gradient of 1.0%. The GRF on the Rio Chama is designed to a gradient of 1.2%.

Figure 22 Sorting of trapezoidal riprap channels into rock clasts (Source: Alan Schlindwein).

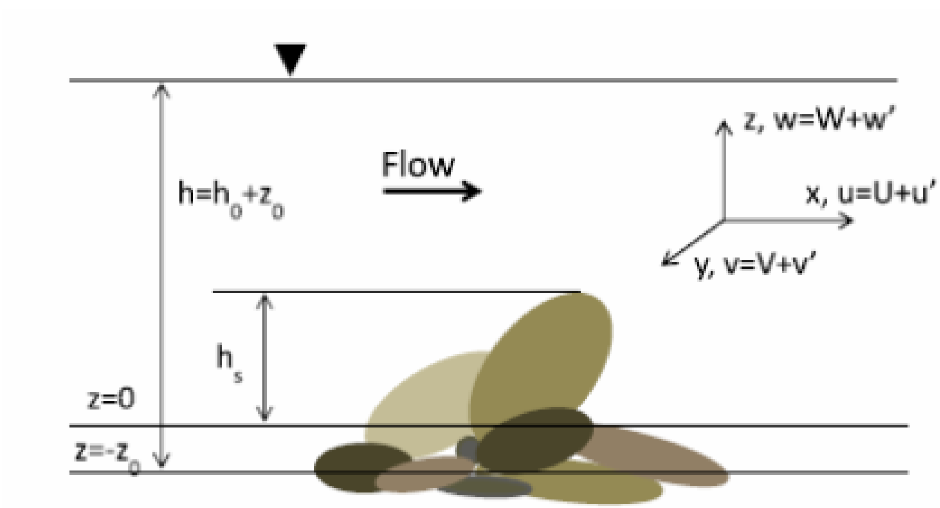

Figure 23 Schematic of a naturally forming rock clast structure (Tan & Curran, 2012).

A natural rock clast structure can be visualized in Figure 23 along with depth relationships and the definitions for turbulence analysis. The characterization of natural rock clast formations, including the turbulence associated with flows over these formations, and the effects of this turbulence on sediment transport has been studied in rivers (Buffin-Belanger & Roy, 1998; Lamarre & Roy, 2005; Lacey & Roy, 2008) and in laboratory flumes (Papanicolaou, Dermisis, & Elhakeem, 2011; Bertin & Friedrich, 2014; Curran & Tan, 2014). The generation of turbulence by these rock clasts does not destabilize natural channel beds (Oldmeadow & Church, 2006) primarily because these rock clasts shift the channel's turbulence off of the bed and into the water column as shown in Figure 24.

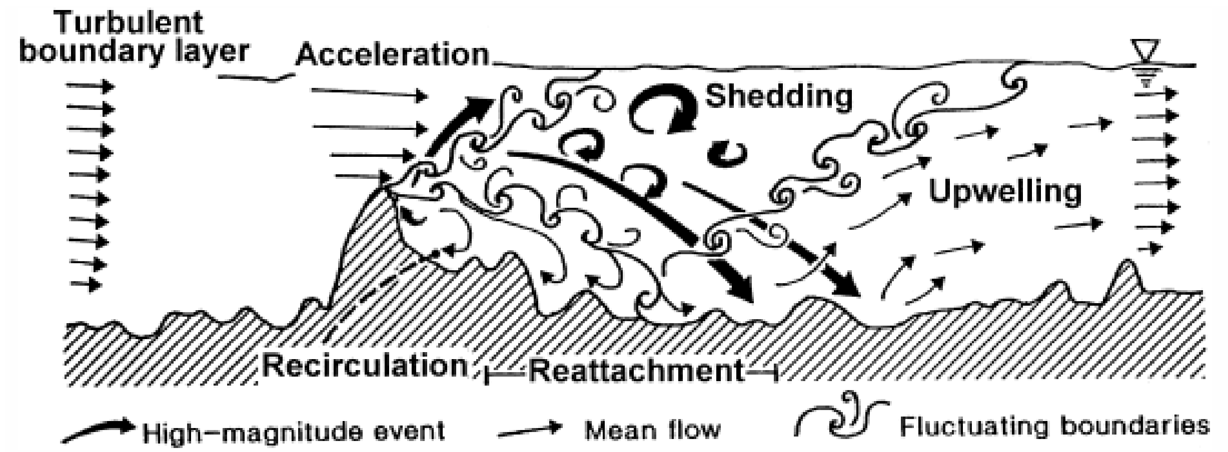

Figure 24 Shedding of vortices and turbulence into the water column (Lacey & Roy, 2008).

8.3.5 Rock Clast Based GRF Design

Many steep channels in mountainous regions are fish passable because they are strewn with large exposed boulders. Research at MIT (Liao, Beal, Lauder, & Triantafllou, 2003) found a swimming gait that fish use to negotiate the turbulent vortices that shed from exposed boulders. The results of this analysis, indicating the upstream thrust component that allows fish to coast up to the next boulder, is shown on Figure 25 with a purple arrow.

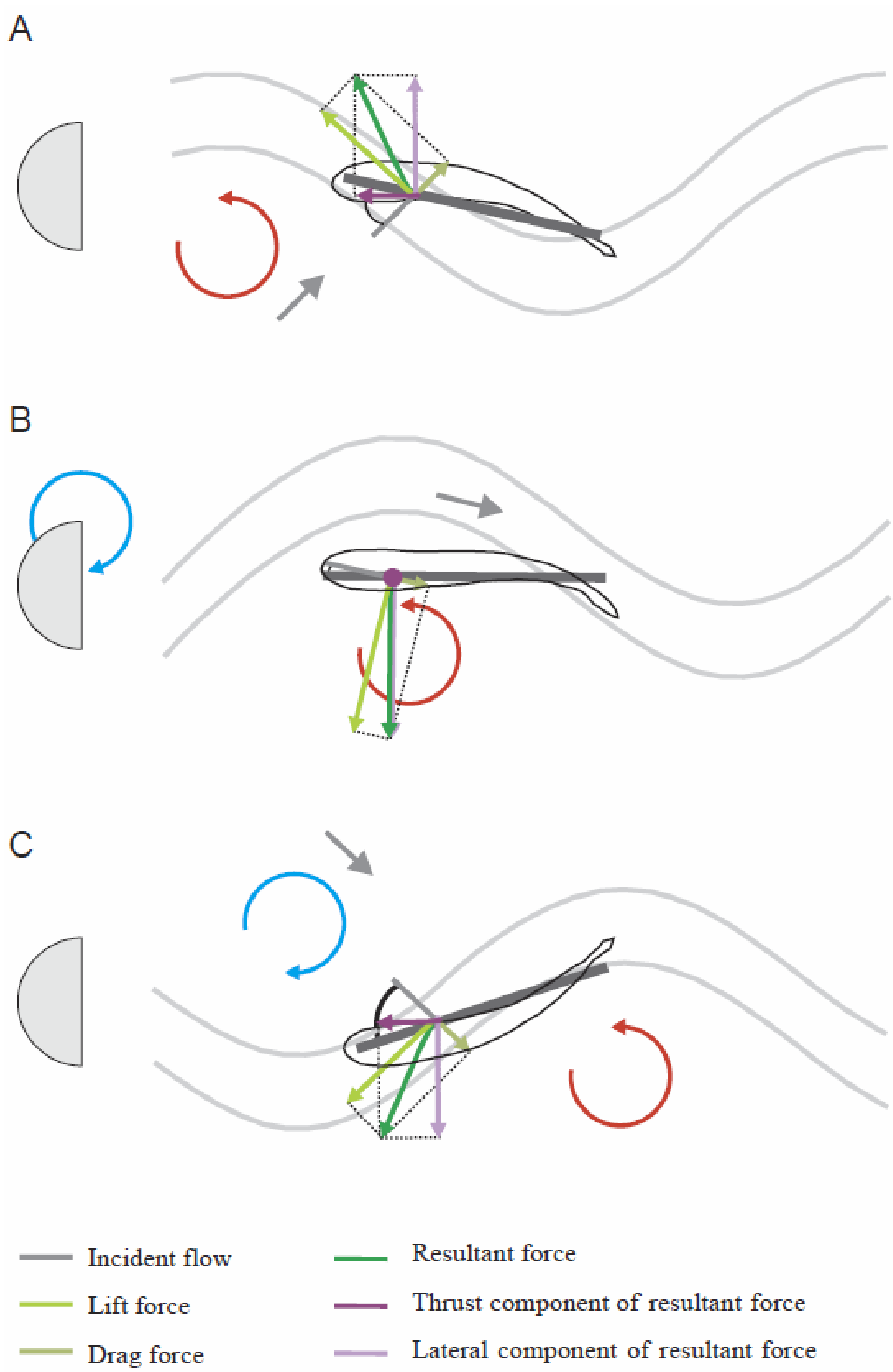

Figure 25 Von Karman gait of fish in repeating turbulent vortices showing upstream resultant force.

It was noticed that there are three locations around an exposed boulder that fish can rest at before moving further upstream. The first recommendations for how to use these boulder fields for habitat structures was based how fish moved from these rest locations to the next upstream boulder cluster.

When boulder fields are used for habitat, the recommended spacing is 4 times the exposed boulder cluster size laterally and 6 times the cluster size longitudinally (Shamloo, Rajaratnam, & Katopodis, 2001). The boulder clusters should not be placed longitudinally in-line, but each row of boulders should be placed in a checkerboard pattern. With this pattern the fish can swim up the edge of the flow separation below a boulder and find a resting spot. When rested, the fish can use the burst speed gait to dart across the high velocity shock wave around the upstream face of the boulder, and into the wake of the next upstream boulder. By using boulder fields, the endurance limitations of fish swimming gaits become a mute point, so these rock clast based GRF structures can have any length.

These exposed boulder clusters will directly increase the depth of flow by constriction. When these boulders are submerged, they will also reduce average velocity and increase flow depth by increasing the roughness of the channel bottom. The Strickler Equation (U.S. Army Corps of Engineers, 1994) is used to calculate the "***n***" resistance coefficient:

$$\boldsymbol{n = K(D_{90})^{1/6}} \qquad \textbf{Equation 1}$$

The $\boldsymbol{D_{90}}$ term is the dimension of the bed particle where 90% of the bed is finer by weight. For a rock clast-based GRF this effectively becomes the average diameter of the boulders in these clusters. This assumption is support by the natural stabilizing effects of clasts in rivers (Oldmeadow & Church, 2006). The **K** term is used two ways. First for the sizing of the rocks in the riprap channel bed, K= 0.034, which produces higher velocities. Second for channel flow capacity and flow depths, K=0.038, which produces lower velocities and deeper depth (U.S. Army Corps of Engineers, 1994).

This roughness coefficient and the proposed geometry of the GRFs were entered into HEC-RAS version 4.1, and modeled across a wide range of flows. For each modeled flow, the velocity $\boldsymbol{V}$ (ft/s) and water depth $\boldsymbol{d}$ (ft) were extracted for analysis using Equation 2 (Maynord, 1993; U.S. Army Corps of Engineers, 1994) to calculate the design rock size, repeated below:

$$\boldsymbol{D_{30} = S_f C_s C_V C_T d \left[\frac{V}{\sqrt{\left(\frac{\gamma_s}{\gamma_w} - 1\right) K_1 g d}} \right]^{2.5}} \qquad \textbf{Equation 2}$$

The $\boldsymbol{D_{30}}$ term is the dimension of the bed particle where 30% of the bed is finer by weight. So this equation is concerned about losing small rock from a riprap bed that would progressively lead to the unraveling of the entire structure.

$\boldsymbol{S_f}$ = safety factor with a minimum of 1.1 (1.3 was used to account for the limitations of a 1-D model)
$\boldsymbol{C_s}$ = stability coefficient for incipient failure (0.30 used for angular rock)
$\boldsymbol{C_v}$ = vertical velocity distribution coefficient (1.0 used because the structures are in a straight reach of the channel)
$\boldsymbol{C_T}$ = thickness coefficient (1.0 use because the channel bed thickness will equal the $\boldsymbol{D_{100}}$)
$\boldsymbol{\gamma_s}$ = density of the stone (165 pcf assumed for design, with 155 pcf sensitivity tested)
$\boldsymbol{\gamma_w}$ = density of water (62.4 pcf)
$\boldsymbol{g}$ = gravitational constant (32.2 ft/s/s)

K_1 = side slope correction factor, calculated with following equation (U.S. Army Corps of Engineers, 1994):

$$K_1 = \sqrt{1 - \frac{\sin^2\theta}{\sin^2\phi}}$$ **Equation 3**

θ = angle of the side slope with horizontal
ϕ = angle of repose of riprap material (40 degrees)

Equation 3, shown above, was considered for side slopes ranging from 2:1 to 5:1 (h:v) and it was found that 2:1 slope require approximately 50% larger rock, 3:1 approximately 20%, 4:1 approximately 10% and that 5:1 was only 8% due to diminishing benefits. When plotted as a blue line on Figure 26, there is an inflection point between 3:1 (33%) and 4:1 (25%), therefore the 4:1 side slope was selected. This selected side slope is practical because the Rio Grande and Rio Chama are naturally wide and shallow. Also shown on Figure 26 are the slope of the "V" shaped chute bottom (red square) and the angle of repose (green line).

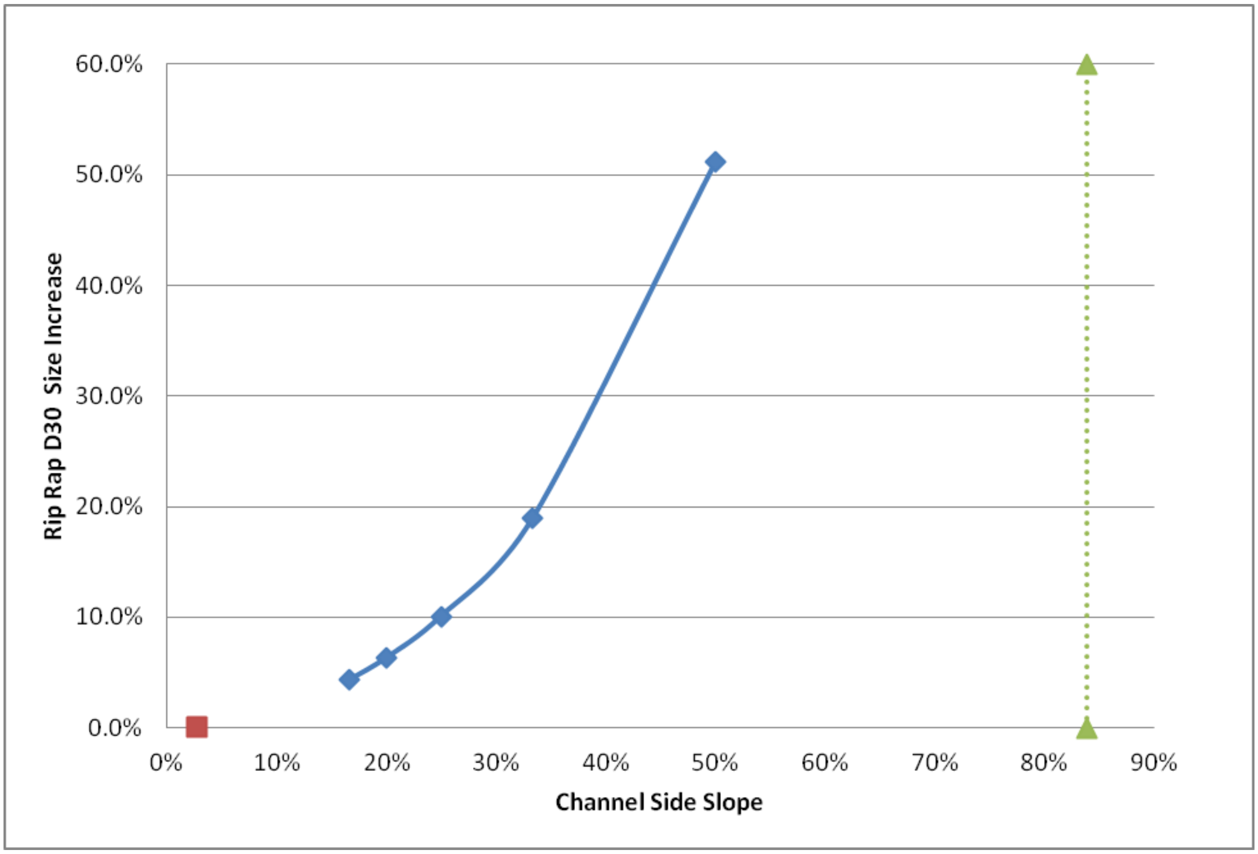

Figure 26 Rip Rap size increase based on side slope. Red for chute bottom, blue for chute side slopes, green indicates the slope for the angle of repose.

Equation 2, shown above, exhibits a relative roughness behavior where velocity is in the numerator and depth is in the denominator. This is significant when there is a strong downstream backwater effect on a GRF structure. These structures can be submerged in the river profile by relatively low flood flows. Therefore, in addition to examining all of the flood flows for the 50% to 0.2% ACE events, a series of flows below the 50% ACE event was examined in HEC-RAS.

Based on the results of Equation 2, the design $D_{30\ (minimum)}$, $D_{90\ (minimum)}$ and the $D_{100\ (maximum)}$ rock classes must be selected using an iterative process until the rock sizing converges on a final geometry and roughness. Then, this information can be used to determine the thickness of the riprap bed. This thickness is used to determine the needed rock quantities for the cost-estimate. The roughness "***n***" values need to be changed one more time by changing the K term in Equation 3 and rerunning the HEC-RAS model to determine the capacity results and official water surface elevations.

Equation 2, shown above, also has a relative density term. As a sensitivity exercise, the density of the rock was changed and the result checked against the standard gradations for different densities (U.S. Army Corps of Engineers, 1994). If the rock size class changed, the new class was not run through HEC-RAS, but the change in quantities was noted for the cost-estimate consideration.

8.3.6 Critical Design Assumptions

HEC-RAS is a gradually-varied-flow computer program that is not automatically suitable for GRF structures that inherently have rapidly varying flow (U.S. Army Corps of Engineers, 2010); therefore, the cross section spacing of the model for the GRF must also have appropriate distances to approximate a gradually-varied-flow condition. When the cross sections in HEC-RAS were spaced 5 feet apart, the model was capable of producing reasonable result for the upstream reach of severe hydraulic drops. The cross sections on the GRF crests were spaced 25 feet apart to accommodate the shallower slopes of the down slope run.

At this stage in the design process, GRF cross sections were estimated based on modeled channel cross sections. Analysis indicates that some GRFs may need to have a sheet pile wall along the structure crest to minimize potential hydraulic pressure-pumping problems. For the GRF structures to be effective, they must hold water on the surface of the structure and prevent water from readily flowing through the voids in the riprap. The void ratio is currently assumed to be 25%. During construction, these voids are intended to be filled hydraulically with sand and pebbles. During normal flow conditions, hydraulic pressure-pumping is possible at locations with large head changes. The highest pumping pressures are found at the crest break. Hydraulic pressure-pumping can loosen the materials in the voids leading to a sapping action through the voids in the upstream direction. This could lead to a large scale evacuation of the voids at the crest of the structures. To prevent this occurrence, a sheet pile wall is proposed across the crests of structures with potential hydraulic pressure-pumping problems.

The crests are also a focal point for debris impacts. To help withstand ice, tree and debris impacts, a sheet pile wall will lend some coherent structural strength to the riprap. And if damaged, the appearance of a sheet pile wall at these crests will be an indication that repairs might be necessary. During repairs, these sheet pile walls can act as templates.

At very specific flow depths, there are some very high local velocities in the immediate vicinity of the exposed boulders in the riprap based chutes (Shamloo, Rajaratnam, & Katopodis, 2001). If not mitigated, a hole is likely to scour next to these exposed boulders in the riprap and eventually the boulders will roll into these scour holes. Local velocity mitigation is provided first by flanking these exposed boulders with foundation stones at the point of highest flow velocities and, second, by choosing a riprap class one size larger than calculated in the above procedure for the bottom of these boulder strewn chutes.

8.3.7 Sequence of Construction for Boulder Fields on GRFs

The goal is to build a checkerboard pattern of boulder clusters similar to Figure 27.

Figure 27 Checkerboard pattern of boulder clusters after a hurricane (Source: Alan Schlindwein).

Figure 27 shows a GRF and the smooth water at the top right is the runout. This GRF, like the six proposed ones in the TSP, has benches on both sides that are blending into the channel cross section in the downstream direction. Because of a gentle "V" shape to the chute bottom, the base flow is concentrated to a reasonable flow depth along the thalweg between the big rocks. The big rocks used at this location are gneiss and the foundation boulders are not observable because they are found in the riprap bed of the GRF chute.

The most stable configuration for a boulder cluster is a four stone cross as shown in the following sequence of placement. Figure 28 through Figure 30 indicate a profile with scales that indicate relative elevation and stationing. Floating above the profile is a plan view of the placed rocks. The shaded solid line rocks are the ones being placed in that step and the dashed black lines are the proposed riprap bed of the chute.

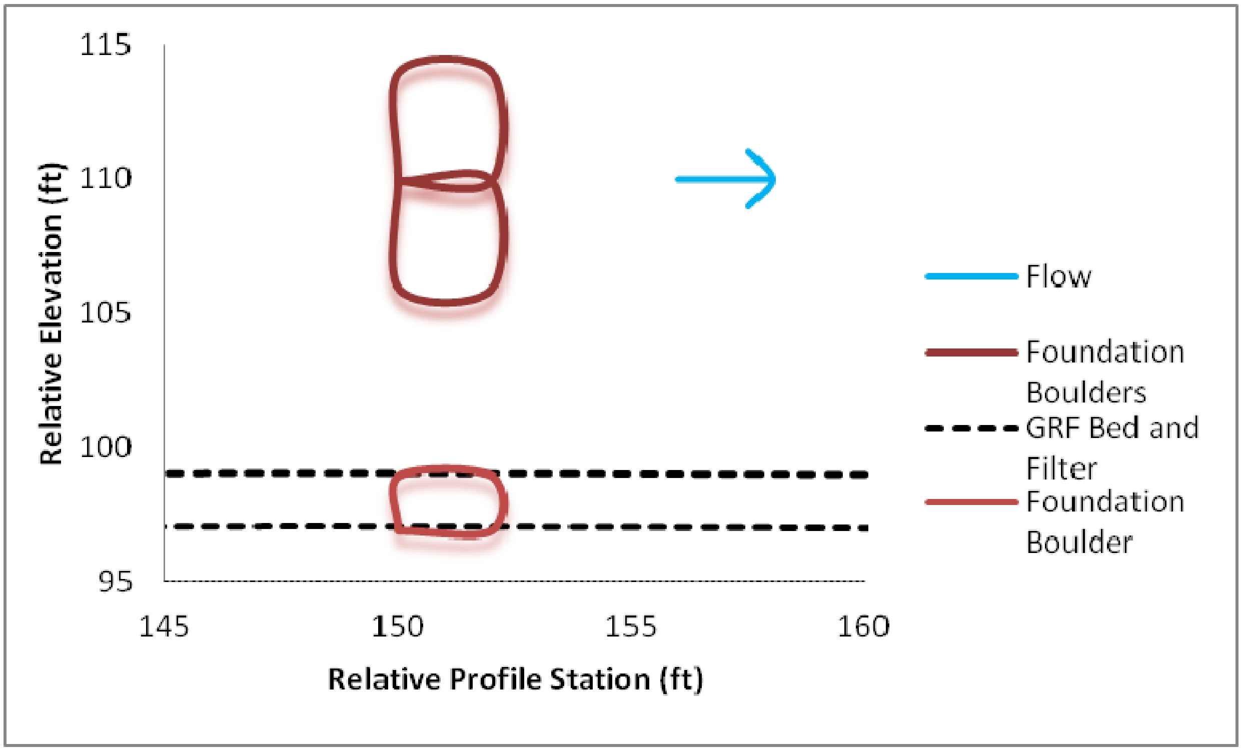

Figure 28 First step in the construction of a boulder cluster: foundation boulders.

Figure 28 indicates that two foundation boulders are first placed end to end perpendicular to the flow direction. The easiest way to approach this is to drive a wood stake at the upstream location of these foundation boulders with a mark indicating the target elevation of these stones.

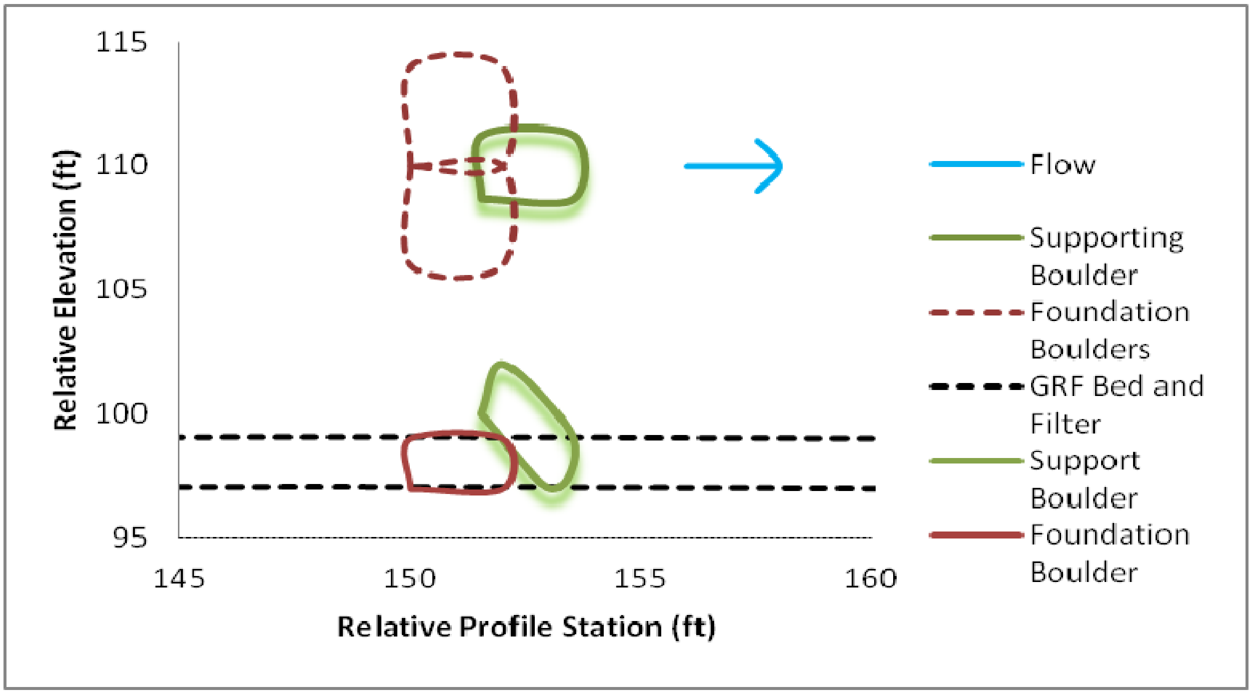

Figure 29 Second step in the construction of a boulder cluster: support boulder.

Figure 29 now shows the foundation stones in plan view with dotted lines. The shaded green support boulder is now placed downstream leaning against the foundation stones. Depending on the shape of the stones being used, filter gravel may be needed under this support boulder so that it will support the final stone placement.

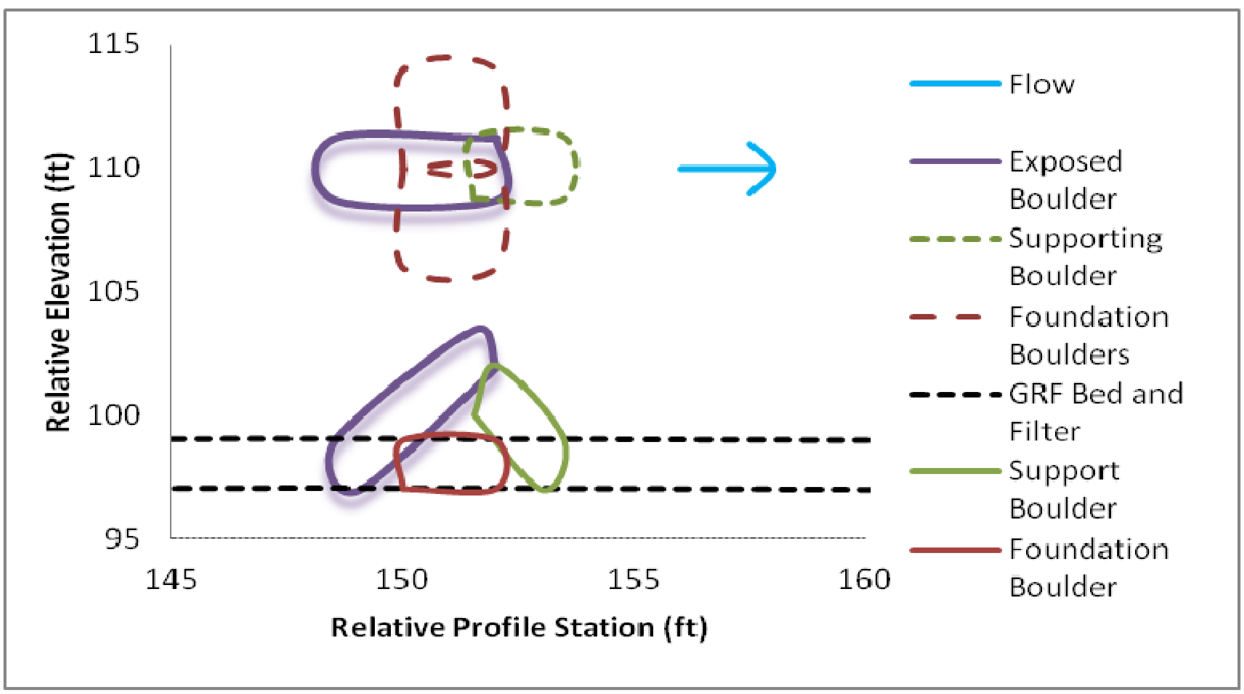

Figure 30 Third step in the construction of a boulder cluster: exposed boulder.

Figure 30 is the final step in building a boulder cluster in the cross configuration. Again based on the shape of the stones being used, gravel filter material may need to be placed such that the exposed boulder can be adequately supported by the three previously placed stones. In general, the exposed boulder should be the largest stone in the cluster. Once this exposed boulder is placed, then the general placement of gravel filter material and riprap can proceed around it.

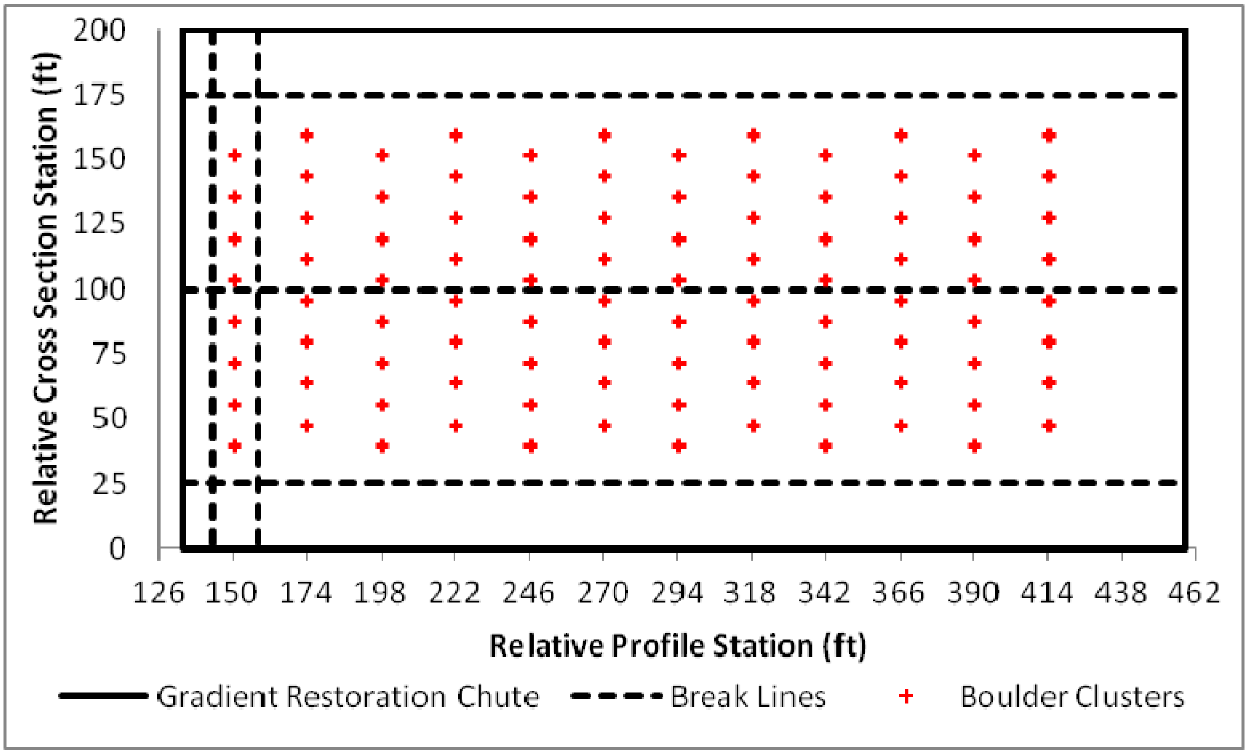

Figure 31 Generalized plan view of GRF chute with stake out locations for the boulder clusters.

Figure 31 is a plan view to show the checkerboard pattern of the boulder clusters on a GRF. At 100 on the vertical scale is a dashed line that indicated the thalweg of the chute. The "V" shape of the chute is between the dashed lines at 25 and 175. The 15 foot wide crest of a typical 300-foot long down slope GRF is shown by two dashed lines at horizontal scale 150. The first row of boulder clusters are shown by red "+" signs that are approximately to scale. Each row of cross configuration boulder clusters are located so that each boulder cluster is exactly at the midpoint of the upstream boulder clusters. A gap is allowed above vertical station 175 and below vertical station 25 so that the turbulence shed by the end boulder clusters does not impinge on the side slopes of the chute. Also, at the runout, the rows of boulders end at horizontal station 414 so that excess turbulence is not shed into the unprotected downstream run.

8.3.8 Sequence of Construction and Construction Quantities for Rio Grande GRFs

This section discusses the sequence of construction and preliminary construction quantity estimates for the Rio Grande GRFs. Most of the rock quantities are directly based on the size of the rock that is hydraulically needed to resist river flows. The hydraulic calculations are based upon 2007 surveys and a 1-D HEC-RAS hydraulic model. The uncertainties associated with the hydraulic modeling are not significant, but will need to be reduced during the final engineering before construction. A more comprehensive survey of the reach with the proposed structures will allow these structures to be better located and the hydraulic model with updated geometry will produce better current condition results. Because of the confluence issues between the Rio Chama and Rio Grande, a 2-D hydraulic model should be used in final design because a more sophisticated hydraulic model will produce more realistic results. Because of the known uncertainties with the current modeling, a larger factor of safety was used for rock sizing.

The hydraulic modeling has one assumption about the resistance of rocks to flowing water that is used for rock sizing and a different assumption for determining the channel capacity and water surface elevations for various flows. The density of the rock also affects the rock sizing. However, because there are standard rock size classes, each with a specific threshold limit, the sensitivity analysis of lighter rock does not always produce a large size class. There is also a minimum size class that is needed to make the rock structure resistant to debris impacts, so denser rock does not always produce a smaller rock class. The rock density is assumed to be 165 lbs/cf for the quantity estimates.

Each structure has slightly different hydraulic characteristics and portions of each structure are more prone to hydraulic damage than other areas. Therefore the rock size gradation is likely to be different for each GRF.

Preliminary GRF material quantities are given in Table 15.

8.3.8.1 Construction Sequence

The major assumption is that each structure will be built in sequence in the dry. This will require a temporary stream diversion for each structure. In general, these incised channels are narrow and deep. The GRFs are preferentially located in channel constrictions where they will have the greatest hydraulic effect on base flows. However, in order that these structures have a minimal effect on flood flows, the channel constrictions will be widened when the temporary stream diversions are excavated. When these temporary steam diversions are retired, the extra width will widen the crest, which will reduce flood depths.

The following sequence is similar to the sequence for the GRFs that were built on the Rio Grande for the Pueblo of Santa Ana. The major differences are:

- Santa Ana had a downriver weir to act as a semi-sacrificial barrier to restrain head cut migration, but the Ohkay Owingeh location does not need one.
- The Ohkay Owingeh location includes a flow diversion at the Vigiles Ditch.
- The Ohkay Owingeh location has a much steeper channel gradient than the channel at Santa Ana, so boulder clusters are added in a checkerboard pattern to manage higher flow velocities.

The general sequence of construction of the boulder clusters was detailed in Section 8.3.7. The following is an overview of the actual steps for the construction of a series of GRFs.

Española Valley GI
Ohkay Owingeh Pueblo

Grade Restoration Facility (GRF) Sequence of Construction on the Rio Grande

Assumptions:

- Trailers, fuel, oil, hydraulic fluids, general parking to be located nearby above 1% ACE event water surface elevation.
- Enough materials (riprap, steel, diversion) produced and reserved before the start of construction of the first upstream structure.
- Enough materials (riprap, steel, diversion) and necessary construction equipment staged for each structure before beginning of that structure's construction.
- GRF in-channel construction will start at the end of a monsoon season.
- Construction from eastern floodplain staging areas.
- Two staging areas, northern one for LRG GRFs #1 and #2, southern one for LRG GRFs #3 and #4.
- Screening, sorting, stockpiling and recycling of excavated materials done on-site at staging areas
- Clean demolition materials (concrete rubble, unusable rock) may be buried on the bottom of a retired temporary stream diversion, provided placement is well downstream of the sheet pile wall.
- URG GRF #1 is not included below, if built, it would stage from the northern staging area and precede (in a very similar manner) LRG GRF #1.

Sequence:

Establish construction management area.

1. Establish northern staging/sorting/stockpiling area.

2. GRF #1
    a. Clear and grub east bank.
    b. Excavate overbank area and access ramp, sort excavated materials.
    c. Establish ford/low water crossing downstream of proposed structure.
    d. Excavate and stabilize temporary stream diversion, sort excavated materials, remove demolition materials.
    e. Divert river, then:
        i. Excavate channel, sort excavated materials, and place general fill to grade.

ii. Place filter.
iii. Place boulder clusters, adjusting filter material into voids.
iv. Place riprap on bottom of chute and side slopes up to crest.
v. Drive sheet pile wall from eastern terminus across chute to the edge of the diversion.
vi. Finish crest and approach construction, cobble on east bank approach.
vii. Place filter and riprap for east bench and its side slope.
viii. Grade exit, cobble on bottom and east bank.

f. Divert river, then:
   i. Place general fill in temporary stream diversion channel to grade.
   ii. Construct crest, irrigation diversion and approach, cobble on west bank approach.
   iii. Finish driving sheet pile wall across channel to western terminus.
   iv. Place filter and riprap of west bench and its side slope.
   v. Grade exit, cobble on bottom and east bank.
g. Remove river diversion and access ramp.
h. Stabilize GRF # 1 construction site.

3. GRF #2
   a. Clear and grub east bank
   b. Excavate overbank area and access ramp, sort excavated materials.
   c. Establish ford/low water crossing downstream of proposed structure.
   d. Excavate and stabilize temporary stream diversion, sort excavated materials.
   e. Divert river, then:
      i. Excavate channel, sort excavated materials, place general fill to grade.
      ii. Place filter.
      iii. Place boulder clusters, adjusting filter material into voids.
      iv. Place riprap on bottom of chute and side slopes up to crest.
      v. Drive sheet pile wall from eastern terminus across chute to the edge of the diversion.
      vi. Finish crest and approach construction, cobble on east bank approach.
      vii. Place filter and riprap for east bench and its side slope.
      viii. Grade exit, cobble on bottom and east bank.
   f. Divert river, then:
      i. Place general fill in temporary stream diversion channel to grade.
      ii. Construct crest and approach, cobble on west bank approach.
      iii. Finish driving sheet pile wall across channel to western terminus.

iv. Place filter and riprap of west bench and its side slope.
v. Grade exit, cobble on bottom and east bank.

g. Remove river diversion and access ramp.
h. Stabilize GRF # 2 construction site.

4. Establish southern staging/sorting/stockpiling area.

5. GRF #3
   a. Clear and grub east bank.
   b. Excavate access ramp, sort excavated materials.
   c. Establish ford/low water crossing downstream of proposed structure.
   d. Excavate and stabilize temporary stream diversion, sort excavated materials.
   e. Divert river, then:
      i. Excavate channel, sort excavated materials, place general fill to grade.
      ii. Place filter.
      iii. Place boulder clusters, adjusting filter material into voids.
      iv. Place riprap on bottom of chute and side slopes up to crest.
      v. Drive sheet pile wall from western terminus across chute to the edge of the diversion.
      vi. Finish crest and approach construction, cobble on west bank approach.
      vii. Place filter and riprap for west bench and its side slope.
      Grade exit, cobble on bottom and west bank.
   f. Divert river, then:
      i. Place general fill in temporary stream diversion channel to grade.
      ii. Construct crest, irrigation diversion and approach, cobble on east bank approach.
      iii. Finish driving sheet pile wall across channel to eastern terminus.
      iv. Place filter and riprap for east bench and its side slope.
      v. Grade exit, cobble on bottom and east bank.
   g. Remove river diversion and access ramp.
   h. Stabilize GRF # 3 construction site.

6. GRF #4
   a. Clear and grub east bank.
   b. Excavate access ramp, sort excavated materials.
   c. Establish ford/low water crossing downstream of proposed structure.

d. Excavate and stabilize temporary stream diversion, sort excavated materials.

e. Divert river, then:

   i. Excavate overbank area, sort excavated materials.
   ii. Excavate channel, sort excavated materials, place general fill to grade.
   iii. Place filter.
   iv. Place boulder clusters, adjusting filter material into voids.
   v. Place riprap on bottom of chute and side slopes up to crest.
   vi. Finish crest approach construction, cobble on east bank approach.
   vii. Place filter and riprap for east bench and its side slope.
   Grade exit, cobble on bottom and east bank.

f. Divert river, then:

   i. Place general fill in temporary stream diversion channel to grade.
   ii. Construct crest and approach, cobble on west bank approach.
   iii. Place filter and riprap of west bench and its side slope.
   iv. Grade exit, cobble on bottom and east bank.

g. Remove river diversion and access ramp.

h. Stabilize GRF # 4 construction site.

7. Remove remaining materials and equipment from both staging/sorting/stock piling areas.

8. Stabilize both staging areas.

9. Re-vegetate construction area as required.

10. Remove material, equipment and trailers from construction management area.

11. Stabilize construction management area.

8.3.8.2 Rock Sizes and Coarse Materials

The riprap size classes are for rocks with a D_{max} of 15-inches, 18-inches, 21-inches and possibly 24-inches. The riprap will have bedding assumed to be 6-inches thick for the two smaller riprap classes and 9-inches for the two larger riprap classes. The volume for these materials is based on the footprint of the structure multiplied by the associated depth of material. The lengths of these structures are 250-feet, 300-feet or 400-feet, each with a 15-foot long flat crest and 10-foot long glide approach. Each structure will have a central chute with benches on both sides. The wider bench will cover the temporary stream diversion. The will be four side slopes, each set at 4:1

(h:v). The bottom widths of the chutes will be 150-feet wide on the Rio Grande and 80-feet wide on the Rio Chama. Side slopes and benches will have varying widths.

The bottom of all chutes will include a field of boulder clusters built into the riprap bed. An individual boulder cluster will consist of four large rocks. The lateral spacing will be 4 times the effective size of the cluster, with the longitudinal spacing to be 6 times the effective size of the cluster. The boulder field will consist of rows in a checkerboard pattern; each row is offset 2 times the effective size of the cluster from adjacent rows. Longitudinally, the first row is located in the middle of the flat crest and spaced down the chute, with a gap at the bottom to allow turbulence to settle down before leaving the riprap surface. Laterally, a space is provided between the chute side slopes and the nearest boulder cluster because of the same turbulence concern.

Because the placed riprap will have voids between the rocks, to keep the river flow on top of the structure, these voids will have to be choked. It is envisioned that recycled ½-inch-minus material will be washed into these voids when each phase of riprap placement is completed. This estimate assumes a 25% void rate in the placed riprap.

The uncertainty for the quantities of materials for the riprap placement is primarily based on the reliability of the footprint dimensions.

The existing channel has a pavement of cobbles that currently provides the bulk of the channel stability. Over this pavement, there are gravel bedforms that move in floods and sand deposits that move with every freshet. The riprap GRFs must be inserted into this cobble pavement. Therefore the channel bottom under the structure's footprint will be excavated to remove this pavement for recycling. All excavation should be screened to recover and stockpile 3-inch-plus material. This 3-inch-plus material will be placed at the upstream and downstream locations on both the bottom and banks to make a smooth transition between the riprap structure and natural channel.

Eventually the quantity of recycled cobbles will be estimated based on sampling the overbank areas and trenching the channel bed. For the current quantities, it is assumed that a half foot of cobbles will be removed from the footprint of each structure.

Any recycled excavation materials not used for riprap bedding, cobble bedding, or riprap choking may be used as general fill to retire the temporary stream diversions, retire ramps for fords, or to smooth transitions.

8.3.8.3 Sheet Piling

Sheet piling is envisioned at the downstream edge of the flat crest of structures where the hydraulic stresses are the greatest. Not all structures are envisioned to require a sheet pile wall. At several locations, the extent of the sheet pile placement into the channel banks is limited by property lines. Therefore, is was assumed that the piling will extend 25 feet into the Rio Grande banks and 20 feet into the Rio Chama banks. The depth of the sheet piling was assumed to be 6 times the thickness of the chute riprap and bedding.

Sheet piling is not anticipated to be placed into fill material in the overbanks, but only driven through placed fill in retired stream diversions. The sheet piling is anticipated to reduce the pressure flow of water through the placed riprap, particularity on the crests where this can lead to lost materials in the choked voids.

The uncertainty for the measure for sheet piling is primarily the width of the final location of the crest and any structural design recommendations that may be based on future channel trenching to determine the alluvial material in the foundation of these GRFs.

8.3.8.4 Clearing Quantities

Clearing is necessary for staging, stock piling, recycling materials, and for building the proposed structures. Three large nearby locations are envisioned as necessary for construction, with a higher location above the 1% ACE event stage being used for the construction trailers and fuel storage. Most of the construction areas already have small dirt roads for access to nearby paved highways.

8.3.8.5 Cut and Fill Quantities

Cut quantities have the highest uncertainty simply because of the methods used to survey these rivers. The floodplain was surveyed in 2007 with using LiDAR. The channel was surveyed also in 2007, primarily at locations of existing USBR range lines. The LiDAR doesn't measure underwater and the USBR range lines typically miss the location of bedforms. Therefore, the excavation of the channel bed is likely to be underestimated using available data, and the overbank excavation estimate is likely to be overestimated due to simple bank erosion since the last survey.

8.3.8.6 Waste Quantities

The removal of trees and brush for channel construction cannot be avoided. However, the sites for staging areas will be selected to minimize the loss of trees. The possibility of recycling woody materials locally has not yet been raised with the sponsor. Therefore, the cost of the disposal of trees will most likely include off-site hauling and disposal until a local alternative is identified.

The accumulation of debris and demolition materials is inevitable along a river. There is one site with a large quantity of waste concrete that needs to be removed. Only the cleanest concrete rubble may be recycled into the structures. Other waste material will require off-site hauling and disposal.

Excessive alluvial material from excavations should not be returned to the river if smaller than 1/2–inch in diameter. Clean materials may be used to reclaim nearby mining spoil areas or stockpiled for Pueblo uses. The amount of excess materials cannot be accurately estimated until better surveys and sampling can be completed.

The disposal of woody and excess materials should not be considered independent of the other proposed ecosystem restoration measures. Two of the proposed GRFs are intended to feed water into adjacent terrace lowering sites and high flow channels. The ecosystem restoration activities will not recycle materials efficiently and will produce large amounts of woody and alluvial materials.

Table 15 shows the results of a preliminary approximation of the quantities needed for the four GRFs for the head cut on the top of the table and the two GRFs for the water diversions on the bottom of the table. The basic quantities are summed up on the left of the table while the right of the table indicates the values used to calculate these final quantities. The yellow, orange, red and green cells on the left of the table correspond to the same color cells on the right of the table where the dimensions of the material sizes on each of the features of the GRF are identified.

Several of the final quantities on Table 15 come from locations not shown, including incidental structures, and particularly the estimate of quantities in the cut and fill. Generally, most of the quantities of incidental sand, gravel and cobble are assumed to come from the sorting and recycling of cut material. Left over materials from the sorting are assumed to be suitable for general fill. Only riprap and boulders are anticipated to be imported from local quarries.

Planing Level Restoration Features
Espanola Valley GI Study
Grade Reduction Facilities (GRF) 165 lbcf

4:1 SS 1.0308 | 4:1 SS 1.0308

Rio Grande effective cluster Size: 4

Ohkay Owingeh Construction Quantities to Arrest the Head Cut below Rio Chama Confluence

Rio Grande extension: 50 | Rio Grande GRF slope: 0.01 | diversion length: 150 | spacing: 16 | spacing: 24

Restoration Feature	Clearing & Grubbing	Over Bank Excavation	Over Bank Backfill	Channel Excavation	Channel Backfill	Cobble Channel Backfill	Sand/ Gravel Riprap Backfill	Dmax 21-inch Riprap	Dmax 18-inch Riprap	Dmax 15-inch Riprap	Dmax 3 inch gravel filter	3-foot boulders	sheetpile	Demo-lition	Excess Alluvial Material
	(ac)	(yd3)	(yd3)	(yd3)	(yd3)	(yd3)	(yd3)	(yd3)	(yd3)	(yd3)	(yd3)	(#)	(ft2)	(yd3)	(yd3)
Lower Rio Grand GRF #1	0.5	12,085	276	10,547	9,363	2,236	1,999	3,594	4,040	361	3,031	384	6,675	1,320	5,727
Lower Rio Grand GRF #2	2	16,921	89	4,139	12,674	2,859	1,943		3,155	4,617	2,899	384	6,300		596
Lower Rio Grand GRF #3	2	180	180	13,500	21,665	4,329	2,658		4,126	6,508	3,978	512	7,200		-19,131
Lower Rio Grand GRF #4	0.5	26,422	14,097	19,082	13,860	2,769	2,091		2,708	5,654	3,164	384			9,523
Sub-Total	5	55,608	14,641	47,268	57,563	12,192	8,691	3,594	14,029	17,140	13,073	1,664	20,175	1,320	-3,285

Restoration Feature	GRF drop	GRF Length	Crest Width	sheetpile depth	Chute Width	chute riprap depth	chute filter depth	chute ave side slope width	Chute ss riprap depth	Chute ss filter depth	Bench Ave Width	Bench riprap depth	bench filter depth	Bench ss ave width	Bench ss riprap depth	Bench ss filter depth	diversion riprap width	diversion riprap depth	Diversion filter depth	Chute Downslope Length	Chute bottom width	Boulder Columns	Boulder Rows
	(ft2)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(#)	(#)
Lower Rio Grand GRF #1	3	325	395	15	150	1.75	0.75	20	1.75	0.75	199	1.5	0.5	24	1.5	0.5	52	1.25	0.5	300	150	8	12
Lower Rio Grand GRF #2	3	325	475	12	150	1.5	0.5	24	1.5	0.5	278	1.25	0.5	28	1.25	0.5				300	150	8	12
Lower Rio Grand GRF #3	4	425	550	12	150	1.5	0.5	24	1.5	0.5	306	1.25	0.5	24	1.25	0.5				400	150	8	16
Lower Rio Grand GRF #4	3	325	460		150	1.5	0.5	24	1.25	0.5	316	1.25	0.5	34	1.25	0.5				300	150	8	12

sensitivity of density for head cut structures

		lbcf			Wave	L		extra d	extra cyd
LRG	GRF#1	155	330	410	370	325	120,250	0.25	1,113

Chama effective cluster Size: 3

Ohkay Owingeh Construction Quantities for Grade Support for diversions for Ecosystem Restoration

Rio Chama extension: 40 | Rio Chama GRF slope: 0.012 | spacing: 12 | spacing: 18

Restoration Feature	Clearing & Grubbing	Over Bank Excavation	Over Bank Backfill	Channel Excavation	Channel Backfill	Cobble Channel Backfill	Sand/ Gravel Channel Backfill	Dmax 21-inch Riprap	Dmax 18-inch Riprap	Dmax 15-inch Riprap	Dmax 3 inch gravel filter	3-foot boulders	sheetpile		
	(ac)	(yd3)	(yd3)	(yd3)	(yd3)	(yd3)	(yd3)	(yd3)	(yd3)	(yd3)	(yd3)	(#)	(ft2)		
Rio Chama GRF #1	2	4,986	50	1,229	2,915	373	758		1,332	1,699	1,124	312	3,120		994
Upper Rio Grand GRF #1	0.5	19,631	7,523	3,565	5,207	2,292	1,827	2,931	4,379		2,716	288	7,500		3,631
Sub-Total	2.5	24,617	7,573	4,794	8,123	2,665	2,585	2,931	5,711	1,699	3,840	600	10,620	0	
Grand Total	7.5	80,224	22,214	52,062	65,686	14,857	11,276	6,525	19,740	18,839	16,912	2,264	30,795	1,320	

Restoration Feature	GRF drop	GRF Length	Width	sheetpile depth	Chute Width	chute riprap depth	chute filter depth	chute ave side slope width	Chute ss riprap depth	Chute ss filter depth	Bench Ave Width	Bench riprap depth	bench filter depth	Bench ss ave width	Bench ss riprap depth	Bench ss filter depth	Chute Downslope Length	Chute bottom width	Boulder Columns	Boulder Rows
	(ft2)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(#)	(#)
Rio Chama GRF #1	3	275	220	12	80	1.5	0.5	7	1.5	0.5	117.5	1.25	0.5	15.5	1.25	0.5	250	80	6	13
Upper Rio Grand GRF #1	2.5	275	450	15	150	1.75	0.75	14	1.75	0.75	266	1.5	0.5	20	1.5	0.5	250	150	8	9

Table 15 Preliminary GRF material quantities. Quantities by bright colors on the left are based on dimensions by same color on the right.

8.3.9 Expected Hydraulic Effects of GRF Structures on the Rio Grande and Rio Chama

The hydraulic effects of the GRF structures will first be presented on the Rio Grande downstream of the Rio Chama confluence, second above this confluence on the Rio Grande, and then third on the Rio Chama. The level of detail found in this analysis was primarily driven by improving the hydraulic results that went into sizing the riprap in each structure, so that reasonable representation of quantities could be produced for Section 8.3.8 above.

The presented hydraulic effects are quite conservative due to the preliminary nature of the current flood risk analysis. All six GRFs are to be built in conjunction with terrace lowering and high flow channel measures. However, the following analysis does not include these measures. Therefore, this current analysis has the most extreme values which may occur if these GRFs are constructed prior to these other measures being installed. These six GRFs by themselves are anticipated to result in increased residual flood risk for those flood events that enter the floodplain. To build only these GRFs to eliminate all additional residual flood risks would require much larger structures with more excavation and much larger quantities of riprap. The terrace lowering and high flow channel measures are relatively inexpensive to install when compared to GRFs. These latter two measures are capable of mitigating for the residual flood risks from building the planned GRFs. The hydraulic design during the final engineering will need to balance the geometry of all three measures to produce the most economical combination that eliminates significant residual flood risks.

The hydraulic results of GRFs are traditionally shown in profile (U.S. Army Corps of Engineers, 2001) before other engineering concerns are addressed. The profile shown in Figure 32 comes from a standard HEC-RAS output that includes the channel profile, the four proposed GRFs below the confluence, the left and right bank elevations as dashed lines, and various water surface elevation (WSE) as blue line profiles. The WSE profiles come in two groups, the 50% ACE event is a solid blue line without symbols with a large gap above it to the profiles of less frequent flood events. Below this solid blue line is a tight series of flow events that are used to discern the highest stress environment for each GRF. Based on location geometry, some of the planned GRFs are most prone to damage by flows that are not considered to be flood related.

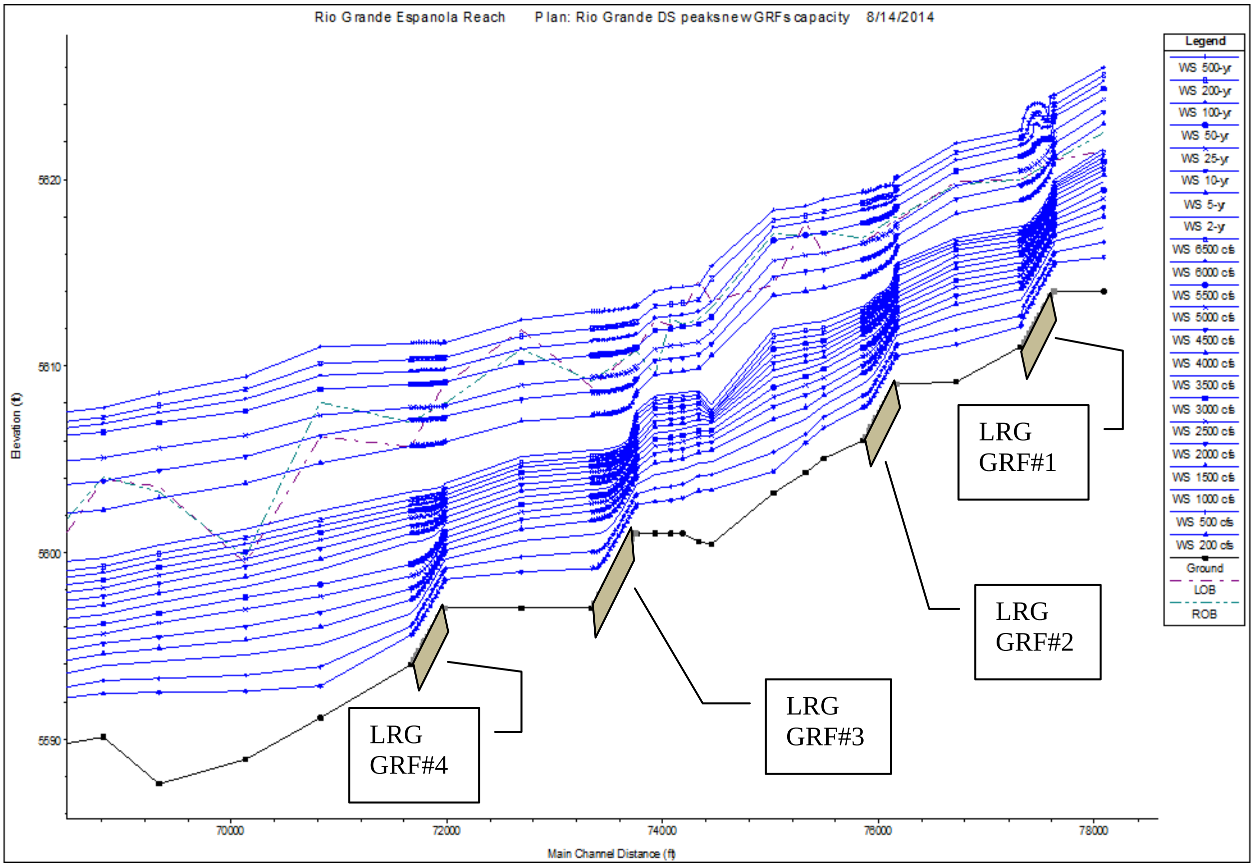

Figure 32 HEC-RAS profile of the four GRFs below the Rio Chama along the Rio Grande thalweg.

Figure 32 indicates the four GRFs with grey boxes on the black thalweg profile line. LRG GRF#3 in the middle of Figure 32 has a 400-foot long drop chute, while the other three are 300 feet long. They all have the same 1% slope that appears steep in this figure due to vertical exaggeration. The left side of the figure is the low gradient Rio Grande channel in the area of the mining activity; as a result, the WSE lines also have relatively low gradients. The downriver structure (LRG GRF#4) only has steep flow gradients at the lowest flow stages and then submerges for all flood flows. Therefore, this structure needs the smallest riprap sizes to be stable.

8.3.9.1 Lower Rio Grande Grade Restoration Facility #1

LRG GRF #1 is found just below the confluence of the Rio Chama and is unusual for several reasons. The upstream crest of this structure, shown in Figure 34, will have the highest hydraulic stresses and will be complicated by the Vigiles Ditch diversion. On 1973 aerial photos, the entrance of the Vigiles Ditch included a rock-based run-of-the-river rubble dam that crossed the Rio Grande at an angle that (as a result of complicated hydrodynamic flow patterns) actually minimized the amount of sediment that entered the water diversion. This run-of-the-river diversion was destroyed by the first headcut to pass upriver and evidently couldn't be successfully rebuilt at its former location. As a consequence, the entrance was extended with a broken concrete rubble wall 800 feet upstream of the original diversion location indicated on Figure 33. This concrete wall shows up on Figure 34 as the spike on the existing condition line in the middle of the channel and also on Figure 1.

Figure 33 Site of the Vigiles Ditch diversion and proposed LRG GRF #1 (source: Alan Schlindwein).

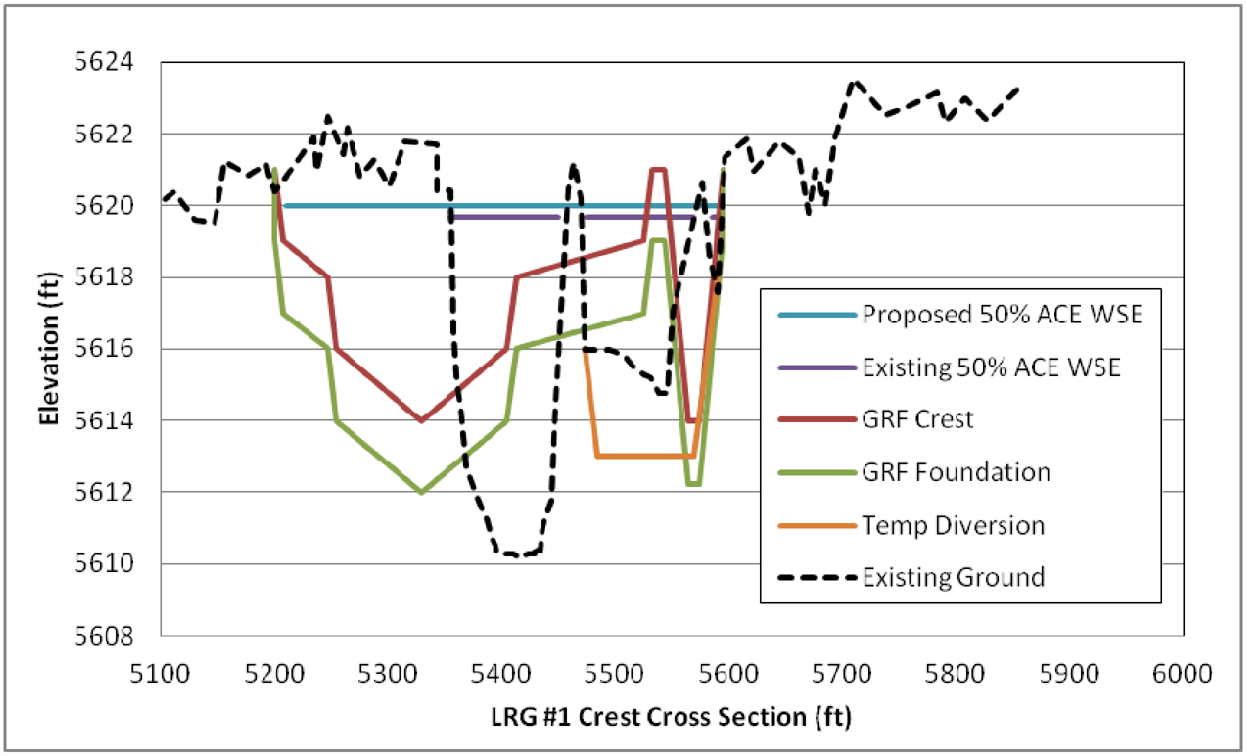

Figure 34 Cross section (downstream view) of the crest of the Lower Rio Grande GRF #1.

The crest location of LRG GRF #1 is too narrow for both a stream diversion and the construction of the chute; consequently, the chute will be constructed into the east bank as shown in Figure 34. The depth of this channel is an indication of a local instability because the channel at the crest has a lower elevation than the channel invert shown for the run in Figure 35.

The location of the LRG GRF #1 runout transition (only 300 feet downriver) is much wider as shown in Figure 35. The existing Vigiles Ditch is shown to the right with WSE from the upstream crest diversion point. Downstream of this cross section there will be a complex of existing gates, with one returning flow to the Rio Grande to flush sediments out of the reconstructed diversion entrance.

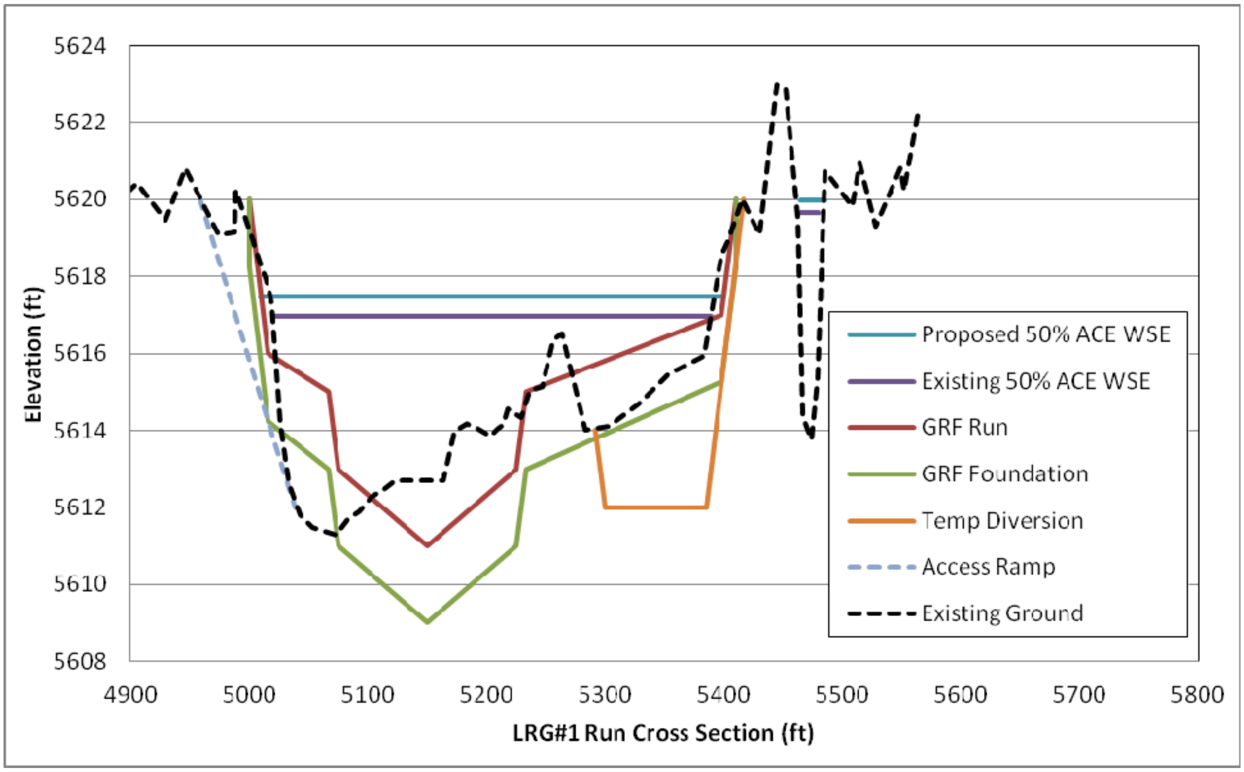

Figure 35 Cross section (downstream view) of the runout of the Lower Rio Grande GRF #1.

In this sequence of cross sections, the existing and proposed 50% ACE WSE are shown as an example of how residual flood risks are proposed to be mitigated. These GRFs are intended to pick up the low flows in elevation, but not to adversely affect residual flood risks. This is largely accomplished by creating benches on both sides of the chute for additional bank stability and the bench on the former stream diversion will add flood conveyance.

The 50% ACE WSE increase on the crest shown on Figure 34 is actually less than that on Figure 35. This is occurring because the downriver GRF is located so that it hydraulically supports the upriver structure. As long as these increases in the 50% ACE SWE are kept within the channel banks, the residual flood risks to structures in the floodplain will not generally be increased. Because LRG GRF #1 will elevate the 50% ACE WSE back up to the top of the banks, it will have greater issues with residual flood risks that are shown on Figure 36.

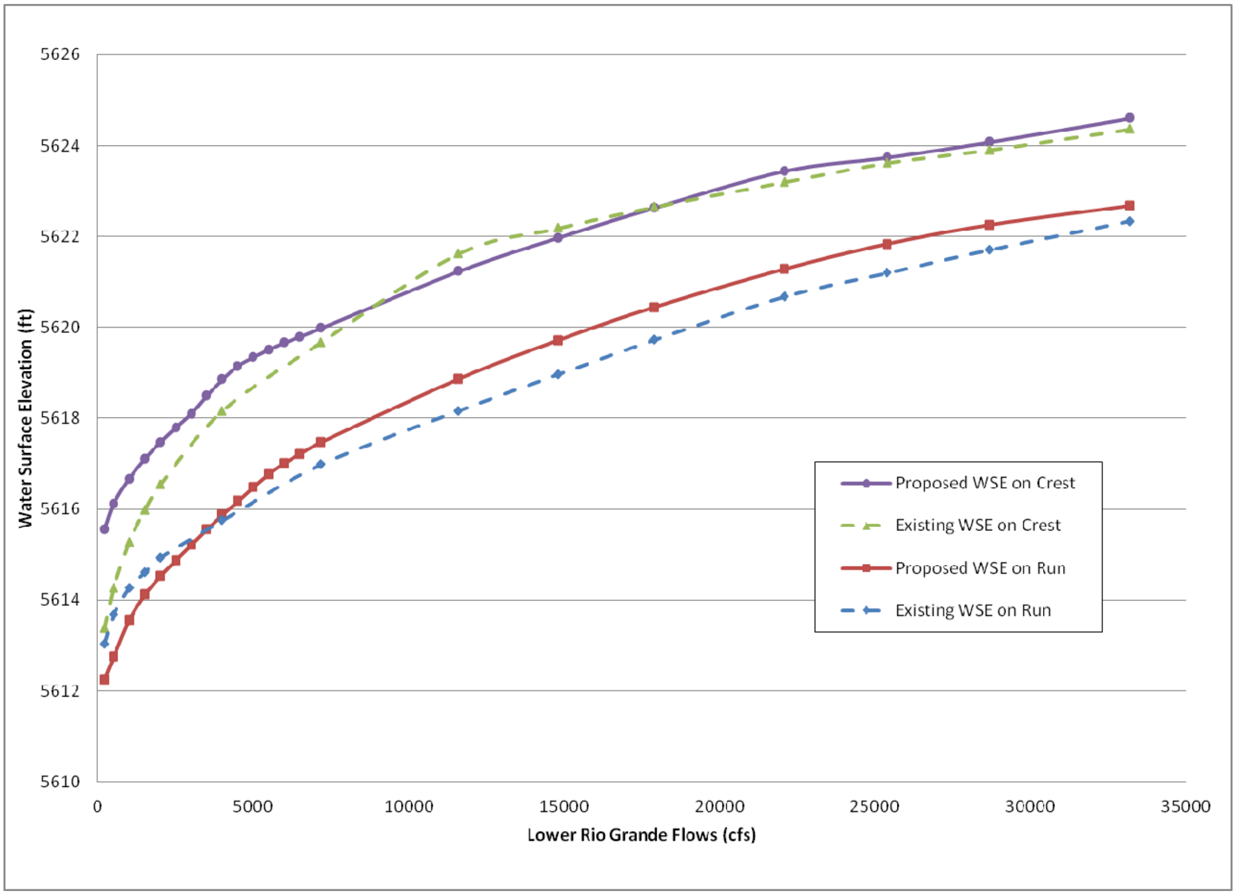

Figure 36 Rating curves of the existing locations and proposed crest and run of LRG GRF #1.

Figure 36 shows rating curves for the crest and run of LRG GRF #1. Both existing hydraulic conditions and proposed expected future hydraulic conditions are shown across a wide range of flows all the way up to the 0.2% ACE event. The prime indicator that these two cross sections, 300 feet apart, represent extreme channel instability is that the dashed existing conditions lines converge together at the left side of the figure. A good indication that the GRF is working correctly is that the separation between the solid lines starts 3 feet apart and reduces down to 2 feet apart at the highest flows.

The slight increase in the crest residual flood risks will be eliminated with terrace lowering or a high flow channel diversion. The larger increase in the run residual flood risk is largely due to the roughness of the two adjacent GRFs slowing water down across a single cross section; more cross sections are necessary for final design. Figure 36 shows that, during planning level modeling, the geometry of the crest heavily dominates the upstream hydraulics, while the transition to the run is dominated by the complex downriver geometry. With better topographic surveys of the channel and the Vigiles Ditch diversion structure, the downstream transition will be optimized during final design. This additional survey will also include the changes in the Vigiles Ditch diversion structure since 2007, which will be needed to update the existing condition hydraulic model for the residual flood risk assessment.

8.3.9.2 Lower Rio Grande Grade Restoration Facility #2

LRG GRF#2 has is located next to an island. The island is the tree strewn bank on the left of Figure 37 and the upper headcut location is above the rapid flow conditions passing this island. A sandy bar with ripples is evident in the lower left corner.

Figure 37 Location of proposed LRG GRF #2 just below the rapids of the upper headcut (Source: Alan Schlindwein).

The river flow will be diverted around one side of the island while the chute is constructed on the other side. The hydraulic model at this location is lacking in detail because only the upriver tip of this island shows on Figure 38 and only the downriver tip of this island shows on Figure 39.

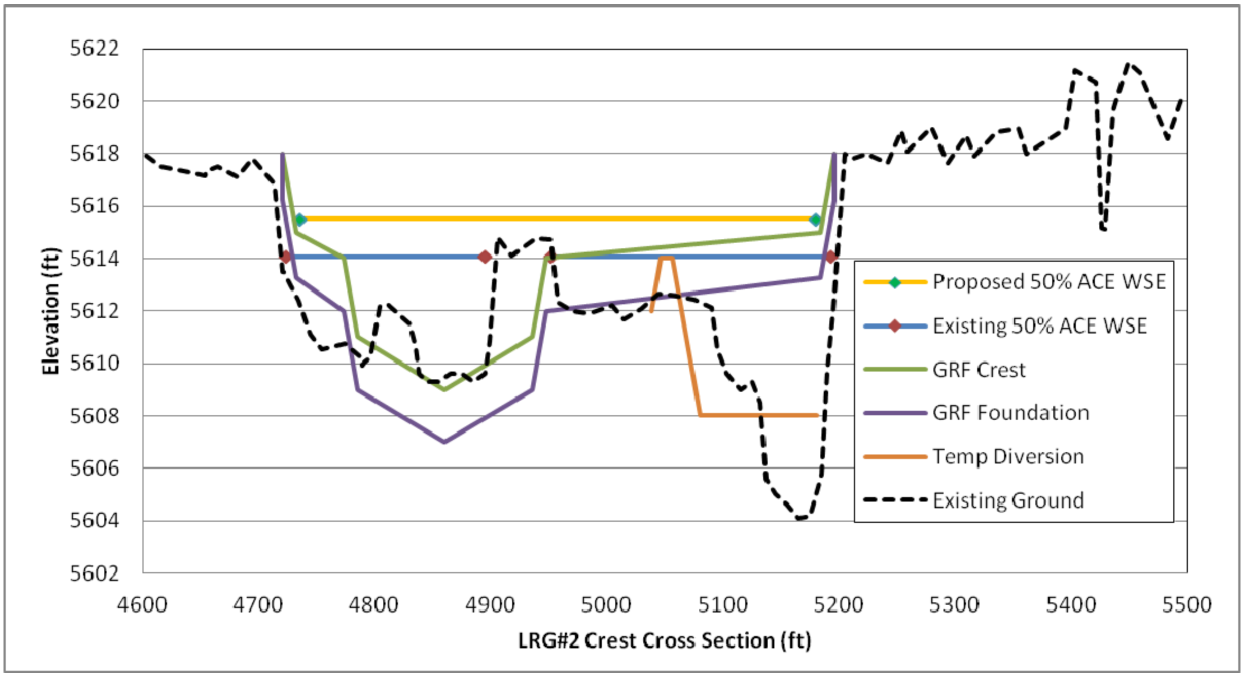

Figure 38 Cross section (downstream view) of the crest of the Lower Rio Grande GRF #2.

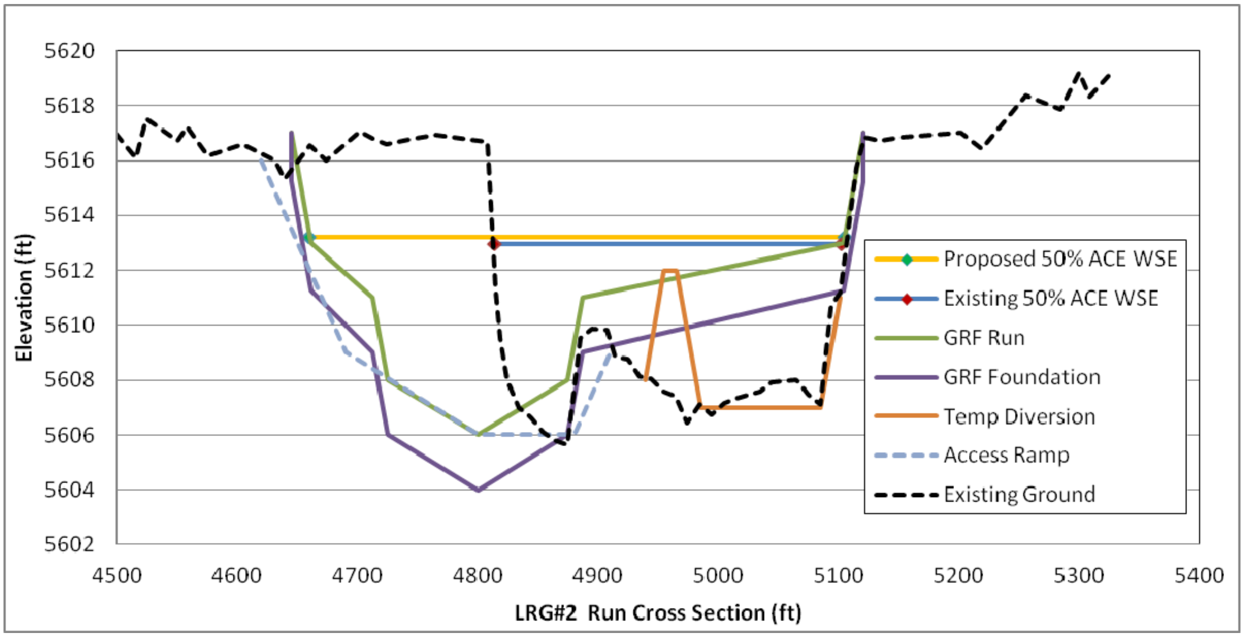

Figure 39 Cross section (downstream view) of the runout of the Lower Rio Grande GRF #2.

Because LRG GRF#2 is being constructed downstream of the headcut, there is a deliberate effort to have a substantial rise in all flows contained in the channel. The existing and proposed expected future rating curves for LRG GRF#2 are shown on Figure 40. Once again the dashed lines converge at the low flow stages indicating the inherent instability in this reach. The curve for the proposed crest has an unusual shape, but it does come back below the existing curve just before reaching the top of bank at 5618 ft elevation. The high flows for the proposed run indicate that modifications to floodplain topography (via terrace lowering and high flow channels) will be necessary to mitigate for any significant increases in residual flood risks.

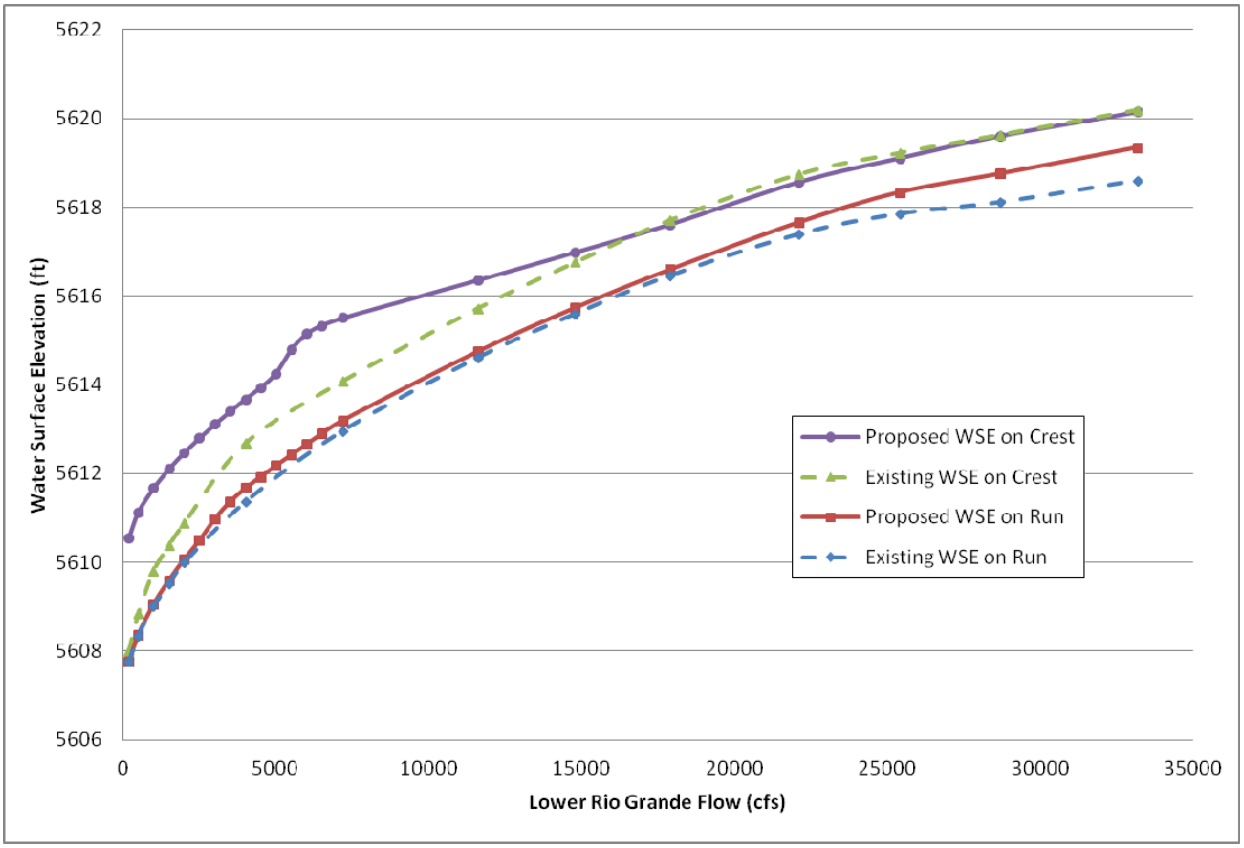

Figure 40 Rating curves of the existing locations and proposed crest and run of LRG GRF #2.

8.3.9.3 Lower Rio Grande Grade Restoration Facility #3

LRG GRF#3 will be constructed on top of the lower headcut shown on Figure 41. To overcome the hydraulic drop of this headcut and upstream influences, the structure needs to be 400 feet long. Both the crest and the run for this structure are located on a wide reach of the Rio Grande and, as a result, this GRF will have a large requirement for general fill and riprap.

Figure 41 Location of proposed LRG GRF #3 and the lower head cut (Source: Alan Schlindwein).

Because this headcut is currently in a wide reach, it is migrating upriver slowly. However, as the WSE profiles on Figure 32 shows, there is a dip in the lower flows at station 74,400 that represents a narrows. This narrows is only 700 feet upstream of the lower headcut, which will speed up as it approaches and moves through this narrows. Because of this narrows, there is a very deliberate attempt to provide a large increase in the 50% ACE event WSE on the crest of this GRF as shown on Figure 42.

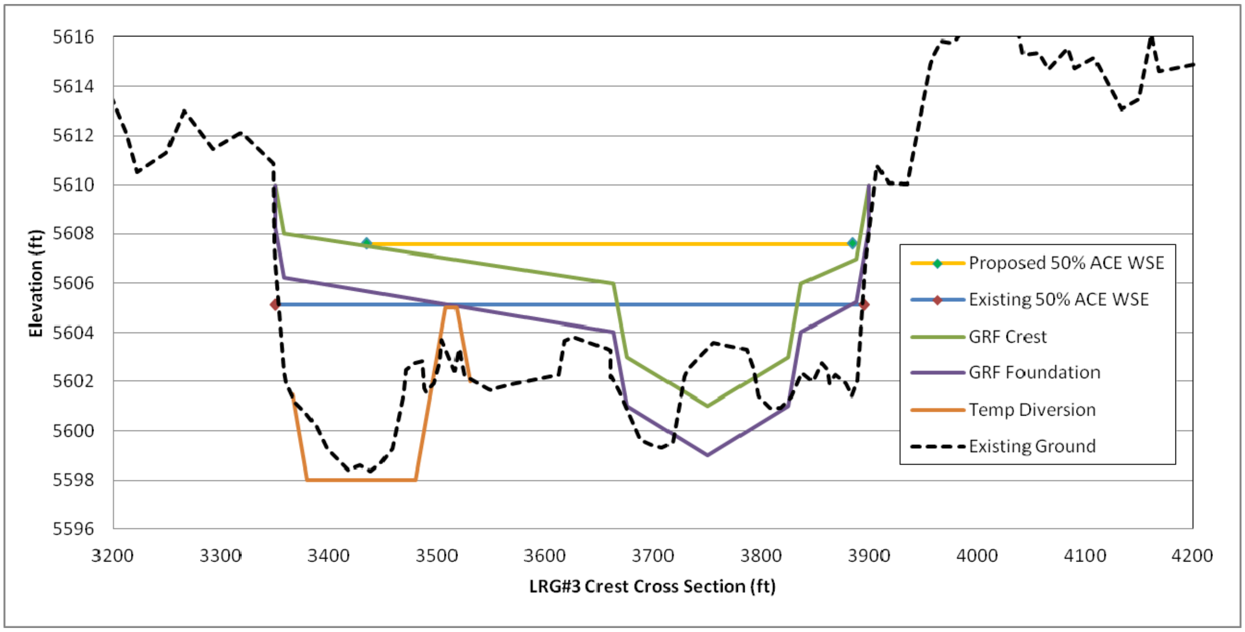

Figure 42 Cross section (downstream view) of the crest of the Lower Rio Grande GRF #3.

LGR GRF#3 is located in a very incised location of the Rio Grande. When the rating curves on Figure 44 are considered with this cross section, the 0.2% ACE event does not overtop the west bank and there is very little flood flows on the east bank above elevation 5612 ft.

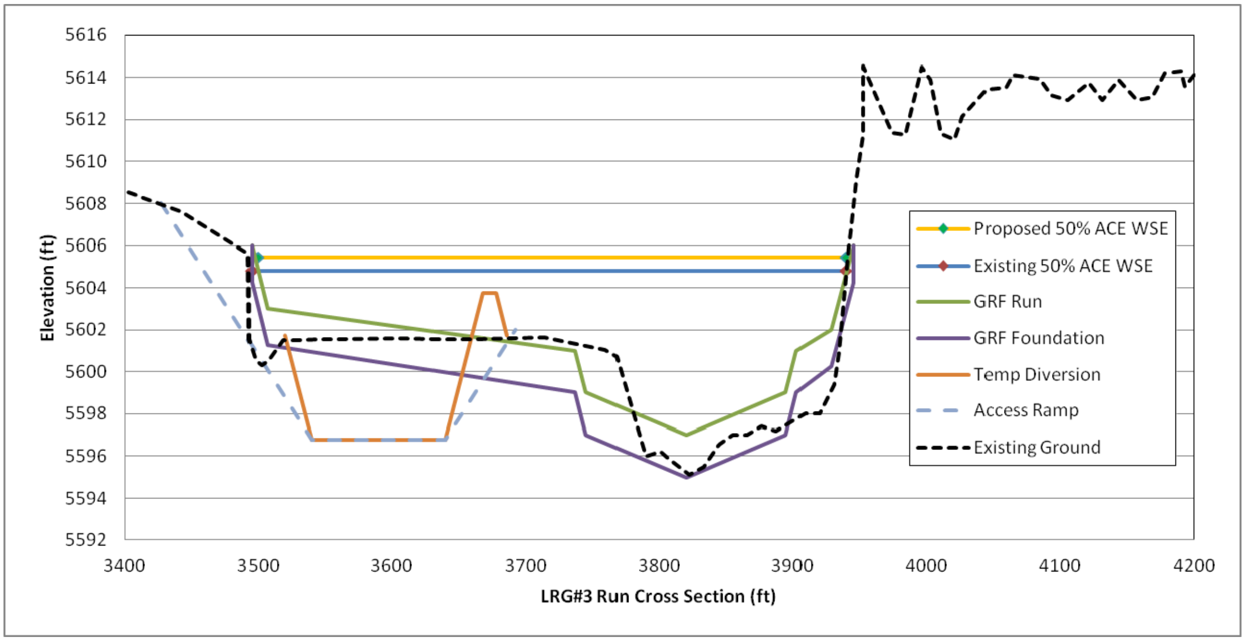

Figure 43 Cross section (downstream view) of the runout of the Lower Rio Grande GRF #3.

The location of LRG GRF#3 will allow for a relatively simple stream diversion for construction of the chute and straight forward transitions both upstream and downstream. However the runout transition is not optimally located. The runout transition is located at a cross over bar where one bend in the river transitions to a bend going the opposite direction. Evidence of the downstream bend can be seen on the left side of Figure 43, where there is indicated point bar. This point bar is covered in willows and while these willows won't benefit from LRG GRF#3, they will see a significant hydrologic improvement from LRG GRF#4. The close downriver proximity of LRG GRF#4 will provide a significant tailwater effect on the runout of this GRF. Because of this tailwater support, this cross over reach can be used for a runout transition.

On Figure 44, the proposed expected future condition curves for the crest and run are almost the same for high flood flows because this structure gets submerged from downriver tailwater effects. The same is noticeable for the existing curves where the greatest separation is at the lowest flows. On Figure 44, the greatest separation for the proposed crest and run are the low flows, which starts with a 4 foot vertical separation (the rise of the GRF) and varies with local topography in the direction of the greater flood flows.

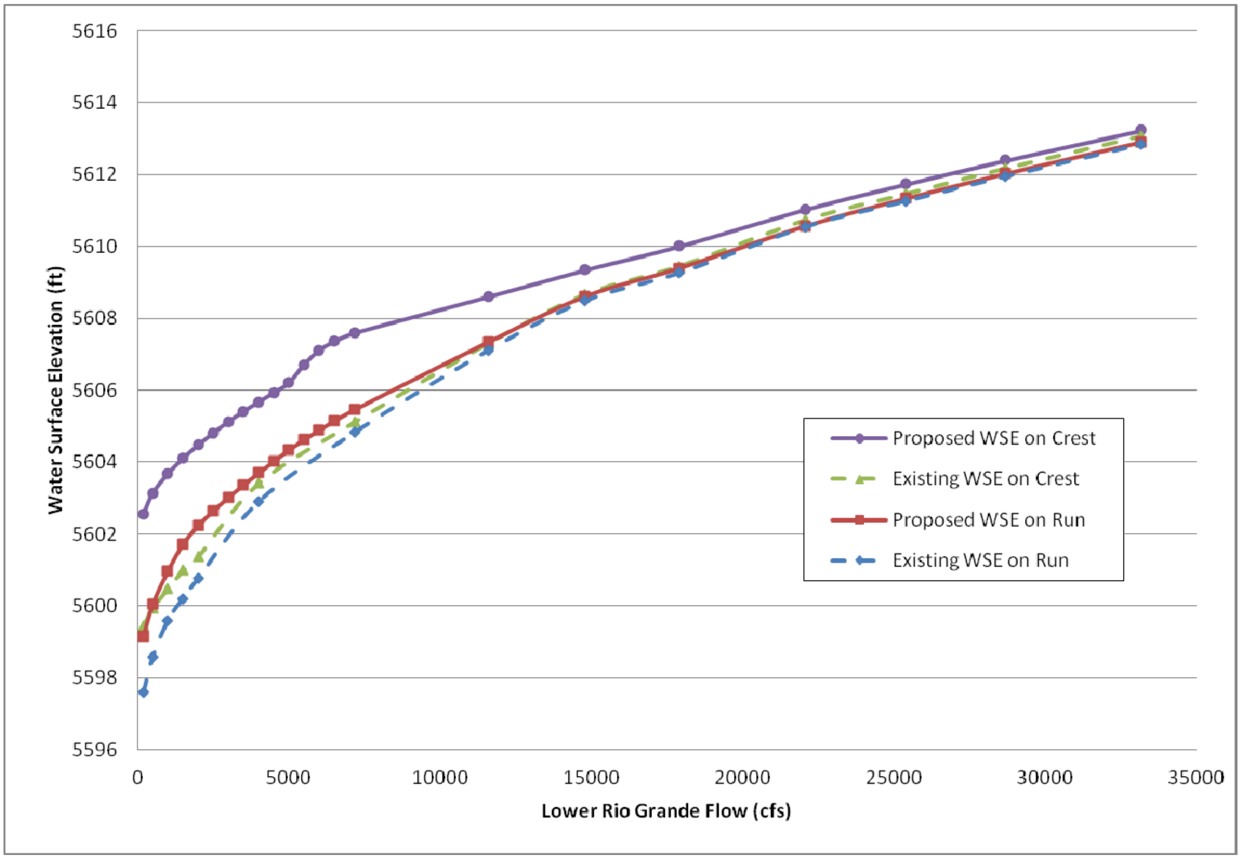

Figure 44 Rating curves of the existing locations and proposed crest and run of LRG GRF #3.

8.3.9.4 Lower Rio Grande Grade Restoration Facility #4

By definition LRG GRF#4 is the anchor that holds the river reach in place and protects all of the upriver GRFs. It is located in a low gradient downriver reach of the Rio Grande just above where the channel mining occurred. During floods, this GRF will to quickly submerge; therefore, the highest hydraulic stresses for design will be from relatively low flows. Its location is also the farthest away from the confluence with the Rio Chama. The Rio Chama has built a delta on the west side of the Española Valley. The Rio Grande cuts through this delta and is exiting this depositional formation in the area of LRG GRF#4 as shown in Figure 45. Therefore the site of LRG GRF#4 is both less incised and less entrenched than the large upriver GRF that it is directly supporting.

Figure 45 Location of LRG GRF #4 and the downriver Rio Grande in the direction of the 1980s channel mining (Sources: Alan Schlindwein).

Because LRG GRF#4 is in a reach that is less entrenched, the cross section shown on Figure 46 does not show the high adjacent terraces both east and west. The five foot deep floodplain feature on the left side of this figure is an existing wetland swale constructed by the Pueblo for habitat restoration. The floodplain to the right could also be called a low terrace because it is infrequently flooded; it will be excavated for the stream diversion and then terrace lowered for a bench. The existing and proposed 50% ACE WSEs are an indication of how quickly this structure is submerged. However, when the proposed chute is compared to the thalweg, the low flows will be substantially raised by this GRF.

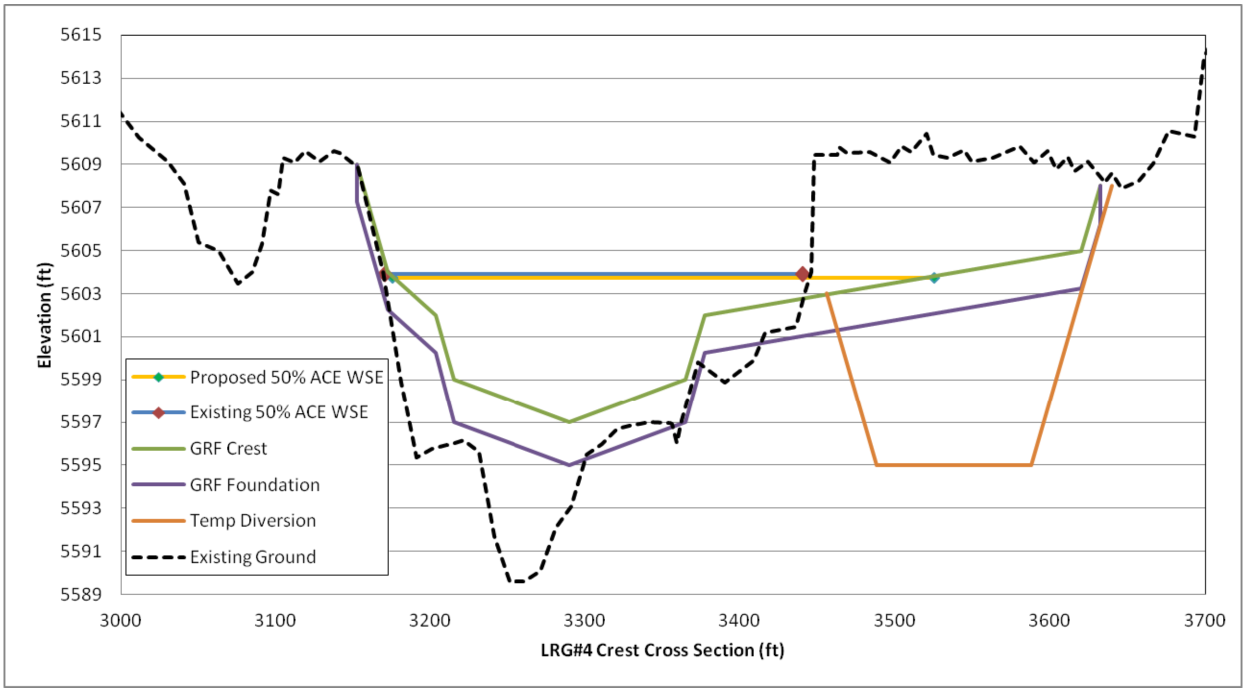

Figure 46 Cross section (downstream view) of the crest of the Lower Rio Grande GRF #4.

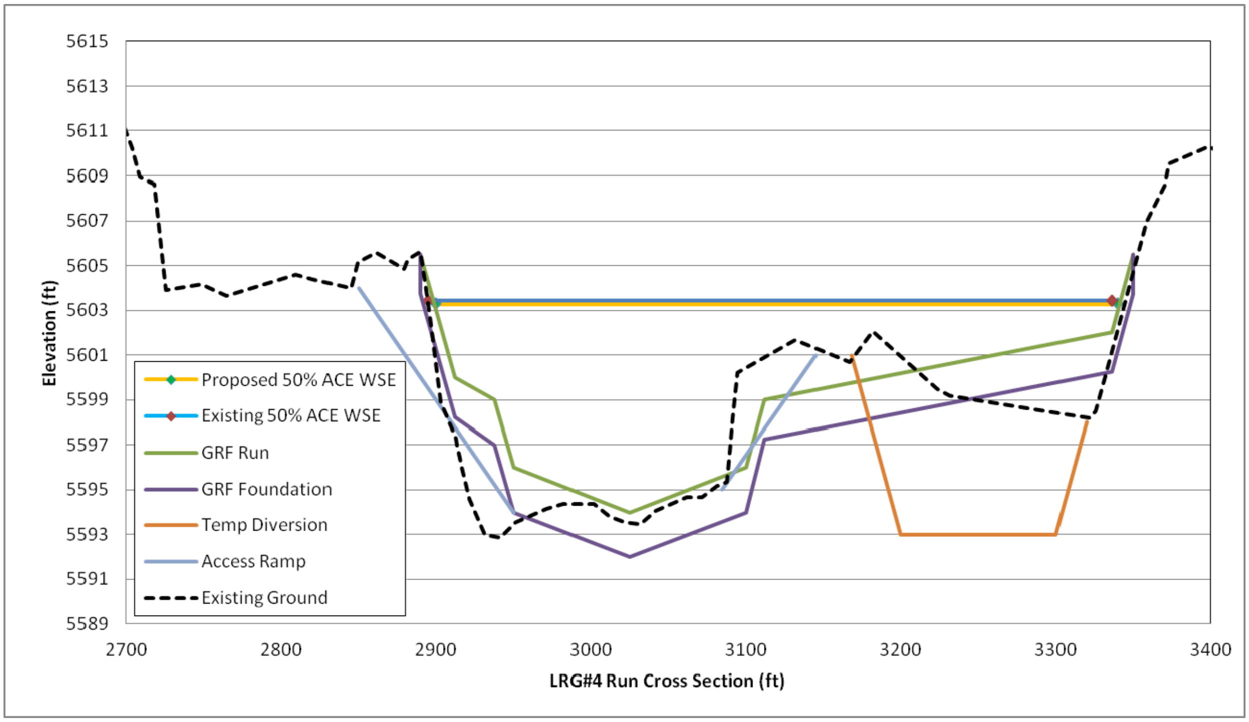

Figure 47 Cross section (downstream view) of the runout of the Lower Rio Grande GRF #4.

The runout transition for LRG GRF#4 has an easy to match cross section to the downriver run. With some minor modifications to the chute, a small diversion should be possible to feed the low natural bench to the right of Figure 47.

Figure 48 show how easy it is to submerge LRG GRF#4. All of the increases in the proposed expected future WSE rating curves occur at low flows and these flows are well within the channel boundaries.

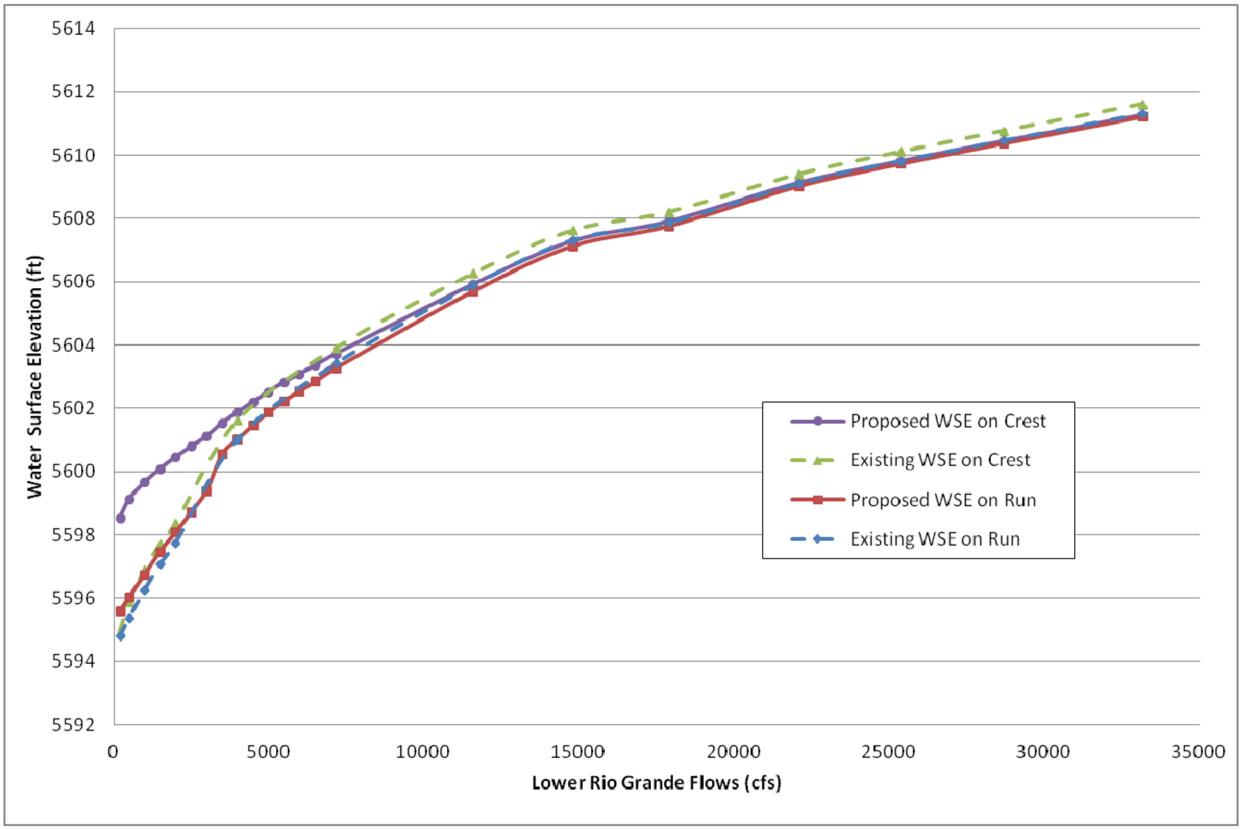

Figure 48 Rating curves of the existing locations and proposed crest and run of LRG GRF #4.

8.3.9.5 Upper Rio Grande Grade Restoration Facility #1

The URG GRF #1 is a measure intended to raise the water table in the adjacent floodplain and provide a water diversion into the downriver terrace of the eastern floodplain. The structure will be constructed on an existing gravel riffle to reduce the material quantities needed to build it and to maximize its stability along the Rio Grande channel. However, this GRF cannot be built without the support of the four downriver GRFs.

A WSE profile is not provided herein because the structure of the HEC-RAS hydraulic model made it impossible to provide a realistic simulation at the confluence of the Rio Grande and Rio Chama: the Rio Grande above and below the confluence were modeled separately rather than as a continuous system. To correctly model the WSE at this GRF, the two separated Rio Grande hydraulic models, one below the confluence and one above the confluence, will need to be combined. With a combined model, the interaction between the LRG GRF #1 and the URG GRF #1, along with the effects of the terrace lowering and high flow channel measures, and the effects of the removal of the Vigiles rubble wall can be analyzed.

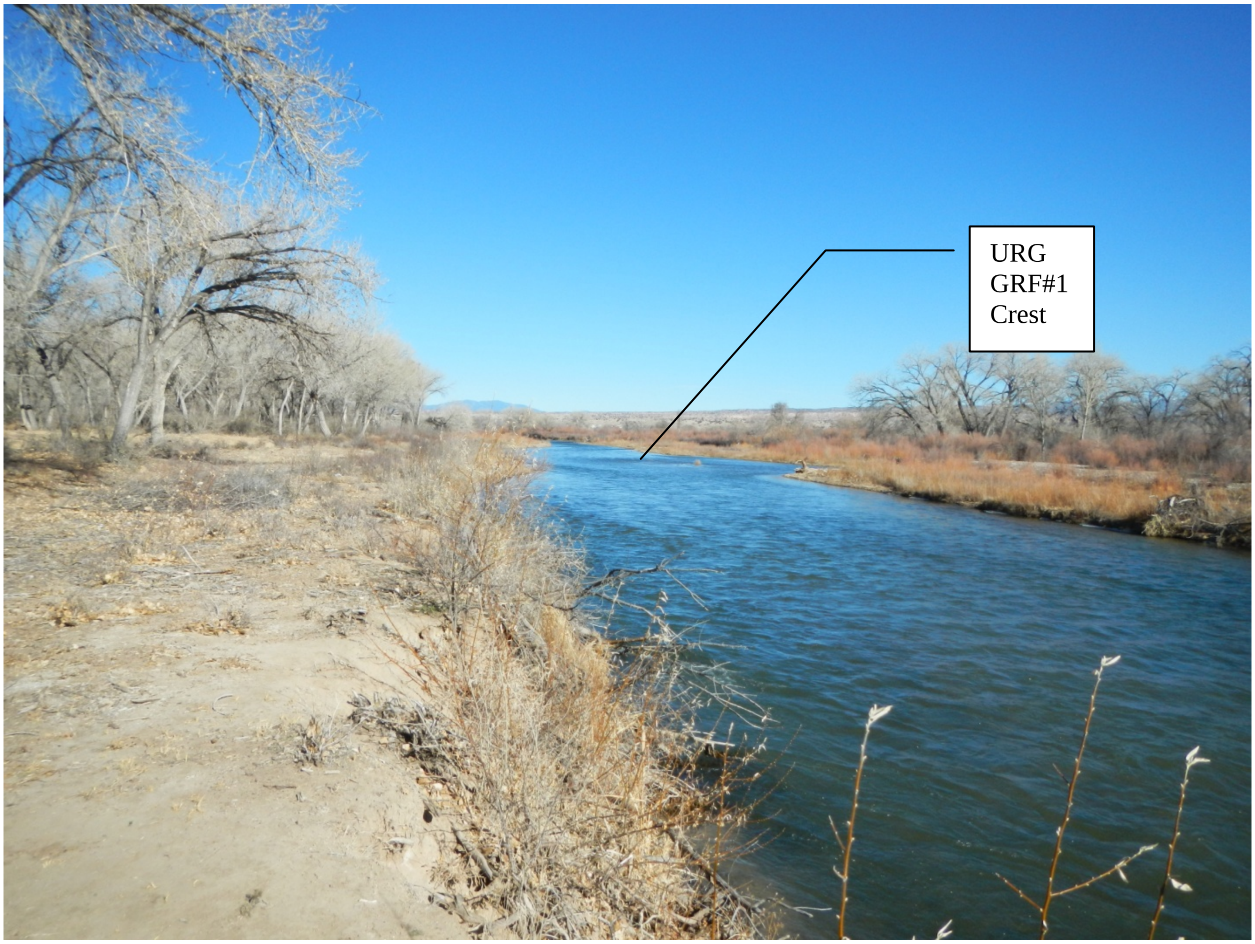

Figure 49 proposed Location of URG GRF #1 on the upriver riffle (Source: Alan Schlindwein).

Figure 49 shows the Rio Grande as it is current passing the delta of the Rio Chama located on the left of this figure. The willow covered floodplain on the right is just below the cottonwood covered terrace to the east. This terrace is the intended location of a high flow channel proposed in combination with the GRF crest on Figure 50 to be located on the upriver riffle.

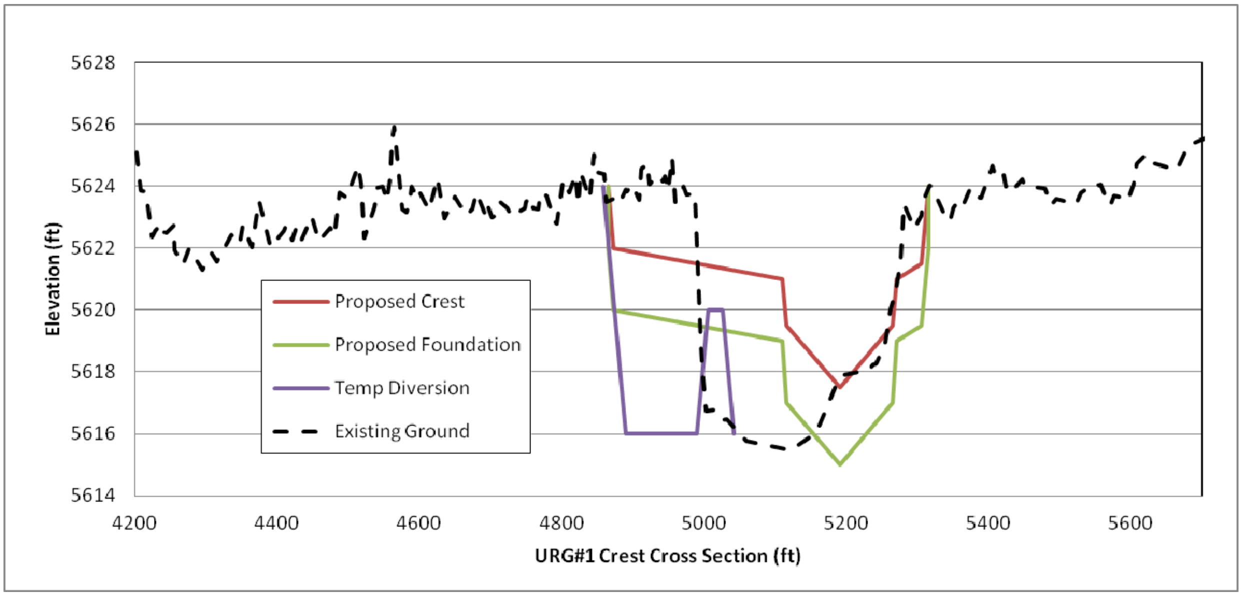

Figure 50 Cross section (downstream view) of the crest of the Upper Rio Grande GRF #1.

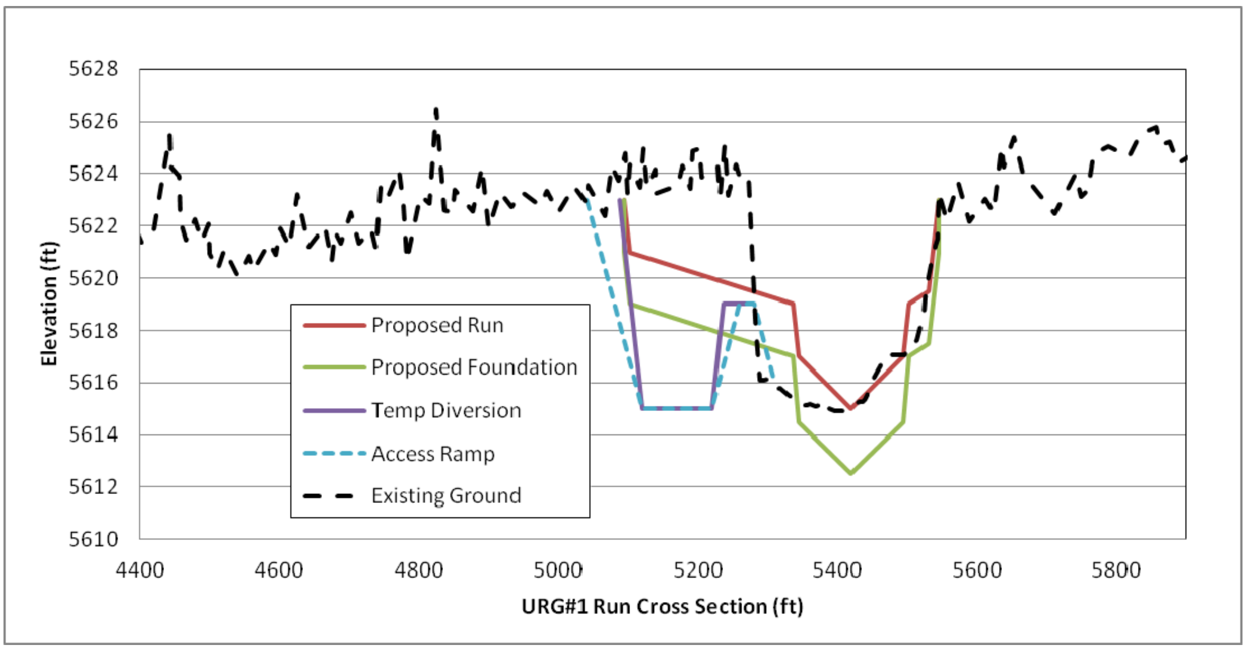

Figure 51 Cross section (downstream view) of the runout of the Upper Rio Grande GRF #1.

Figure 51 shows the runout transition approaching the narrows associated with the Rio Chama confluence. An aggressive terrace lowering measure on the left bank will be needed downriver to the next RGF to compensate for local residual flood risks.

8.3.9.6 Rio Chama Grade Restoration Facility #1

Because the Rio Chama GRF #1 is a mile upriver from the Rio Grande, the HEC-RAS model is capable of providing a representative profile of the WSEs for this structure. As with any tributary to a major river, there will be a wide range of mainstem flows for any given tributary flow. Consequently, on a channel as steep as the Rio Chama, the WSE may not be completely independent of the Rio Grande for the first half mile above the confluence. In Figure 52, the first WSE points that are independent of water levels in the Rio Grande are at and upstream of station 2400.

In the middle of Figure 52, there is an existing pool and an upstream riffle. The proposed GRF location is just below the start of the alluvial fan leading down to the Rio Grande.

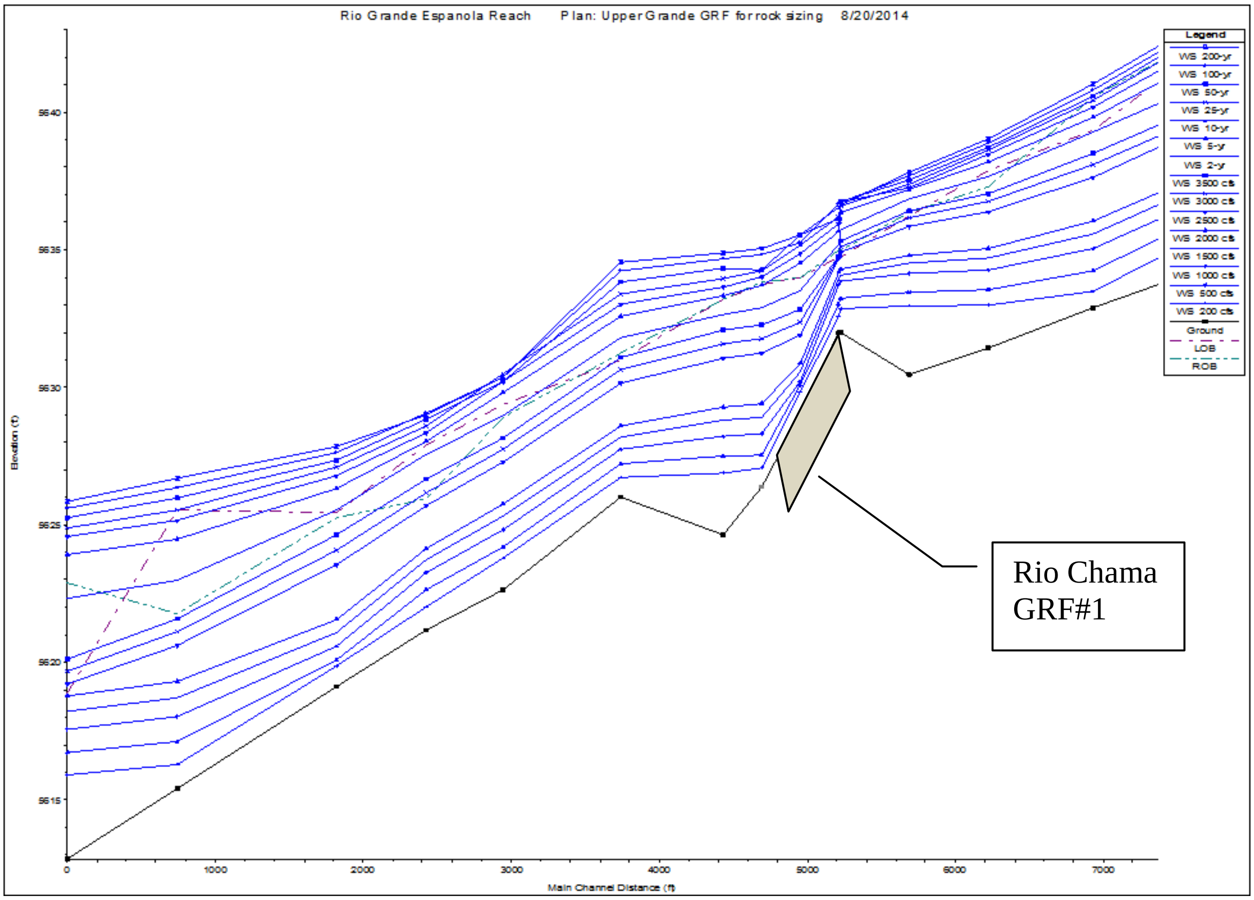

Figure 52 HEC-RAS profile of the GRF below the Salazar Diversion along the Rio Chama thalweg.

The elevation of the diversion for a high flow channel may need to be set above this GRF such that water supply releases are not diverted. This elevation would at a minimum be above the maximum release rate at the dam for water supply calls.

The cross section presented in Figure 53 is a location where the Rio Chama channel narrowed from left to right with the development of a vegetated point bar. The intent is to construct the chute into this point bar and to shift channel flows away from the south bank (shown on the right). The indicated rise in the 50% ACE WSE is still contained in the channel and residual flood risks for larger floods will be mitigated with the high flow channel diversion that bypasses the GRF and passes flow onto adjacent the alluvial fan. Once onto the alluvial fan the diverted flow will be allowed to return to the Rio Chama or to run the length of the alluvial fan and enter the Rio Grande directly.

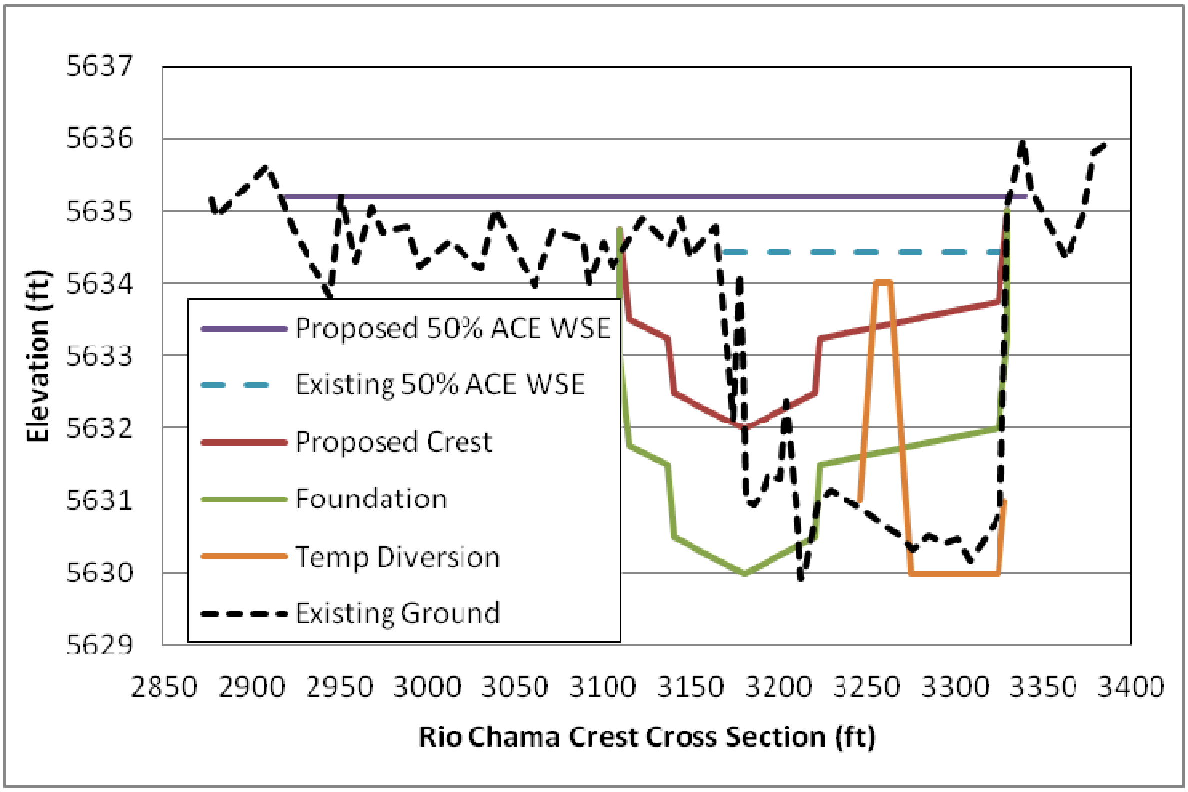

Figure 53 Cross section (downstream view) of the crest of the Rio Chama GRF #1.

Figure 53 shows the upstream crest of the Rio Chama GRF#1 while Figure 54 shows the downstream connection to the run.

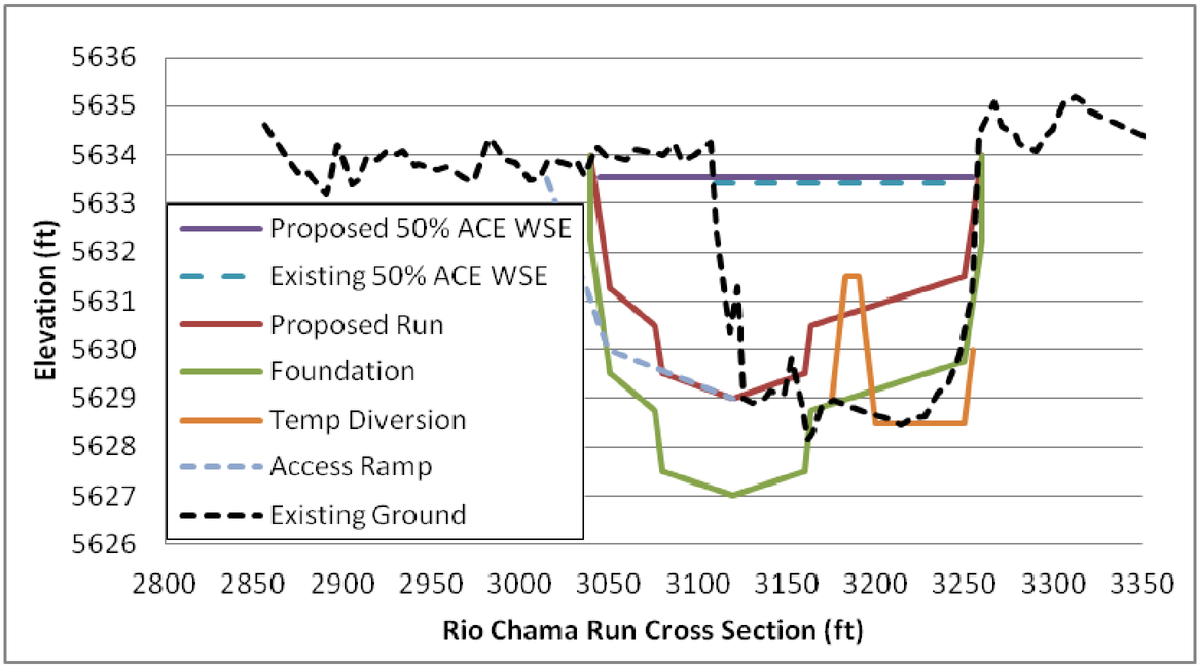

Figure 54 Cross section (downstream view) of the runout of the Rio Chama GRF #1.

The existing condition dashed lines on Figure 55 are well separated at low flows, which is an indication that this riffle is a stable feature on the Rio Chama. The proposed expected future WSE rise on the crest for low flows is primarily within the existing channel and will adequately feed a diversion onto the adjacent splayed alluvial fan.

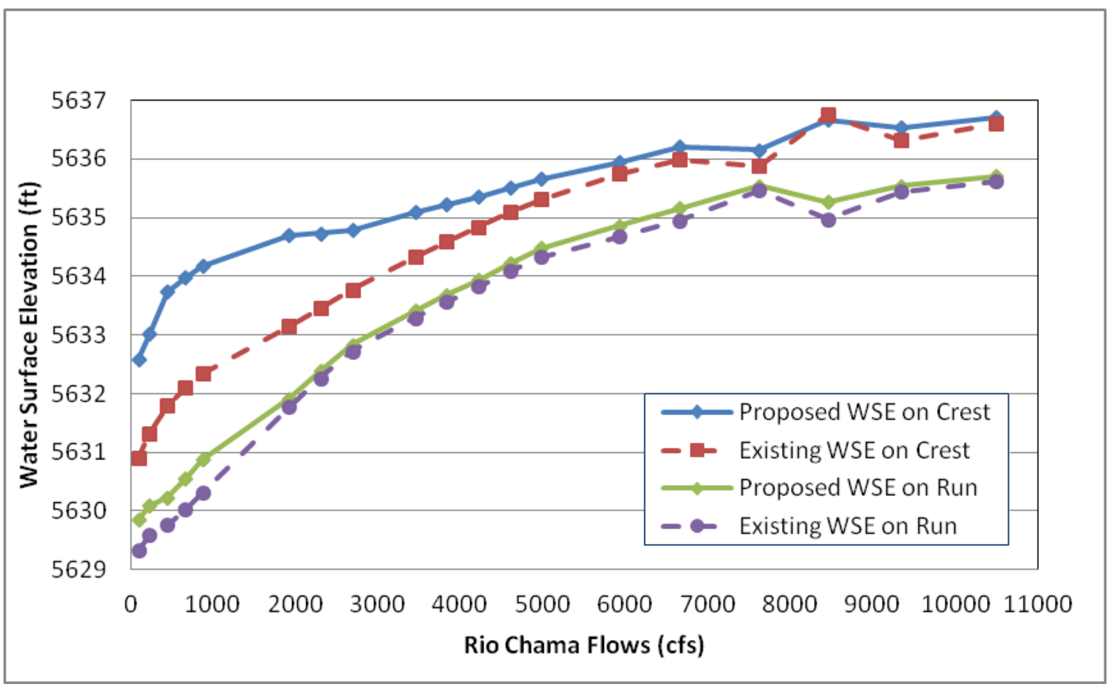

Figure 55 Rating curves of the existing locations and proposed crest and run of Rio Chama GRF #1.

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ATTACHMENT 1 HYDROLOGY REPORT

ATTACHMENT 2 GEOMORPHOLOGY REPORT

ATTACHMENT 3 HYDRAULIC REPORTS

ATTACHMENT 4 SEDIMENT TRANSPORT REPORTS

ATTACHMENT 5 INUNDATION MAPS

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ATTACHMENT 6 RESTORATION POTENTIAL REPORTS

APPENDIX B – ECONOMIC CONSIDERATIONS

U. S. Army Corps of Engineers
Albuquerque District

Española Valley, Rio Grande and Tributaries, New Mexico
Detailed Feasibility Study

June 2015

US Army Corps
of Engineers ®
Albuquerque District

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1 - Economic Considerations – Without-Project Conditions

1.1 Areas of Consideration

The Española Valley study area is located in southern Rio Arriba County and includes a small portion of northern Santa Fe County. The City of Española lies within the Española Valley and extends along both the east and west banks of the Rio Grande. Española is approximately 25 miles north-northwest of Santa Fe and 85 miles south of the New Mexico-Colorado border. The 2010 U.S. Census determined that 10,224 of Rio Arriba County's 40,246 people lived within the City of Española. The study area consists of structures commonly found in a U.S. urbanized area, such as residential, outbuildings (such as detached garages, sheds, etc), public and commercial structures. The study area also consists of agricultural fields as well as undeveloped Native American properties.

Three Native American Reservations (also referred here as pueblos) lie within the Española Valley study area.They include: the Ohkay Owingeh Pueblo (formerly San Juan Pueblo), the Santa Clara Pueblo and the San Ildefonso Pueblo. The 2010 U.S. Census determined that for the Ohkay Owingeh Pueblo, the Santa Clara Pueblo and the San Ildefonso Pueblo, the population of these pueblos were 1,143, 1,018 and 524 respectively.

Ohkay Owingeh Pueblo is the northern most pueblo in the study area. It's located north of the City of Española and includes Rio Chama/Rio Grande confluence. Furthermore, Ohkay Owingeh includes both banks of the Rio Chama, the Rio Grande north of the confluence (denoted in this appendix as "upstream Rio Grande") and the northern section of the Rio Grande south of the confluence (denoted in this appendix as the "downstream Rio Grande"). To the north of the Ohkay Owingeh Pueblo and within the study area is non-Tribal land.

Santa Clara Pueblo is located south of the Ohkay Owingeh Pueblo and is separated from the Ohkay Owingeh Pueblo by non-Tribal land. Santa Clara Pueblo is situated immediately downstream of the City of Española along the Rio Grande and includes three tributaries that flow directly into the Rio Grande. They include: the Santa Cruz River, which flows into the Rio Grande from the east; Arroyo de Guachupangue, flows into the Rio Grande from the west; and the Santa Clara Creek**, which flows into the Rio Grande from the west and is located south of the Arroyo de Guachupangue. The City of Española is situated along both banks of the Rio Grande and is sandwiched by the Santa Clara Pueblo to the south and Ohkay Owingeh lands to the north.

<u>NOTE</u>: *In 2011, the Santa Clara Creek Watershed was severely impacted due to the Las Conchas wildfire. As a result, Santa Clara Pueblo has experienced significant flooding from Santa Clara Creek. A separate study (Santa Clara Creek 205 of the Continuing Authorities Program) will address the economic damages associated with increased flooding along Santa Clara Creek and therefore damages associated with flooding along Santa Clara Creek are not included in this analysis.*

San Ildefonso Pueblo is the southernmost pueblo in the study area. It lies downstream of the City of Española and immediately south of the Santa Clara Pueblo along the Rio Grande. San Ildefonso also encompasses the Pojoaque River, which flows into the Rio Grande from the east. Figure 1 displays maps of where significant structures were located as well as an overall map of the study area.

Figure 1 - Inventory at Ohkay Owingeh Pueblo [1% (green) and .02% (blue) floodplains]

Figure 1 (continued) - Inventory at Santa Clara Pueblo [1% (green) and .02% (blue) floodplains]

Figure 1 (continued) - Inventory at San Ildefonso Pueblo [1% (green) and .02% (blue) floodplains]

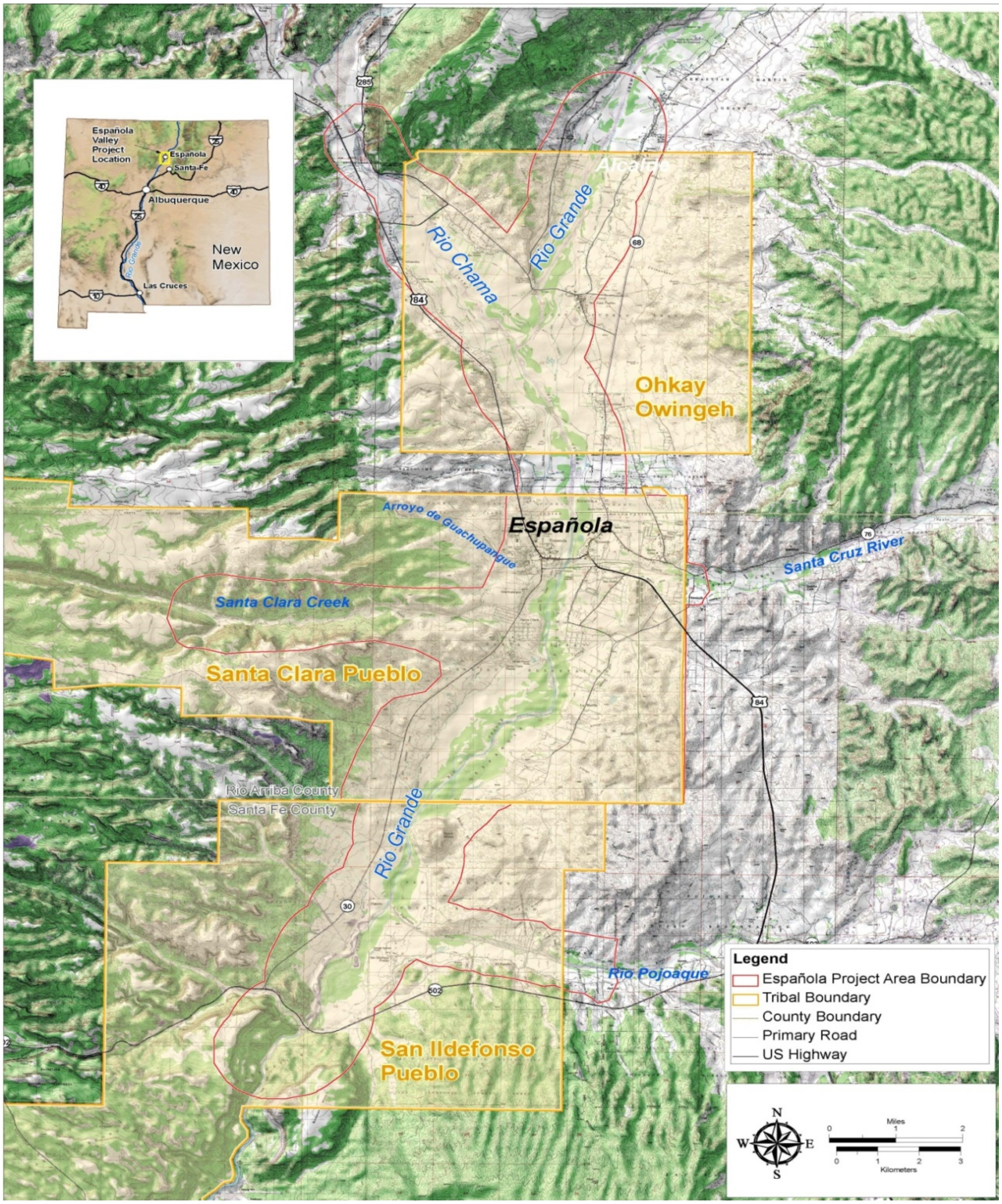


Figure 1 (continued) - Map of study area overview

1.2 General Computational Procedures

The assumptions and procedures used to analyze and quantify the economic variables are presented in this section. The hydro-economic model used to develop expected annual damages is based on discharge-frequency, stage-discharge, and depth-damage curves used to develop a damage-frequency curve. Depth-percent damage curves express damages resulting from varying depths of water based on a percentage of the value of structure and contents.

Each surveyed property is assigned to a category (e.g., commercial, residential, public, apartment, transportation facilities, utilities, and vehicles) with as many subcategories (e.g., contents) as necessary, and details of ground and first floor elevations are noted. Each category has an associated depth-damage relationship expressed as a cumulative percentage of value for each foot of inundation. The depth-damage relationships were derived from historical data obtained from insurance companies, a recent commercial content survey, the Flood Insurance Administration, and U.S. Army Corps of Engineers (USACE) experience. Note that the 2003 residential curves developed by the USACE Institute for Water Resources (IWR) were used; thus, the residential content damages are a function of structure value.

The elevation of each property (determined from GIS-based topographic maps and field investigations) is aggregated by location and structure type to compute the vertical distribution of damageable property at that location. Each property category is then tabulated in terms of the number of units, average value per unit and aggregate value, within consecutive inundation depth ranges for each location. That inventory is set into the Hydrologic Engineering Center's Flood Damage Analysis (FDA) ver. 1.2.5 to compute expected annual and equivalent annual damages (EAD).

This report contains descriptive tables (number of structures subject to flooding by event, value of damageable property by property type and event, and single occurrence damages associated with specific frequency events) that were generated as a reality check of the FDA analysis. The study area's floodplain is fairly wide and flat, such that structure first floor height has a tremendous bearing on start of damages and damages attributable to specific events. To compute the number of structures in a given floodplain, the FDA_StrucDetail.out file was consulted, which computes number of structures, value of damageable property, and single occurrence damages. This computation assumes "without-risk" but serves as a consistency check on EAD and equivalent annual benefit calculations.

Table B-1 displays the depth-damage relationships used in this study. Table B-2 and Table B-3 display the number of damageable property units by floodplain, in the present and the future hydraulic conditions. Table B-4 and Table B-5 present the value of damageable property units by floodplain. As a quality check, these tables also display average value per structure, which is computed by dividing the number of structures in Tables 4 and 5 by the corresponding values in Tables B-2 and B-3. The 2010 Census indicates the average household size in Santa Clara Pueblo (where most of the damageable property is located) is 2.52 persons. Multiplying this figure by the number residential and apartment structures in the 1% chance and 0.2% chance floodplains suggest that the study area has a population at risk (PAR) of 930 persons from the 1% chance flood and 1,208 persons from the 0.2% chance flood.

Section 308 of the Water Resources Development Act of 1990 states "The Secretary shall not include in the benefit base for justifying Federal flood damage reduction projects...any new or substantially improved structure...built in the 100-year flood plain with a first floor elevation less than the 100-year flood elevation after July 1,1991." To comply with that requirement, the latest Flood Insurance Rate Maps (FIRM) of the study area were consulted and compared to identified study floodplains. The latest FIRM data was acquired online at https://msc.fema.gov/portal.

The latest applicable FIRM mapping has an effective date of 3/15/2012 and applies to Rio Arriba County. The study area was evaluated against this mapping, and while there are areas on the FIRM that indicate a flood problem, there is no identified 100-year flood plain elevation identified that would trigger the Section 308 exclusion. All structures identified in the field inventory were included in benefit computations.

For each category, the aggregate value of property at each flood depth is combined with the depth-damage relationship to compute total, single event damages for each level of flooding. Table B-6 and Table B-7 displays the single occurrence damages by category for the floodplain evaluated, both in the present and future without project conditions. These damage estimates are combined with the discharge-frequencies of the reference floods to calculate damage-frequency relationships. Damage-frequency relationships provide probable average annual damages for each category under the conditions of each reference flood, and can then be compared to the hydrologic, hydraulic, and economic data analyzed within FDA. Tables B-8 thru Table B-11 present the expected annual damages computation from the FDA analysis for both the present and future without project conditions.

Figure 2 demonstrates the integration of hydrology and hydraulics data with the economic information developed in this appendix to generate the EAD computation:

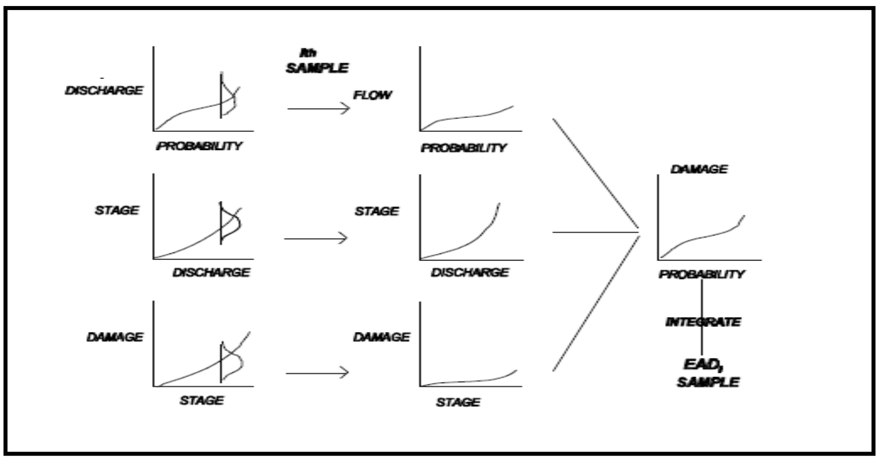


Figure 2 – EAD methodology.

1.3 Value of Property

A survey of structures within the floodplain was conducted in September of 2008 (main stem Rio Grande and Rio Chama) and in January of 2009 (the four tributaries) to evaluate the flood threat to the study area. In November of 2013, the entire inventory was re-evaluated, by using Google Earth and a through a windshield survey to ensure that (1) no structures were added/removed from the study area and (2) the characterizations of structures determined in 2008/2009 remained the same. No significant changes were noted. Also, as previously stated, the inventory update included removing structures along Santa Clara Creek as those structures were now being evaluated under a separate flood risk management study .

The property examined was categorized into residential, commercial, and public buildings, as well as, vehicles, streets and utilities, and outbuildings (sheds and detached garages). The field survey gathered primary data such as structure description (quality of construction, construction materials, number of floors and presence of basements), an estimate of effective age for depreciation purposes, occupancy type, elevation above grade, an estimate of structure size in square feet, and the number of nearby structures that share these attributes. Tables B-2 and B-3 and Tables B-4 and B-5 show the number of property units and the value of damageable property affected by the 10-percent, 2-percent, 1-percent and 0.2 percent chance flood events, respectively. These tables were generated using HEC-FDA's FDA_StrucDetail.out file for descriptive purposes only, to better understand the nature of the damages reported by FDA.

Depreciated, replacement residential structure values were computed using the factors and methods described in the Marshall Valuation Service, published by the Marshall and Swift Company. USACE regulations require cost-benefit evaluations use depreciated replacement costs. Replacement cost is the cost of physically replacing (reconstructing) the structure. Depreciation accounts for deterioration occurring prior to flooding, and variation in remaining useful life of structures. Depreciated replacement cost computations include factors such as construction type (wood, masonry) and quality, effective age (for depreciation purposes), and local market prices that bring the value of the structure to what we'd expect to spend on a "replacement in kind" structure in the study area. That computation was then verified in the field through interviews with local realtors and insurance agents to verify structure ages and replacement costs of structures in the floodplain. A windshield survey of all structures was also conducted to establish first floor elevation above grade of structures in each damage reach. That elevation above grade was added to the ground surface elevation Digital Terrain Model (DTM) data used in the hydraulic model to tie the economic inventory to the floodplain model. Commercial, public and apartment structures were inventoried in the field survey using the Marshall and Swift Valuation Service.

Content values were estimated from several sources. Residential content values were held at 50% of the structure value. Insurers who were contacted provided estimated content values that are greater than 55% of structure value. Where the IWR 2001 and 2003 structure and content depth-damage relationships were used, content damages are expressed as a percentage of structure value. Commercial and public content values were computed using surveys of similar establishments and interviews. Vehicle values were determined using in-house data and published surveys. Total vehicles in the floodplain are for residential structures and apartments. The typical household in Rio Arriba County has 1.83 vehicles. It is assumed that one of these vehicles is driven out of the floodplain before any flood event. The remaining vehicles were distributed to the residential and apartment structures located within the 0.2 percent chance exceedance floodplain. It was assumed that all business-related vehicles were already evacuated from the floodplain.

1.4 Valuation of Roads, Utilities, Agricultural and Emergency Services

Streets were measured from floodplain maps to determine quantities susceptible to flooding for each event. Streets and roads within the floodplain were elevated to a median elevation for each particular flood event for which floodplains were generated, and were "damaged" per elevation-damage relationships developed by the Galveston District. The resulting damages per event were then probability-adjusted per the likelihood of the event, and summed to compute EAD. Figure 3 displays sample of that calculation follows:

Roads

Freq	Interval	Value	Single Occ.	Total
0		36,715,390.98		
	0.002		36,715,390.98	73,430.78
0.002		36,715,390.98		
	0.008		30,868,198.44	246,945.59
0.01		25,021,005.91		
	0.01		23,370,744.67	233,707.45
0.02		21,720,483.42		
	0.08		16,093,455.23	1,287,476.42
0.1		10,466,427.03		
	0.01		5,233,213.52	52,332.14
0.11		0.00		
Sum				1,893,892.37

Figure 3- Sample event-damage calculation

Construction costs for roads were obtained from the City of Alamogordo, NM (http://ci.alamogordo.nm.us/Assets/COA+Document/City+Clerk/Minutes/04-08-2008+Regular+Minutes.pdf, accessed 10/30/2009) and the Arkansas State DOT (http://www.arkansashighways.com/roadway_design_division/Cost_per_Mile_JULY_2009.pdf, accessed 10/30/2009). It was assumed that utility quantities (expressed in linear feet) were identical to paved street quantities. Utility construction costs were obtained from the Arizona and Texas Departments of Transportation. Damage estimates were calculated from published data provided by the Galveston District. Agricultural acreage was measured using aerial photography of the floodplains used in this study. Agricultural valuation and damage assessment for crops within the study area was calculated using crop budgets from the NMSU Cooperative Extension Service for the study area. Using the same hydrologic data developed for recreation damage assessment, the crop budget was applied to a typical calendar year to calculate sunk costs if the flood event were to occur before the harvest. The flood events predicted suggest a total loss of that year's crop if the event occurs before the harvest. Flood events occurring after harvest activities were conservatively assumed not to damage the value of the agricultural land, since the crop was already harvested. Officials at the NMSU Cooperative Extension Service provided confirmation of the crop composition (alfalfa hay, permanent pasture and grass hay) and relative distribution for the study area.

Emergency services include the costs of evacuation, reoccupation, disaster relief, and other similar expenses. The emergency costs incurred are dependent upon factors including number of residences damaged, evacuated, etc. Factors used in this study are based upon historical flooding in Carlsbad, NM and interviews with American Red Cross personnel.

1.5 Sources of Uncertainty

The major sources of economic uncertainty include many of the same variables identified above in the damage estimate analysis and others noted as follows:

1. Value of property;
2. Value of property contents;
3. Flood stage at which damage begins;
4. First floor elevations of structures;
5. Responses to flood forecasts and warnings;
6. Flood fighting efforts;
7. Cleanup costs;
8. Business losses;
9. Depth-percent damage curves;
10. Estimate of the stage associated with a given discharge;
11. Estimate of damage for a given flood stage; and
12. Estimate of future land use

Principal sources of error affecting the depth-damage relationship were examined in a risk and uncertainty framework. Those sources of error are 1) errors associated with the damageable property elevation, 2) errors associated with the values of structures in the floodplain inventory, 3) errors associated with values of structure contents in the floodplain inventory, 4) errors associated with the damage functions used against the floodplain inventory.

There are numerous factors which affect the frequency distributions as well as the rating curves for the study area's hydraulic reaches. Those factors are discussed in detail in the Hydrology & Hydraulics Appendix (Appendix A).

1.5.1 Elevation of Damageable Property

A standard deviation of 0.4 feet was used to account for the uncertainty associated with the elevation of damageable property. In the floodplain, the flooding depths are relatively shallow and the flood plains are large and flat; therefore, an elevation difference of one foot could potentially double the damages associated with a given stage. The 0.4 feet standard deviation was used for two reasons. First, since the economic inventory was conducted by a visual windshield inspection, the first floor elevations of structures were estimated rather than measured. Second, the DTM used to develop specific frequency event floodplains introduces a source of uncertainty relative to elevation.

1.5.2 Structure Value

It was assumed that the estimated structure value, which was derived from property tax information, and a field inventory, has a standard deviation of 15 percent of the structure value. That 15 percent standard deviation comes from prior Albuquerque District studies, and prior experience of the Ft. Worth District, which developed that estimate from interviews with various County Assessor's offices.

The structure inventory values and associated error distribution were then evaluated to compute floodplain inventory that incorporates errors concerning structure value. It was assumed that the estimated structure value (derived from field inventory and consultations with Realtors, insurance agents) could be off by 15% of the structure value. The floodplain inventory was then assessed using these assumptions, dropping all values more than three standard deviations from the reported (mean) value. The resulting distribution of structure values with error would contain 99% of possible values given the assumptions above.

1.5.3 Content Value

The error distribution associated with content value varied by structure type. In terms of average annual damages for residential contents the damage curves relate to the structure value rather than the content value.

USACE guidance stipulates residential content values should be held to no more than 50% of structure values, though local insurers note that contents are valued at 55%-60% of structure value, or more. Residential and apartment content value distributions with error were fixed to the error distributions associated with residential and apartment structures. New stage-damage relationships published by IWR in 2003 compute content damages as a percentage of structure value. Content valuation in this appendix is for illustrative purposes only, and content damages for residences use the IWR methods. Commercial and public contents used standard deviations that were equal to the content value to develop the content value with error. The standard deviations were obtained from prior Albuquerque District studies. All content relationships were truncated to eliminate the possibility of negative values.

1.5.4 Depth-Percent Damage Relationship

Depth-percent damage curves are among the most important and least exact data in benefit estimation. Depth-percent damage curves express dollar damages resulting from varying depths of water based on a percentage of the value of structure and contents. Errors associated with the depth-damage functions were applied after the structure and content values were determined. The errors associated with the depth-percent damage relationship were evaluated for structures and contents of all occupancy types. The standard deviations used were those estimated by IWR for residential structures and contents, which comprise the majority of the damages.

The errors associated with the depth-percent damage relationship were evaluated for structures and contents of all occupancy types. It was assumed that 95% of the times, the true damages for a given depth of flooding fall between ±40% of the estimated damage value by structure and content. Errors associated with the depth-damage functions used were applied after the uncertain structure and content values were determined.

1.6 Use of HEC-FDA 1.2.5 and Special Considerations for the Study Area

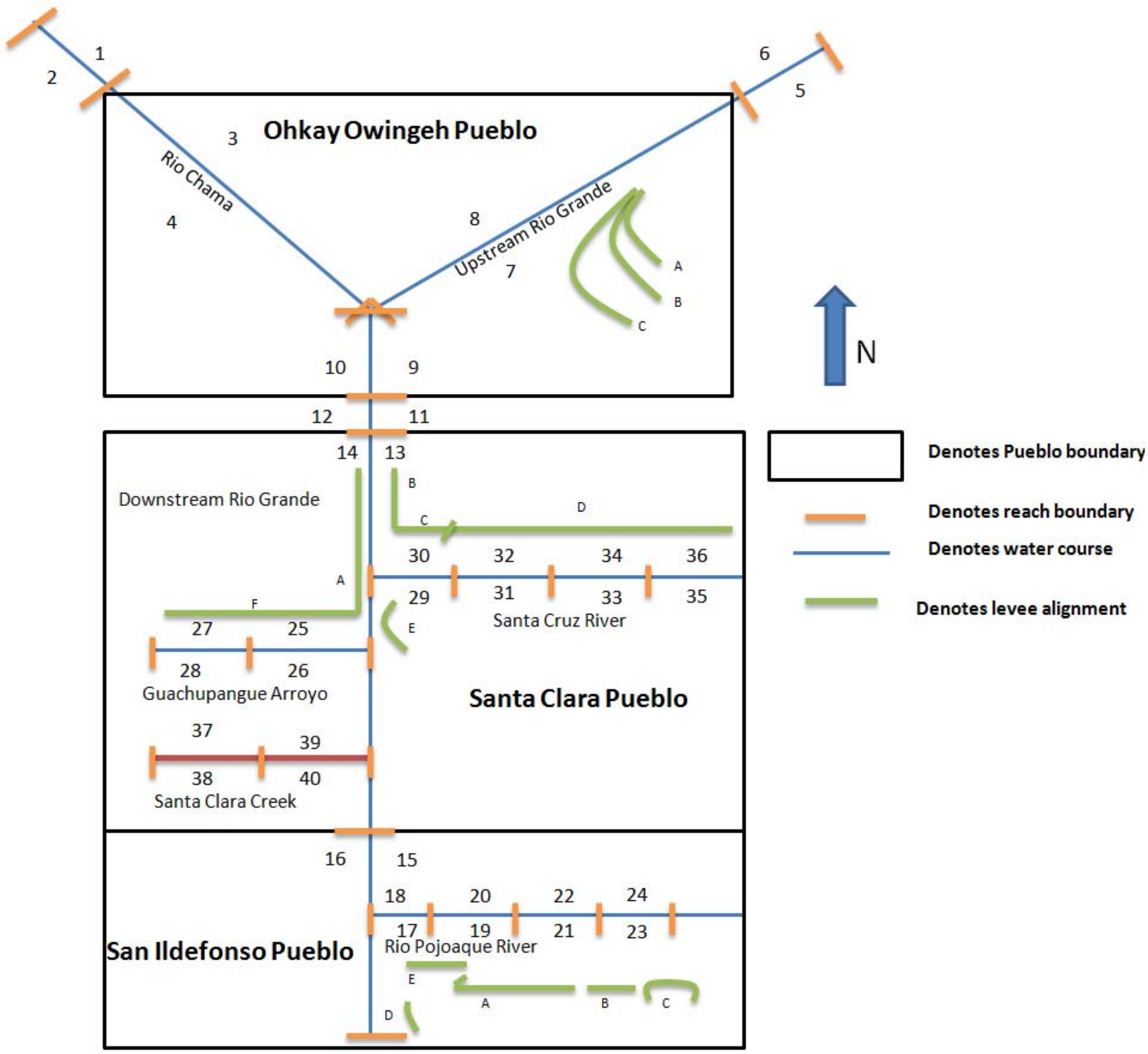
Consistent with the requirements set forth in EC 1105-2-412, *Assuring Quality of Planning Models* HEC-FDA version 1.2.5 was used to compute average annual damages and EAD. USACE guidance stipulates that the plan which reasonably maximizes net National economic development benefits, consistent with the Federal objective, be identified. Project benefits for flood risk management measures are identified through successive iterations of existing and future without-project scenarios, changing key hydrologic and/or hydraulic variables as the measures warrant. FDA is the only model certified for formulation and evaluation of flood risk management plans using risk analysis methods, and was used in this study. Damages are computed in October, 2014 price levels using the fiscal year 2015 Federal discount rate of 3.375%. The period of analysis is 50 years

The study area included three Native American Reservations including non-tribal land. Furthermore, Tribal boundaries encompass portions of the main stem Rio Grande, as well as portions of a number of tributaries. Largely due to the hydrology/hydraulic changes in these rivers and tributaries, reaches were needed to differentiate the benefits associated with the four different entities and for each stream within those entities. Table 1 below displays the reaches used in this study.

Table 1 – Description of Economic Reaches and Wiring Diagram

Reach Name	Description
ESP-1	Along Rio Chama, left bank, from 28075.65 to 21570.12 on non-tribal property. Index point 28075.65
ESP-2	Along Rio Chama, right bank, from 28075.65 to 21570.12 on non-tribal property. Index point 28075.65
ESP-3	Along Rio Chama, left bank, from 17010.09 to 5958.59 on Ohkay Owiengeh property. Index point 12387.10
ESP-4	Along Rio Chama, right bank, from 17010.09 to 5958.59 on Ohkay Owiengeh property. Index point 12387.10
ESP-5	Along Upstream Rio Grande left bank from 95223.62 to 95223.61 on non-tribal property Index point 95223.62
ESP-6	Along Upstream Rio Grande right bank from 95223.62 to 95223.61 on non-tribal property Index point 95223.62
ESP-7	Along Upstream Rio Grande left bank, from 95223.61 to 84545.25 on Ohkay Owiengeh property. Index point 89565.54

Reach Name	Description
ESP-8	Along Upstream Rio Grande right bank, from 95223.61 to 84545.25 on Ohkay Owiengeh property. Index point 89565.54
ESP-9	Along Downstream Rio Grande left bank from 82450.43 to 74499.63 on Ohkay Owiengeh property. Index point 74499.63
ESP-10	Along Downstream Rio Grande right bank from 82450.43 to 74499.63 on Ohkay Owiengeh property. Index point 74499.63
ESP-11	Along Downstream Rio Grande left bank at 68232.63. On non-tribal property. Index point is 68232.63
ESP-12	Along Downstream Rio Grande right bank at 68232.63. On non-tribal property. Index point is 68232.63
ESP-13	Along Downstream Rio Grande left bank at 62350.51 to 35516.98. On Santa Clara property. Index point is 62350.51
ESP-14	Along Downstream Rio Grande right bank at 62350.51 to 35516.98. On Santa Clara property. Index point is 62350.51
ESP-15	Along Downstream Rio Grande left bank at 30322.24 to 8544.51. On San Ildefonso property. Index point is 19857.95
ESP-16	Along Downstream Rio Grande right bank at 30322.24 to 8544.51. On San Ildefonso property. Index point is 19857.95
ESP 17 & 18	Along the Rio Pojoaque left/right bank at 187 to 3220. San Ildefonso Property. Index point is 2015 (Sub-reach 5)
ESP 19 & 20	Along the Rio Pojoaque left/right bank at 3326 to 7603. San Ildefonso Property. Index point is 7200 (Sub-reach 4)
ESP 21& 22	Along the Rio Pojoaque left/right bank at 8036 to 12464. San Ildefonso Property. Index point is 11216 (Sub-reach 3)
ESP 23 & 24	Along the Rio Pojoaque left/right bank at 12526 to 16635. San Ildefonso Property. Index point is 13399 (Sub-reach 2)
ESP 25 & 26	Along Guachupangue left/right bank at 197to 1412. On Santa Clara property. Index point is 1305 (Downstream)
ESP 27 & 28	Along Guachupangue left/right bank at 1531 to 3966. On Santa Clara property. Index point is 1949 (Above NM30)
ESP 29 & 30	Along Santa Cruz left/right bank at 152 to 2625. On Santa Clara property. Index point is 1512 (Sub-reach 4)
ESP 31 & 32	Along Santa Cruz left/right bank at 2670 to 7196. On Santa Clara property. Index point is 3310 (Sub-reach 3)
ESP 33 & 34	Along Santa Cruz left/right bank at 7320 to 11668. On Santa Clara property. Index point is 9854 (Sub-reach 2)
ESP 35 & 36	Along Santa Cruz left/right bank at 11747 to 13020. On Santa Clara property. Index point is 12229 (Sub-reach 1)
ESP 37 & 38	Along Santa Clara left/right bank at 230 to 4533. On Santa Clara property. Index point is 3804 (Sub-reach 7) ** ***(Removed from this study. See section 1.1)***
ESP 39 & 40	Along Santa Clara left/right bank at 4622 to 8959. On Santa Clara property. Index point is 5237 (Sub-reach 6) ** ***(Removed from this study. See section 1.1)***



Wiring Diagram

All inventory (including structures and their contents, agriculture, vehicles, roads and utilities) within the assigned reaches was assigned to one index cross-sections in that reach and calculated in FDA. The assignments of cross-sections could be found in the Hydrology and Hydraulics appendix. Table B-12 was created to show the Equivalent Annual Damages (EAD) for both the right and left banks of all streams within the study area. Table B-13 was created to show the EAD for all streams associated with a tribal entity. Each tribe and non-tribal lands were assigned a number of reaches for both the right and left banks of each stream.

The study area had areas of coincidental flooding and due to the complex nature of the flooding in the Santa Clara Pueblo, multiple modules were generated within FDA to accurately capture any damages from the coincidental flooding from the Rio Grande/Santa Cruz and the Rio Grande/Guachupangue. Additional information can be found in Section 1.9 of this appendix.

1.7 Potential Flood Damages

It is currently estimated that the mean 1% chance exceedance flood would cause damages of about $4,440,000 in the study area in the present, without-project condition and due to channel incision in a significant portion of the study area decreases to about $3.5 million in the future. Tables B-6 and B-7 present the single occurrence damages associated with the 10%, 2%, 1%, and 0.2% chance flows in the assorted floodplains. It was assumed that flood events of a magnitude greater than the 20% chance event damage structures, contents, and vehicles in the flooding areas analyzed. It should be noted that many intangible damages (such as loss of life, disruption to community services, and increased health risks) that could occur because of flooding are not represented in these damage values.

Future flood damages resulting from development or growth in the floodplain have not been included, but are not expected to be significant for several reasons: 1) Tribal property, which consists of the majority of the study area, is not expected to develop; 2) local contacts have noted that most development in the study area may occur outside the floodplain.

1.8 Average Annual Damages

Risk and uncertainty analysis was used to derive average annual damages. Hydrologic and hydraulic uncertainty was combined through Monte Carlo simulations within FDA. When flooding from all sources is considered, the study area faces the risk of approximately $533,190 to structures and contents and $922,000 when including all damage categories. Tables B-12 and B-13 presents the average (equivalent) annual damages that could occur from flooding in the study area without any flood protection. A sensitivity analysis was conducted to illustrate that when FDA was computed "without risk," the EAD damages to structures and contents decreased from $533,190 to $336,300.

1.9 Coincidental Flows and Use of FDA 1.2.5

There are two areas within Santa Clara Pueblo that have properties at risk of flooding from more than one source (denoted in this appendix as "coincidental flows areas"). The first area of coincidental flows is located east (left bank) of the Rio Grande and north (right bank) of the Santa Cruz River. In this area, 15 structures, including the waste water treatment plant, are impacted by coincidental flows. The second area of coincidental flows is located west (right bank) of the Rio Grande and along both banks (left and right) of the Arroyo de Guachupangue. In this area, 113 (mostly commercial with some residential) structures are impacted by coincidental flows. Figure 4 shows a visual representation of the areas of coincidental flow.

To determine the impact of coincidental flows, and to determine whether a structural FRM measure would be justified, all structures in the coincidental flow areas were evaluated to determine flood impacts from the Rio Grande as well as from the applicable tributary. The FDA .sty file contained two without-project conditions. The first without-project condition contained the base module, which contained the structural inventory minus the structures impacted by the coincidental flow. The second without-project condition contained four modules. The first module named "Rio Grande 15" analyzed the damages of the 15 structures affected by the Rio Grande and the Santa Cruz coincidental flooding and assigned those structures to the hydrology of the Rio Grande. The second module named "Santa Cruz 15" were the same 15 structures described earlier and assigned those structures to the hydrology of the Santa Cruz

The third module named "Rio Grande 113" analyzed the damages of the 113 structures affected by the Rio Grande and the Guachupangue coincidental flooding and assigned those structures to the hydrology of the Rio Grande. The fourth module named "Guachupangue 113" were the same 113 structures described earlier and assigned those structures to the hydrology of the Guachupangue. The areas that were determined to be the greatest source of damages (between the Rio Grande/Santa Cruz and between the Rio Grande/Guachupangue) were added to the base module to determine EAD for the entire study area.

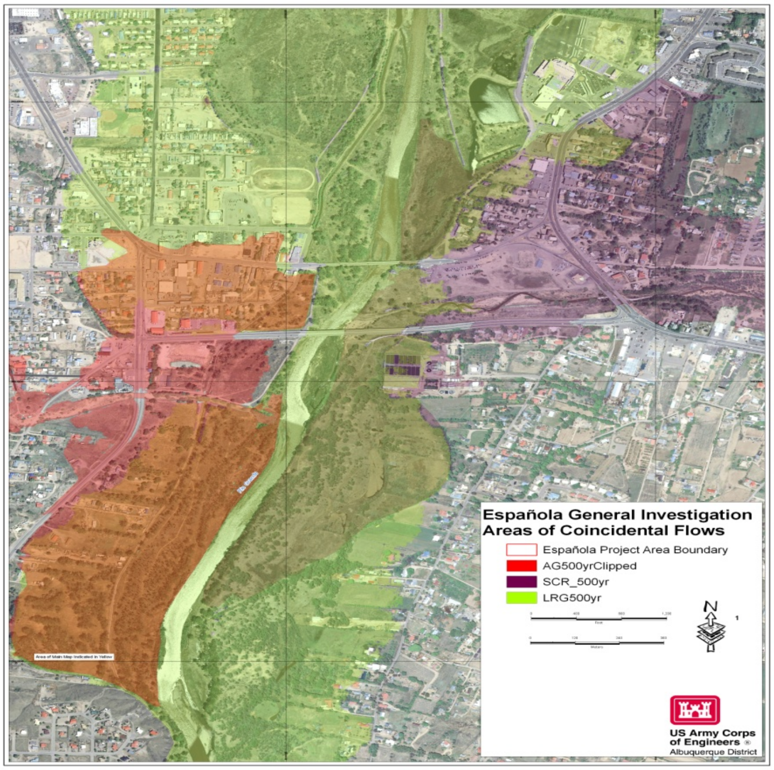


Figure 4 - Representation of coincidental flow areas (.2% Arroyo de Guachupangue (AG), Rio Grande River (LRG) and Santa Cruz River (SCR) floodplains).

Finally, using the FDA_StrucDetail.out file, each individual structure was analyzed individually to the main stem Rio Grande and then to the appropriate tributary to determine if any sort of non-structural was economically feasible for that particular structure. Table 2 displays the modules used in FDA.

Table 2- Modules used in FDA

List of Structure Modules

File View Help

H&H data for Economics
List of Structure Modules

Name	Description
Base	Default module, normally for existing structures
Rio Grande 113	Right Bank RG strucutres impacted by coincidental flows
Rio Grande 15	Left Bank RG structures impacted by coincidental flows
Guachupangue 113	Guachupangue structures that are impacted by coincidental flows
Santa Cruz 15	Santa Cruz strucutures impacted by coincidential flows

Based on this analysis, Table 3 shows the damages to structures and contents from the tributaries (Guachupange and Santa Cruz) is greater when you reassign the structures from Reach 13 and 14 to

Reaches 31/32 (Santa Cruz) and 27/28 (Guachupangue) . As a result the modules “Santa Cruz 15” and “Guachupangue 113” were added to the base module and used to calculate EAD.

Table 3 - Damages from tributaries

Santa Cruz	On Santa Clara and flows into RG from east	ESP-30	SANTA CRUZ RIGHT BANK 152-2625	0.00	0.00	0.00	0.00	0.00	0.00
		ESP-29	SANTA CRUZ LEFT BANK 152-2625	0.00	0.00	0.00	0.00	0.00	0.00
		ESP-32	SANTA CRUZ RIGHT BANK 2670-7196	0.00	15.13	0.00	0.00	4.86	19.99
		ESP-31	SANTA CRUZ LEFT BANK 2670-7196	0.00	54.82	0.00	0.00	0.00	54.82
		ESP-34	SANTA CRUZ RIGHT BANK 7320-11668	0.00	0.00	0.00	0.00	0.00	0.00
		ESP-33	SANTA CRUZ LEFT BANK 7320-11668	0.00	0.00	0.00	0.00	0.00	0.00
		ESP-36	SANTA CRUZ RIGHT BANK 11747-13020	0.00	0.00	0.00	0.00	0.00	0.00
		ESP-35	SANTA CRUZ LEFT BANK 11747-13020	0.00	0.00	0.00	0.00	0.00	0.00
	Total for stream: Santa Cruz			0.00	69.95	0.00	0.00	4.86	74.81
Guachupangue	On Santa Clara and flows into RG from west	ESP-26	GUACHUPANGUE RIGHT BANK 197-1412	0.00	0.00	0.00	0.00	0.00	0.00
		ESP-25	GUACHUPANGUE LEFT BANK 197-1412	0.00	0.00	0.00	0.00	0.00	0.00
		ESP 28	GUACHUPANGUE RIGHT BANK 1531-3966	0.00	0.00	0.00	0.00	0.21	0.21
		ESP-27	GUACHUPANGUE LEFT BANK 1531-3966	0.15	60.45	0.00	36.37	15.43	112.40
	Total for stream: Guachupangue			0.15	60.45	0.00	36.37	15.63	112.60

2 - Economic Considerations –With-project Conditions

2.1 Analysis of Levee Heights

Several alternative levee heights, with sizes corresponding to the mean 1% chance exceedance event stage and plus and minus 1 foot of the mean 1% chance exceedance event stage, were evaluated in a framework incorporating elements of risk and uncertainty in hydrology, hydraulics and economics. Any analysis of alternatives must include the No Action alternative. If no action is taken, the floodplains defined by the study will continue to suffer damages described earlier in this appendix. Each height uses the same real estate footprint and will substantially replace any spoilbank levees so alternative alignments were not considered for this analysis.

Table 4, below, describes how the alternative levee sizes were selected to contain specific flood events. Given the risk and uncertainty framework used in plan selection, it is inappropriate to describe an alternative in terms of "level of protection." The terms ("Base levee", "Base + 1 ft. levee", etc...) describe a height that corresponds to a mean event stage Table 5 describes all the levees/floodwalls analyzed for this analysis and if the alignments are economically justified.

In Appendix J (Attachment B), graphics display the proposed levee alignments found in Table 5. Levee alignments can also be found in Table 1 in this appendix.

Table 4 - Alternative levee heights evaluated

Levee Height	Description
Base	Approximately the mean 1% chance exceedance flood stage, present conditions
Base - 1 ft	Base levee minus 1.0 foot of levee height
Base +1 ft	Base levee plus 1.0 foot of levee height

Table 5 – Benefit-Cost Ratios for levee alignments

Description	Project Cost	Justifiable Construction	Initial Result	Average Annual Cost ($1,000's)	Average Annual Benefits ($1,000's)	BCR
Floodwalls						
Ohkay Owingeh						
Alignment A						
Base -1	$1,511,653	$1,791,775	Carried froward for additional evaluation	64.45	18.40	0.3
Base	$2,007,277	$1,791,775	Project cost exceeds total damage capture	---	---	-
Base +1	$2,419,043	$1,791,775	Project cost exceeds total damage capture	---	---	-
Earthen Levees						
Ohkay Owingeh						
Alignment A						
Base -1	$399,480	$1,791,775	Carried froward for additional evaluation	22.99	18.42	0.8
Base	$618,018	$1,791,775	Carried froward for additional evaluation	35.57	36.12	1.0
Base +1	$857,959	$1,791,775	Carried froward for additional evaluation	57.38	65.17	1.1
Alignment B						
Base -1	$562,955	$1,791,775	Carried froward for additional evaluation	32.40	18.40	0.6
Base	$842,228	$1,791,775	Carried froward for additional evaluation	48.47	36.10	0.7
Base +1	$1,141,188	$1,791,775	Carried froward for additional evaluation	65.68	79.20	1.2
Alignment C						
Base -1	$875,708	$1,791,775	Carried froward for additional evaluation	50.40	10.40	0.2
Base	$1,237,141	$1,791,775	Carried froward for additional evaluation	71.20	36.10	0.5
Base +1	$1,763,187	$1,791,775	Carried froward for additional evaluation	101.48	79.20	0.8
Santa Clara						
Alignment A						
Base	$3,162,244	$548,861	Project cost exceeds total damage capture	---	---	-
Base +1	$4,100,001	$548,861	Project cost exceeds total damage capture	---	---	-
Alignment B						
Base	$395,045	$588,267				
Base +1	$565,769	$588,267	Project cost exceeds total damage capture			
Alignment C						
Base	$821,351	$915,942	Carried froward for additional evaluation	35.02	31.10	0.9
Base +1	$935,699	$915,942	Carried froward for additional evaluation	39.89	37.40	0.9
Alignment D						
Base	$959,327	$2,375,585	Carried froward for additional evaluation	46.90	69.89	1.4
Base +1	$1,301,277	$2,375,585	Carried froward for additional evaluation	55.48	55.48	1.0
Alignment E						
Base	$193,098	---	Out per sponsor request	---	---	-
Base +1	$272,482	---	Out per sponsor request	---	---	-
Alignment F						
Base	$636,661	$1,989,271	Carried froward for additional evaluation	27.14	82.40	3.0
Base +1	$791,046	$1,989,271	Carried froward for additional evaluation	33.73	110.14	3.3
San Ildefonso						
Alignment A						
Base	$2,227,789	$2,285,000	Project cost exceeds total damage capture	---	---	-
Base +1	$2,648,586	$2,285,000	Project cost exceeds total damage capture	---	---	-
Alignment B						
Base	$3,390,672	---	Out per sponsor request	---	---	-
Base +1	$4,115,897	---	Out per sponsor request	---	---	-
Alignment C						
Base	$1,502,110	---	Out per sponsor request	---	---	-
Base +1	$1,794,192	---	Out per sponsor request	---	---	-
Alignment D						
Base	$2,139,112	---	Out per sponsor request	---	---	-
Base +1	$2,551,222	---	Out per sponsor request	---	---	-
Alignment E						
Base	$1,569,893	$2,285,000	Out as Alignment A is needed for Alignment E to be effective	---	---	-
Base +1	$1,893,357	$2,285,000	Out as Alignment A is needed for Alignment E to be effective	---	---	-

2.2 Descriptions of Levees for the Study Area

In total, there were 15 separate alignments in the Espanola Valley study area. Four were located on Ohkay Owingeh Pueblo, six were located in Santa Clara Pueblo and five were located in San Ildefonso Pueblo.

On Ohkay Owingeh, Alignment A (floodwalls and levees) followed the left bank of the Rio Grande above the Rio Grande/ Rio Chama confluence. The primary purpose was to protect an elementary school. Alignments B and C, also following the east bank of the Rio Grande above the confluence, were proposed to be implemented primarily to protect a sparsely populated area of single family housing and residential outbuildings (sheds, detached garages, etc).

On Santa Clara, Alignments A and B were proposed to be aligned along both banks of the main stem Rio Grande (below the Rio Grande/Rio Chama Confluence) within the pueblo boundary. Alignments C, D and E were proposed to be aligned along both banks of the Santa Cruz River. Alignment F was proposed to be aligned along Arroyo de Guachupangue (right bank). Levees A-F were proposed to protect a more heavily populated area of the Espanola Valley, which consists of residential, public and commercial properties.

On San Ildefonso, all alignments (A-E) were proposed to be along the left bank of the Rio Pojoaque. The five alignments of these levees were proposed to protect mostly residential structures and a few public structures.

2.3 Modeling Levees in HEC-FDA 1.2.5

Prior to analyzing the levees found in Table 5 using FDA, the project cost for each alignment was compared to the justifiable construction result for each alignment. The justifiable construction figure is a means to determine if any structural fix might be cost effective, where the benefit-cost ratio (BCR) is greater than 1.0, and was determined by multiplying the EAD of the alignment by the output of the (MS Excel) formula =PMT(x, y,-1), where x = current interest rate (3.375% in FY 2015) and y = proposed project life (50 years). If that final result was less than the proposed construction figure, the alignment was removed from consideration. The alignments that remain include: Alignment A (floodwall) for Ohkay Owingeh (for base and base+1'), Alignments A, B (base+1'), Alignment F for Santa Clara and all alignments for San Ildefonso. Alignments E and F (along the Guchupangue) for Santa Clara were deemed not acceptable due to excessively high real estate acquisition cost that the sponsor would incur and as a result were removed from consideration as well.

The remaining alignments were evaluated using HEC-FDA 1.2.5 to determine the with-project condition, and how much of the Equivalent Annual Damages are actually captured by proposed structures. All results were based off the current interest rate of 3.375% and used a 50 year period of analysis. The results are only based on the construction cost generated and include estimated cost for operations, maintenance, repair, replacement and rehabilitation costs, real estate, and pre-engineering and design. The estimated cost was conservative and it is believed that the actual cost would decrease the net benefits and reduce the benefit/cost (B/C) ratio. The final results of the economic analysis shows that, other than a levee along Arroyo de Guachupangue (which was already eliminated due to real estate issues), no levee alignment for the Española Valley is economically justified and moving below base -1 foot would not significantly reduce the flood threat enough to justify constructing a project.

3 - Evaluation of Non-Structural Alternatives

3.1 Flood Warning Systems

A flood warning and preparedness system is often the most cost effective flood mitigation measure comprised of computer hardware, software, technical activities and/or organizational arrangements aimed at decreasing flood hazards. Advanced warning is not generally effective in reducing structural damages (outside of sandbagging efforts if given early warning); the primary benefits of such a system are credited for providing early evacuation of residents and reduction in damages to vehicles and structure contents.

The high residual damages, as well as the other infrastructure (roads, agriculture, utilities, and public and commercial properties), suggests that a flood warning system is ineffective and incomplete on its own. Further, relative to the structural alternative presented, it's impossible for a flood warning system to provide greater net benefits.

3.2 Flood Proofing

Flood proofing offers the opportunity to provide flood protection on an individual structure-by-structure basis or for a group of structures. Flood proofing techniques typically include buyouts, relocation, elevation, floodwalls or levees, and dry flood proofing. Elevation, buyout, and relocation are the most dependable of these flood proofing methods. Flood proofing costs can vary substantially depending on the type of flood proofing method being considered and the type, size, age, and location of the structure(s). Flood proofing techniques considered for alternative development are:

1) Relocation of Existing Structures: Relocation is perhaps the most dependable flood proofing technique since it totally eliminates flood damages, minimizes the need for flood insurance, and allows for the restoration/reclamation of the floodplain. This technique requires the physical relocation of flood prone structures outside of the identified flood hazard area. This also requires purchase of the flood prone property; selecting and purchasing a new site; and lifting/moving the structure to the new site.

   Corps experience has indicated that relocations and buyouts only work when the land left behind is repurposed to some other public good, such as a public park or reuniting the acquired land with the floodway. In its Homeowner's Guide to Retrofitting (December 2009, page 3-28, Table 3-9), FEMA estimates relocation costs at between $99 and $116 per square foot (2009 dollars), which exceeds the depreciated replacement costs of just about every structure in the floodplain. Relocations are infeasible for large buildings such as schools, clinics, fire stations and other public and commercially owned buildings

2) Buyout or Acquisition: This technique requires the purchase of the flood prone property and structure; demolition of the structure; relocation assistance; and applicable compensation required under Federal and State law. This alternative typically requires voluntary relocation by the property owners and/or eminent domain rights exercised by the non-federal sponsor. As stated previously with relocations, acquiring properties in a floodplain has limited utility. Repurposing land for a public good like a park is also infeasible, as it would represent an incomplete solution to the flood problem.

3) Retrofitting or Dry Flood Proofing: Dry flood proofing of existing structures is a common flood proofing technique applicable for flood depths of three (3) feet or less on buildings that are structurally sound. Installation of temporary closures or flood shields is a commonly used flood proofing technique. A flood shield is a watertight barrier designed to prevent the passage of floodwater though doors, windows, ventilating shafts, and other openings of the structure exposed to

flooding. Such shields are typically made of steel or aluminum and are installed on structures only prior to expected flooding. However, flood shields can only be used on structures with walls that are strong enough to resist the flood-induced forces and loadings. Exterior walls must be made watertight in addition to the use of flood shields. This technique is not applicable to areas subject to flash flooding (less than one hour) or where flow velocities are greater than three (3) feet per second. It would also not be applicable to mobile homes, due to the type of construction and typical lack of anchoring to a foundation.

Aside from the cost, dry flood proofed homes and businesses can still suffer flood damages due to the potentially incomplete nature of the solution. Enclosures for windows and doors require human intervention in order to fully implement the solution and, this action would have to occur in a relatively short time frame. Due to the incomplete nature and limited applicability of this flood proofing method, it was not carried forward for alternative evaluation.

4) Localized Levees or Floodwalls: Ring levees or floodwalls can be built around individual structures to protect single or small groups of structures. Ring levees are earthen embankments with stable or protected side slopes and a wide top. Floodwalls are generally constructed of masonry or concrete and are designed to withstand varying heights of floodwaters and hydrostatic pressure. Closures (e.g., for driveway access) are typically manually operated based on flood forecasting and prediction that would alert the operator. Disadvantages of levees or berms are: 1) can impede or divert flow of water in a floodplain; 2) can block natural drainage; 3) are susceptible to scour and erosion; 4) give a false sense of security; and 5) take up valuable property space. Disadvantages of floodwalls are: 1) high cost to implement; 2) closures for openings are required, and 3) they give a false sense of security.

5) Elevation of Structures: Existing structures can be elevated or raised above the potential flood elevation. Structures can be raised on concrete columns, metal posts, piles, compacted earth fill, or extended foundation walls. Elevated structures must be designed and constructed to withstand anticipated hydrostatic and hydrodynamic forces and debris impact resulting from flooding. The access and utility systems of the structures to be raised would need to be modified to ensure they are safe from flooding.

   FEMA has estimated that elevation in place for slab-on-grade homes (the most common foundation type in the study area) can cost $80-88 per square foot (2009 dollars) for a frame home, and $88-96 per square foot for a masonry home (FEMA, *Homeowner's Guide to Retrofitting*, December 2009, page 3-20, Table 3-3). That value exceeds the per square foot depreciated replacement cost of most of the improvements in the floodplain, which makes this alternative infeasible.

4 - Economic Considerations – Ecosystem Restoration Analysis

4.1 Incremental Cost Analysis and NER Plan Selection

United States Army Corps of Engineers (USACE) policy, presented in Engineer Regulation 1105-2-100, *Planning Guidance Notebook*, requires that potential ecosystem restoration projects be analyzed for cost effectiveness and incremental benefits gained from various restoration alternatives. The plan that reasonably maximizes ecosystem restoration benefits compared to costs, consistent with the Federal objective, is selected and identified as the National Ecosystem Restoration (NER) Plan. Incremental cost and cost-effectiveness analysis (CE/ICA) is the technique used by the USACE to develop cost-effective restoration projects. Analysis of cost effectiveness, in general, compares the relative costs and benefits of alternative plans. The most efficient plans that provide the greatest increase in output for the least increase in cost are called the best buys. The least expensive best buy, which meets the restoration objective, is usually chosen as the tentatively selected plan.

Specifically, cost-effectiveness analysis compares the costs and expected environmental outputs among various alternative plans. If different alternative plans can produce the same level of output, only the least expensive (least-cost) choice makes economic sense for that level of output; economically *inefficient* alternative plans can be eliminated from further consideration. Similarly, if one alternative plan can produce a greater level of output for the same or less cost than others (cost-effective), only the greater output choice makes economic sense; economically *ineffective* alternative plans can be eliminated. After elimination of inefficient and ineffective alternative plans, there remain several least-cost, cost-effective alternative plans offering a range of output values from which to identify the means of meeting the ecosystem restoration objective. All price levels as they relate to ecosystem restoration are in November 2014 price levels.

4.2 CE/ICA Analysis

An alternative plan consists of a system of structural and/or non-structural measures, strategies, or programs formulated to meet, fully or partially, the identified study planning objectives subject to planning constraints. A management measure is a feature or an activity that can be implemented at a specific geographic site to address one or more planning objective. Management measures are the building blocks of alternative plans.

Restoration measures to enact the proposed improvements for this project include: a) high-flow channels, b) swales/wetlands, c) terrace and bank line lowering, d) vegetation removal/re-vegetation, e) ponds and f) grade restoration facilities. Alternative plans for habitat restoration could include one or more of the above measures and also include the No Action option for each restoration measure. Table 6 summarizes each of the restoration measures used in this study. Each of the restoration measures were entered into USACE Institute for Water Resources (IWR) Planning Suite (IWR-Plan). Each measure included the No Action option. IWR-Plan Decision Support Software assists with the formulation and comparison of alternative plans by conducting cost effectiveness and incremental cost analyses, identifying the plans which are the best financial investments, and displaying the effects of each plan on a range of decision variables.

Most federal agencies use annualized output values as a means to display benefits and costs, and ecosystem restoration analyses should provide data that can be directly compared to the traditional benefit/cost analysis. Because habitat value is difficult to express in monetary terms, the cost effectiveness of project features is measured in habitat units (HU). HUs are the product of the amount and value of the habitat. HUs are annualized by summing HUs across all years in the period of analysis and discounting any future variability in those benefits to present values using the administratively published discount rate (3.375% in FY 2015). The results of this calculation are referred to as average annual habitat units (AAHU) and can be expressed mathematically. Using AAHU as metric, plans can be compared over time based on the forecast conditions. In this way, it is possible to quantify a change in habitat by implementing the project and evaluate whether that change is cost effective.

Table 6 - Habitat restoration measures (Nov 2014 price level)

	CEICA CODE	Group (location ID)	Measure Description	Target AAHU	Cost (Actual $)
Ohkay Owingeh Measures	A	3101	High-flow channel	28.80	269,825.80
	B	3102	High-flow channel	19.38	183,325.74
	C	3103	High-flow channel	32.88	306,670.75
	D	3107	High-flow channel	35.34	327,222.66
	E	3000	Swale	72.74	693,613.32
	F	3002	Vegetation Removal (Invasive plant species removal)	245.26	1,252,520.06
	G	3111	High-flow channel	305.00	2,762,148.86
	H	3115	Terrace lowering	93.04	367,389.42
	J	3118	High-flow channel	122.82	1,110,527.84
	K	3129	High-flow channel	95.49	881,827.29
	L	3208	Terrace lowering	22.67	186,972.11
	M	3202	Swale	12.85	135,639.46
	N	3210	Swale	108.33	1,085,865.08
	P	3214	Swale	98.00	982,939.68
	Q	3215	Swale	87.89	882,444.59
	R	3217	Swale	27.91	285,428.30
	S	3218	Swale	22.21	228,724.90
	T	3204	High flow channel	226.82	2,048,626.54
	U	3212	Channel Stabilization (URG)	592.55	$3,458,763.20
	V	3001	Swale	155.53	1,553,903.86
	W	3014	Vegetation Removal (Invasive plant species removal)	227.25	1,031,650.56
	X	3105	High-flow channel	27.04	254,479.25
	Y	3108	High-flow channel	56.80	529,998.73
	Z	3113	High-flow channel	344.62	3,126,112.77
	AA	3116	High-flow channel	533.53	4,864,712.49
	BB	3119	High-flow channel	195.32	1,337,955.54
	CC	3120	High-flow channel	60.85	555,459.97
	DD	3130	High-flow channel	73.65	676,232.47
	EE	3140	High-flow channel	55.29	514,652.19
	FF	3201	Terrace lowering	80.48	643,492.45
	GG	3203	Terrace lowering	140.31	1,116,172.85
	HH	3209	Terrace lowering	119.91	954,353.48
	JJ	3213	High flow channel	49.63	228,265.53
	KK	3211	Channel Stabilization (URC)	296.51	$1,544,843.83
	LL	3016	Bankline lowering (Contouring)	522.38	4,148,736.58
	MM	3123	Terrace lowering	403.22	3,019,775.42
	NN	3124	Terrace lowering	224.53	1,700,623.04
	PP	3125	Terrace lowering	15.27	122,011.60
	QQ	3127	Terrace lowering	4.94	2,200,533.31
	RR	3184	High-Flow channel	155.76	1,667,272.85
	SS	0/3205	Channel Stabilization (combination of 4 GRF's)	2069.61	$15,747,353.08
Santa Clara Measures	A	3007	Swale / wetland (Create groundwater swale / wetland in mixed deciduous)	20.53	195,585.54
	B	3018	Swale / wetland (Create groundwater swale / wetland in mixed deciduous)	21.12	200,142.92
	C	3019	Swale (Swale in middle of cottonwood gallery)	3.27	55,600.96
	D	3020	Bankline lowering (3.5 acre bank lowering next to shrub / scrub & mixed deciduous)	90.65	617,851.89
	E	3021	Vegetation Removal (Invasive plant species removal)	1057.97	3,886,638.00
	F	3022	Swale / wetland (Create wetland in cottonwood gallery)	32.13	289,621.10
	G	3023	Swale / wetland (Create wetland in cottonwood gallery)	22.45	211,113.04
	H	3024	Wetland (Expand existing wetlands)	31.48	284,540.93
	J	3026	Vegetation Removal (Invasive plant species removal)	202.12	761,946.41
	K	3035	Vegetation Removal (Invasive plant species removal)	258.79	1,428,788.12
	L	3037	Wetland / pond (Create open water wetland in salt cedar?, cottonwood & mixed deciduous)	51.30	724,124.01
	M	3038	Wetland / pond (Create open water wetland in salt cedar?, cottonwood & mixed deciduous)	51.30	724,124.01
	N	3046	Swale	558.98	4,691,348.11
	P	3047	Vegetation Removal (Invasive plant species removal)	156.25	594,079.45
	Q	3049	Swale	590.75	4,847,540.17
	R	3050	Wetland / pond (Create open water / wetland in shrub / scrub)	109.46	1,512,029.12
	S	3051	Wetland / pond (Create open water / wetland in shrub / scrub)	124.35	1,712,219.58
	T	3145	Bank destabilization (Bank destabilization along shrub / scrub)	32.82	242,253.36
	U	3151	High-flow channel	90.37	729,208.01
	V	3156	High-flow channel	39.67	470,308.92
	W	3158	High-flow channel	84.29	688,438.50
	X	3159	High-flow channel	83.94	672,541.78
	Y	3162	High-flow channel	4.81	497,002.54
	Z	3034	Vegetation Removal (Invasive plant species removal)	279.09	2,015,843.98
	AA	3164	High-flow channel	68.25	538,865.07
	BB	3165	High-flow channel	0.47	33,051.39
	CC	3167	High-flow channel	1.26	39,070.43
	DD	3005	Wetland / pond (Create Wastewater Treatment Wetland in shrub / scrub & mixed deciduous)	95.19	1,317,388.09
	EE	3027	Wetland / pond (Create pond / wetland in shrub / scrub & mixed deciduous)	122.19	1,684,408.50
	FF	3028	Wetland / pond (Create pond / wetland in shrub / scrub & mixed deciduous)	40.56	578,626.41
	GG	3029	Wetland / pond (Create pond / wetland in shrub / scrub & mixed deciduous)	58.83	826,110.38
	HH	3032	Vegetation Removal (Invasive plant species removal)	45.00	193,773.48
	JJ	3039	Pond (Open water pond in cottonwood gallery inside 10-year)	123.89	2,599,583.31
	KK	3041	Swale	20.53	195,585.54
	LL	3042	Swale	20.53	195,585.54
	MM	3053	Pond (Open water pond in shrub / scrub inside 10-year)	167.05	3,513,572.58
	NN	3054	Swale (Wetland / marsh / wet meadow swale)	461.88	3,775,364.44
	PP	3144	Bankline lowering (Remove spoil bank)	85.76	585,935.00
	QQ	3146	Swale	141.05	1,173,214.01
	RR	3150	High-flow channel	29.44	251,147.03
	SS	3154	High-flow channel	44.24	366,359.02
	TT	3155	High-flow channel	47.52	392,829.19
	UU	3161	High-flow channel	102.80	793,756.55

4.2.1 Combinability and Dependability

Combinability and dependency are two types of relationships used in the CE/ICA analysis. In a typical USACE study, management measures may or may not be mutually exclusive, and it is the property of combinability that allows planners to mix and match measures into different plans. Conversely, some measures may preclude others, and this will limit the ability to mix and match the measures. In consideration of combinability, two measures might be mutually exclusive because of:

- Location, where two different measures cannot occupy the same space at the same time.
- Function, where two different measures may work against one another.

In addition to being combinable, many measures may be dependent on other measures in order to be implemented. Dependency relationships between two measures may exist for several reasons, including:

- Necessary to function.
- Reduce risk or uncertainty.
- Improve performance.

In this analysis, the only dependencies were a few high-flow channels (located along the Rio Chama) to a channel stabilization feature also located along the Rio Chama.

4.2.2 Plan Generation

Within IWR-Plan, and once a planning study comprised of variables, outputs, and attributes has been defined with the plan editor, the plan generation module is used to populate a new planning set with plan alternatives. IWR-Plan displays generated planning sets with the information needed to assist planners manage the plans and keep the plans in context.

Three main models were created due to the complexity and the number of measures in this study area. The first main model was for Santa Clara Pueblo. Due to the sheer number of management measures, it was separated into to two smaller sub-models. The first of these two sub-models incorporated all management measures as their own solution (A-UU) for Santa Clara Pueblo (See measures below the red line in Table 6) and computed for four reaches. The reaches are: Santa Cruz, Middle Rio Grande East Bank and Middle Rio Grande West Bank #1 and #2. The first sub-model for the Santa Clara Pueblo generated these plans in the following reaches: Santa Cruz - 8 total plans, 4 of those are cost effective and 3 were best buys; Lower Rio Grande East Bank – 267 total plans, 198 of those are cost effective and 16 were best buys; and Lower Rio Grande West Bank #1 and #2 – 1,153 total plans, 635 of those are cost effective and 25 were best buys.

The second sub-model for the Santa Clara Pueblo uses the four reaches (from the first sub-model) as solutions and the best buys as scales within those solutions. The second sub-model analyzed only the best buys from each of the reaches from the first sub-model. The computation of this model resulted in 9,984 total plans, which 833 were classified as cost effective and 40 were classified as best buy plans. Table 7 displays the best buy plans. The best buy plans for Santa Clara were then loaded into the main and final model which will be discussed later in this section. ***NOTE:*** *Each name in Tables 7-10 is a string of measures where '0' is the No Action alternative and any number greater than '0' is the implemented measure alternative*

Table 7 - Santa Clara Best Buy Plans

Total and Average Cost 4/10/2015 12:35:06 PM

Best Buy Plan Alternatives **Planning Set:** Best Buy Plans SC

Counter	Name	Output HU	Cost $1000	Average Cost
1	No Action Plan	0.00	0.00	
2	SC1SCE0SCM0SCX0	1,057.97	3,886.64	3.67
3	SC2SCE0SCM0SCX0	1,260.09	4,648.58	3.69
4	SC2SCE1SCM0SCX0	1,416.34	5,242.66	3.70
5	SC2SCE1SCM0SCX1	1,461.34	5,436.44	3.72
6	SC3SCE1SCM0SCX1	1,720.13	6,865.23	3.99
7	SC4SCE1SCM0SCX1	1,810.78	7,483.08	4.13
8	SC4SCE1SCM0SCX2	1,896.54	8,069.01	4.25
9	SC4SCE2SCM0SCX2	2,175.63	10,084.86	4.64
10	SC4SCE3SCM0SCX2	2,208.45	10,327.11	4.68
11	SC4SCE3SCM0SCX3	2,311.25	11,120.87	4.81
12	SC4SCE3SCM1SCX3	2,379.50	11,659.73	4.90
13	SC4SCE4SCM1SCX3	2,463.44	12,332.27	5.01
14	SC4SCE5SCM1SCX3	2,553.81	13,061.48	5.11
15	SC4SCE6SCM1SCX3	2,638.10	13,749.92	5.21
16	SC4SCE6SCM1SCX4	3,099.98	17,525.28	5.65
17	SC4SCE7SCM1SCX4	3,690.73	22,372.82	6.06
18	SC4SCE7SCM1SCX5	3,738.25	22,765.65	6.09
19	SC4SCE7SCM1SCX6	3,782.49	23,132.01	6.12
20	SC4SCE7SCM1SCX7	3,923.54	24,305.23	6.19
21	SC4SCE8SCM1SCX7	4,482.52	28,996.57	6.47
22	SC4SCE8SCM1SCX8	4,511.96	29,247.72	6.48
23	SC5SCE8SCM1SCX8	4,544.09	29,537.34	6.50
24	SC6SCE8SCM1SCX8	4,575.57	29,821.88	6.52
25	SC7SCE8SCM1SCX8	4,598.02	30,033.00	6.53
26	SC8SCE8SCM1SCX8	4,619.14	30,233.14	6.55
27	SC9SCE8SCM1SCX8	4,639.67	30,428.73	6.56
28	SC8SCE8SCM1SCX9	4,660.20	30,624.31	6.57
29	SC9SCE8SCM1SCX9	4,680.73	30,819.90	6.58
30	SC9SCE9SCM1SCX9	4,720.40	31,290.21	6.63
31	SC9SCE10SCM1SCX9	4,844.75	33,002.42	6.81
32	SC9SCE10SCM1SCX10	4,966.94	34,686.83	6.98
33	SC9SCE11SCM1SCX10	5,076.40	36,198.86	7.13
34	SC9SCE11SCM1SCX11	5,171.59	37,516.25	7.25
35	SC9SCE11SCM1SCX12	5,230.42	38,342.36	7.33
36	SC10SCE11SCM1SCX12	5,333.02	39,790.61	7.46
37	SC10SCE11SCM1SCX13	5,373.58	40,369.24	7.51
38	SC11SCE11SCM1SCX13	5,376.85	40,424.84	7.52
39	SC11SCE11SCM1SCX14	5,500.74	43,024.42	7.82
40	SC11SCE11SCM1SCX15	5,667.79	46,537.99	8.21

The second model was created for the Ohkay Owingeh Pueblo. Due to the number of management measures this was also separated into to two smaller "sub-models". The first of these two models incorporated all management measures as their own solution (A-SS) for Ohkay Owingeh Pueblo (see measures above the red line in Table 6) and computed for three reaches. The reaches are: Rio Chama East and West Bank and Middle Rio Grande. The first sub-model for the Ohkay Owingeh Pueblo generated these plans in the following reaches: Rio Chama East Bank - 8192 total plans, 217 of those are cost effective and 14 were best buys; Rio Chama West Bank – 524,288 total plans, 954 of those are cost effective and 20 were best buys; and Middle Rio Grande – 128 total plans, 50 of those are cost effective and 8 were best buys.

The second sub-model for the Ohkay Owingeh Pueblo uses the four reaches (from the first sub-model) as solutions and the best buys as scales within those solutions, the second sub-model analyzed only the best buys from the first sub-model. The computation of this model resulted in 2,240 total plans, which 394 were classified as cost effective and 40 were classified as best buy plans. Table 8 displays the best buy plans. The best buy plans for Ohkay Owingeh Pueblo were then loaded into the main and final model which will be discussed later in this section.

Table 8 - Ohkay Owingeh Best Buy Plans

Total and Average Cost 4/10/2015 12:32:38 PM

Best Buy Plan Alternatives **Planning Set:** Best Buys OOP

Counter	Name	Output HU	Cost $1000	Average Cost
1	No Action Plan	0.00	0.00	
2	OO1OOE0OOX0	93.04	367.39	3.95
3	OO1OOE1OOX0	320.29	1,399.04	4.37
4	OO1OOE2OOX0	369.92	1,627.31	4.40
5	OO2OOE2OOX0	615.18	2,879.83	4.68
6	OO2OOE3OOX0	911.69	4,424.67	4.85
7	OO3OOE3OOX0	1,504.24	7,883.43	5.24
8	OO3OOE3OOX1	1,907.46	10,903.21	5.72
9	OO3OOE3OOX2	2,131.99	12,603.83	5.91
10	OO3OOE3OOX3	4,201.60	28,351.18	6.75
11	OO3OOE3OOX4	4,723.98	32,499.92	6.88
12	OO3OOE4OOX4	4,864.29	33,616.09	6.91
13	OO3OOE5OOX4	4,984.20	34,570.45	6.94
14	OO3OOE5OOX5	4,999.47	34,692.46	6.94
15	OO3OOE6OOX5	5,079.95	35,335.95	6.96
16	OO4OOE6OOX5	5,102.62	35,522.92	6.96
17	OO5OOE6OOX5	5,329.44	37,571.55	7.05
18	OO6OOE6OOX5	5,452.26	38,682.08	7.09
19	OO7OOE6OOX5	5,757.26	41,444.23	7.20
20	OO7OOE7OOX5	6,101.88	44,570.34	7.30
21	OO7OOE8OOX5	6,635.41	49,435.05	7.45
22	OO7OOE9OOX5	6,709.06	50,111.29	7.47
23	OO8OOE9OOX5	6,804.55	50,993.12	7.49
24	OO9OOE9OOX5	6,839.89	51,320.34	7.50
25	OO9OOE10OOX5	6,895.18	51,834.99	7.52
26	OO10OOE10OOX5	6,928.06	52,141.66	7.53
27	OO10OOE11OOX5	6,984.86	52,671.66	7.54
28	OO11OOE11OOX5	7,013.66	52,941.48	7.55
29	OO11OOE12OOX5	7,040.70	53,195.96	7.56
30	OO12OOE12OOX5	7,060.08	53,379.29	7.56
31	OO13OOE12OOX5	7,132.82	54,072.90	7.58
32	OO13OOE13OOX5	7,288.35	55,626.80	7.63
33	OO14OOE13OOX5	7,396.68	56,712.67	7.67
34	OO15OOE13OOX5	7,494.68	57,695.61	7.70
35	OO16OOE13OOX5	7,582.57	58,578.05	7.73
36	OO17OOE13OOX5	7,610.48	58,863.48	7.73
37	OO18OOE13OOX5	7,632.69	59,092.21	7.74
38	OO19OOE13OOX5	7,645.54	59,227.85	7.75
39	OO19OOE13OOX6	7,801.30	60,895.12	7.81
40	OO19OOE13OOX7	7,806.24	63,095.65	8.08

Finally, the third main model combined the best buy plans from Santa Clara (40 best buy plans from the first model) and Ohkay Owingeh (40 best buy plans from the second model) Pueblos. In all, 1,638 plans were generated by IWR-Plan. Of those, 465 were deemed to be cost-effective and 78 were best buys. Due to the number of total plans generated by the model, Table 9 only displays the best buy plans from the final model. Figure 5 is a graphic representation of all plans generated by the IWR Planning Suite for the third model.

By creating a separate model for each Pueblo and then combining the results (i.e. best buys), the naming conventions had to be changed. For example, from Table 9, counter #5 is best buy #5 in the final results, however in the Santa Clara model (Table 7) that plan is actually best buy #04 and for the Ohkay Owingeh model (Table 8) that plan is actually best buy #02. By continually to focus the results to get a range of best buys for the entire study area, thousands of plans were generated and in the process of focusing in only on the best buys, thousands of plans for each pueblo became not efficient and cost effective and fell out from consideration. By creating the third model (the combination of the two pueblos models), the PDT was able to develop efficient and effective plans from those prior runs to provide efficient and effect ways to generate output for the entire Espanola Valley region. The final results display the best array of plans for each of the two pueblos and the communities that neighbor them. To determine how each measure progresses through the CEICA analyses, the results from Table 9 can trace back to Tables 7 and 8, which in turn can be traced to the individual measures in Table 6. Table 10 displays the measures from Tables 6-9, which describes how a measure progresses through the CEICA analyses.

Each measure from Table 6 has four potential outcomes. Each measure can be inefficient and ineffective for the pueblo (and therefore eliminated from consideration), each measure can be inefficient and ineffective when combined with the other pueblo (and therefore eliminated from consideration), each measure can be efficient and effective but too far to the right in the supply curve pueblo (and therefore eliminated from consideration) or each plan can be efficient and effective.

Table 9 - Best Buy plan combinations incorporating best buys from the 1st and 2nd model runs for each Pueblo

Best Buv Plan Alternatives **Planning Set:** CEICA Analysis for Espanola GI

Counter	Name	Output HU	Cost $1000	Average Cost
1	No Action Plan	0.00	0.00	
2	SA1SAE0SCAM0OA0OAE0	1,057.97	3,886.64	3.67
3	SA2SAE0SCAM0OA0OAE0	1,260.09	4,648.58	3.69
4	SA3SAE0SCAM0OA0OAE0	1,416.34	5,242.66	3.70
5	SA3SAE0SCAM0OA1OAE0	1,509.38	5,610.05	3.72
6	SA4SAE0SCAM0OA1OAE0	1,554.38	5,803.83	3.73
7	SA4SAE0SCAM0OA2OAE0	1,781.63	6,835.48	3.84
8	SA4SAE0SCAM0OA3OAE0	1,831.26	7,063.75	3.86
9	SA4SAE0SCAM0OA4OAE0	2,076.52	8,316.27	4.00
10	SA4SAE0SCAM0OA5OAE0	2,373.03	9,861.11	4.16
11	SA5SAE0SCAM0OA5OAE0	2,631.82	11,289.90	4.29
12	SA5SAE0SCAM0OA6OAE0	3,224.37	14,748.66	4.57
13	SA6SAE0SCAM0OA6OAE0	3,315.02	15,366.51	4.64
14	SA7SAE0SCAM0OA6OAE0	3,400.78	15,952.44	4.69
15	SA8SAE0SCAM0OA6OAE0	3,679.87	17,968.29	4.88
16	SA9SAE0SCAM0OA6OAE0	3,712.69	18,210.54	4.90
17	SA9SAE0SCAM0OA7OAE0	4,115.91	21,230.32	5.16
18	SA9SAE0SCAM0OA8OAE0	4,340.44	22,930.94	5.28
19	SA9SAE0SCAM0OA9OAE0	6,410.05	38,678.29	6.03
20	SA10SAE0SCAM0OA9OAE0	6,512.85	39,472.05	6.06
21	SA11SAE0SCAM0OA9OAE0	6,581.10	40,010.91	6.08
22	SA11SAE0SCAM0OA10OAE0	7,103.48	44,159.65	6.22
23	SA11SAE0SCAM0OA11OAE0	7,243.79	45,275.82	6.25
24	SA11SAE0SCAM0OA12OAE0	7,363.70	46,230.18	6.28
25	SA11SAE0SCAM0OA13OAE0	7,378.97	46,352.19	6.28
26	SA11SAE0SCAM0OA14OAE0	7,459.45	46,995.68	6.30
27	SA12SAE0SCAM0OA14OAE0	7,543.39	47,668.22	6.32
28	SA13SAE0SCAM0OA14OAE0	7,633.76	48,397.43	6.34
29	SA14SAE0SCAM0OA14OAE0	7,718.05	49,085.87	6.36
30	SA15SAE0SCAM0OA14OAE0	8,179.93	52,861.23	6.46
31	SA16SAE0SCAM0OA14OAE0	8,770.68	57,708.77	6.58
32	SA16SAE0SCAM0OA15OAE0	8,793.35	57,895.74	6.58
33	SA17SAE0SCAM0OA15OAE0	8,840.87	58,288.57	6.59
34	SA18SAE0SCAM0OA15OAE0	8,885.11	58,654.93	6.60
35	SA19SAE0SCAM0OA15OAE0	9,026.16	59,828.15	6.63
36	SA0SAE1SCAM0OA15OAE0	9,585.14	64,519.49	6.73
37	SA0SAE2SCAM0OA15OAE0	9,614.58	64,770.64	6.74
38	SA0SAE3SCAM0OA15OAE0	9,646.71	65,060.26	6.74
39	SA0SAE3SCAM0OA16OAE0	9,873.53	67,108.89	6.80
40	SA0SAE4SCAM0OA16OAE0	9,905.01	67,393.43	6.80
41	SA0SAE4SCAM0OA17OAE0	10,027.83	68,503.96	6.83
42	SA0SAE4SCAM0OA18OAE0	10,332.83	71,266.11	6.90
43	SA0SAE4SCAM0OA19OAE0	10,677.45	74,392.22	6.97
44	SA0SAE4SCAM0OA0OAE1	11,210.98	79,256.93	7.07
45	SA0SAE4SCAM0OA0OAE2	11,284.63	79,933.17	7.08
46	SA0SAE4SCAM0OA0OAE3	11,380.12	80,815.00	7.10
47	SA0SAE4SCAM0OA0OAE4	11,415.46	81,142.22	7.11
48	SA0SAE4SCAM0OA0OAE5	11,470.75	81,656.87	7.12
49	SA0SAE4SCAM0OA0OAE6	11,503.63	81,963.54	7.13
50	SA0SAE4SCAM0OA0OAE7	11,560.43	82,493.54	7.14
51	SA0SAE4SCAM0OA0OAE8	11,589.23	82,763.36	7.14
52	SA0SAE5SCAM0OA0OAE8	11,611.68	82,974.48	7.15
53	SA0SAE5SCAM0OA0OAE9	11,638.72	83,228.96	7.15
54	SA0SAE5SCAM0OA0OAE10	11,658.10	83,412.29	7.15
55	SA0SAE6SCAM0OA0OAE10	11,679.22	83,612.43	7.16

Best Buy Plan Alternatives **Planning Set:** CEICA Analysis for Espanola GI

Counter	Name	Output HU	Cost $1000	Average Cost
56	SA0SAE9SCAM0OA0OAE10	11,740.81	84,199.19	7.17
57	SA0SAE9SCAM0OA0OAE11	11,813.55	84,892.80	7.19
58	SA0SAE9SCAM0OA0OAE12	11,969.08	86,446.70	7.22
59	SA0SAE9SCAM0OA0OAE13	12,077.41	87,532.57	7.25
60	SA0SAE9SCAM0OA0OAE14	12,175.41	88,515.51	7.27
61	SA0SAE9SCAM0OA0OAE15	12,263.30	89,397.95	7.29
62	SA0SAE9SCAM0OA0OAE16	12,291.21	89,683.38	7.30
63	SA0SAE9SCAM0OA0OAE17	12,313.42	89,912.11	7.30
64	SA0SAE9SCAM0OA0OAE18	12,326.27	90,047.75	7.31
65	SA0SAE9SCAM0OA0OAE19	12,482.03	91,715.02	7.35
66	SA0SAE10SCAM0OA0OAE19	12,521.70	92,185.33	7.36
67	SA0SAE11SCAM0OA0OAE19	12,646.05	93,897.54	7.43
68	SA0SAE12SCAM0OA0OAE19	12,768.24	95,581.95	7.49
69	SA0SAE13SCAM0OA0OAE19	12,877.70	97,093.98	7.54
70	SA0SAE14SCAM0OA0OAE19	12,972.89	98,411.37	7.59
71	SA0SAE15SCAM0OA0OAE19	13,031.72	99,237.48	7.62
72	SA0SAE16SCAM0OA0OAE19	13,134.32	100,685.73	7.67
73	SA0SAE17SCAM0OA0OAE19	13,174.88	101,264.36	7.69
74	SA0SAE18SCAM0OA0OAE19	13,178.15	101,319.96	7.69
75	SA0SAE19SCAM0OA0OAE19	13,302.04	103,919.54	7.81
76	SA0SAE0SCAM1OA0OAE19	13,469.09	107,433.11	7.98
77	SA0SAE0SCAM2OA0OAE19	13,470.35	107,472.18	7.98
78	SA0SAE0SCAM3OA0OAE19	13,470.82	107,505.23	7.98

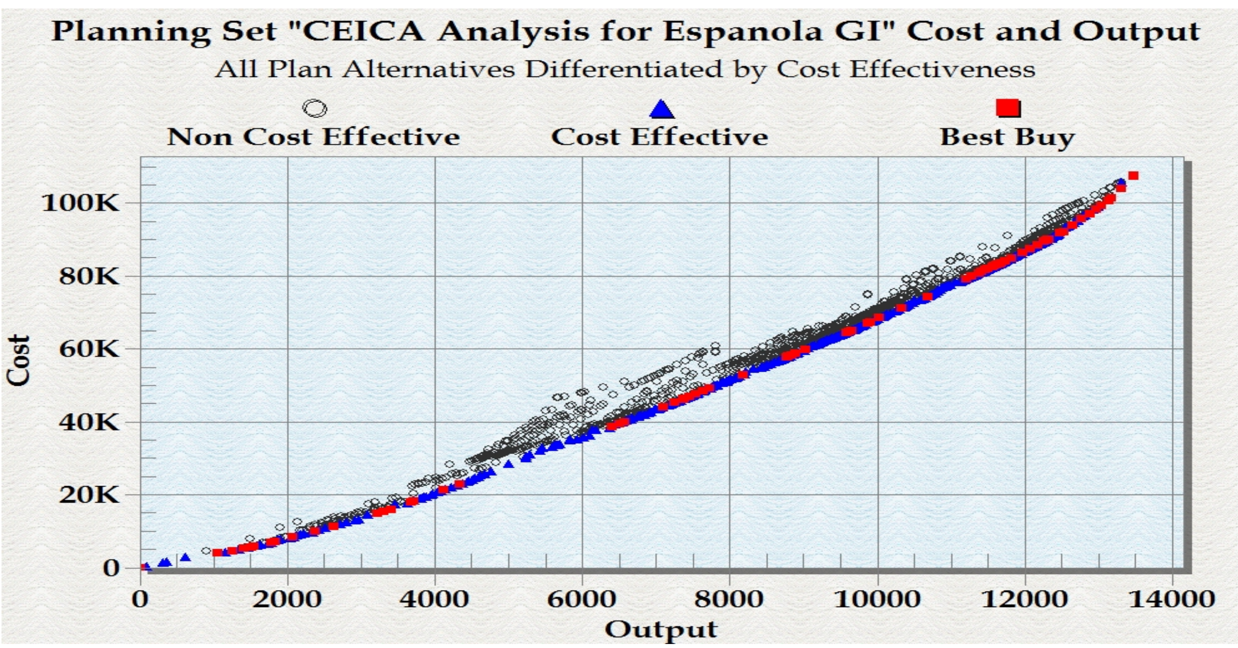


Figure 5 - Graph of alternative outputs and costs from the third model run.

Table 10 - Measures from Table 6-9

Measures from Table 9	Coding that describes Measures from Table 8	Measures from Table 8	Coding that describes Measures from Table 6	Measures from Table 6																		
OA1	OO1OOE0OOX0	OO1	A0B0C0D0E0F0G0H1J0K0L0M0N0P0Q0R0S0T0U0								H											
OA2	OO1OOE1OOX0	OO2	A0B0C0D0E0F1G0H1J0K0L0M0N0P0Q0R0S0T0U0						F		H											
OA3	OO1OOE2OOX0	OO3	A0B0C0D0E0F1G0H1J0K0L0M0N0P0Q0R0S0T0U1						F		H											U
OA4	OO2OOE2OOX0	OO4	A0B0C0D0E0F1G0H1J0K0L1M0N0P0Q0R0S0T0U1						F		H			L								U
OA5	OO2OOE3OOX0	OO5	A0B0C0D0E0F1G0H1J0K0L1M0N0P0Q0R0S0T1U1						F		H			L							T	U
OA6	OO3OOE3OOX0	OO6	A0B0C0D0E0F1G0H1J1K0L1M0N0P0Q0R0S0T1U1						F		H	J		L							T	U
OA7	OO3OOE3OOX1	OO7	A0B0C0D0E0F1G1H1J1K0L1M0N0P0Q0R0S0T1U1						F	G	H	J		L							T	U
OA8	OO3OOE3OOX2	OO8	A0B0C0D0E0F1G1H1J1K1L1M0N0P0Q0R0S0T1U1						F	G	H	J	K	L							T	U
OA9	OO3OOE3OOX3	OO9	A0B0C0D1E0F1G1H1J1K1L1M0N0P0Q0R0S0T1U1				D		F	G	H	J	K	L							T	U
OA10	OO3OOE3OOX4	OO10	A0B0C1D1E0F1G1H1J1K1L1M0N0P0Q0R0S0T1U1			C	D		F	G	H	J	K	L							T	U
OA11	OO3OOE4OOX4	OO11	A1B0C1D1E0F1G1H1J1K1L1M0N0P0Q0R0S0T1U1	A		C	D		F	G	H	J	K	L							T	U
OA12	OO3OOE5OOX4	OO12	A1B1C1D1E0F1G1H1J1K1L1M0N0P0Q0R0S0T1U1	A	B	C	D		F	G	H	J	K	L							T	U
OA13	OO3OOE5OOX5	OO13	A1B1C1D1E1F1G1H1J1K1L1M0N0P0Q0R0S0T1U1	A	B	C	D	E	F	G	H	J	K	L							T	U
OA14	OO3OOE6OOX5	OO14	A1B1C1D1E1F1G1H1J1K1L1M0N1P0Q0R0S0T1U1	A	B	C	D	E	F	G	H	J	K	L		N					T	U
OA15	OO4OOE6OOX5	OO15	A1B1C1D1E1F1G1H1J1K1L1M0N1P1Q0R0S0T1U1	A	B	C	D	E	F	G	H	J	K	L		N	P				T	U
OA16	OO5OOE6OOX5	OO16	A1B1C1D1E1F1G1H1J1K1L1M0N1P1Q1R0S0T1U1	A	B	C	D	E	F	G	H	J	K	L		N	P	Q			T	U
OA17	OO6OOE6OOX5	OO17	A1B1C1D1E1F1G1H1J1K1L1M0N1P1Q1R1S0T1U1	A	B	C	D	E	F	G	H	J	K	L		N	P	Q	R		T	U
OA18	OO7OOE6OOX5	OO18	A1B1C1D1E1F1G1H1J1K1L1M0N1P1Q1R1S1T1U1	A	B	C	D	E	F	G	H	J	K	L		N	P	Q	R	S	T	U
OA19	OO7OOE7OOX5	OO19	A1B1C1D1E1F1G1H1J1K1L1M1N1P1Q1R1S1T1U1	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q	R	S	T	U
OAE1	OO7OOE8OOX5	OOE1	V0W1X0Y0Z0AA0BB0CC0DD0EE0FF0GG0HH0JJ0KK0		W																	
OAE2	OO7OOE9OOX5	OOE2	V0W1X0Y0Z0AA0BB0CC0DD0EE0FF0GG0HH0JJ1KK0		W											JJ						
OAE3	OO8OOE9OOX5	OOE3	V0W1X0Y0Z0AA0BB0CC0DD0EE0FF0GG0HH0JJ1KK1		W											JJ	KK					
OAE4	OO9OOE9OOX5	OOE4	V0W1X0Y0Z0AA0BB0CC0DD0EE0FF0GG1HH0JJ1KK1		W									GG		JJ	KK					
OAE5	OO9OOE10OOX5	OOE5	V0W1X0Y0Z0AA0BB0CC0DD0EE0FF0GG1HH1JJ1KK1		W									GG	HH	JJ	KK					
OAE6	OO10OOE10OOX5	OOE6	V0W1X0Y0Z0AA0BB0CC0DD0EE0FF1GG1HH1JJ1KK1		W								FF	GG	HH	JJ	KK					
OAE7	OO10OOE11OOX5	OOE7	V0W1X0Y0Z1AA0BB0CC0DD0EE0FF1GG1HH1JJ1KK1		W			Z					FF	GG	HH	JJ	KK					
OAE8	OO11OOE11OOX5	OOE8	V0W1X0Y0Z1AA1BB0CC0DD0EE0FF1GG1HH1JJ1KK1		W			Z	AA				FF	GG	HH	JJ	KK					
OAE9	OO11OOE12OOX5	OOE9	V0W1X0Y0Z1AA1BB0CC0DD1EE0FF1GG1HH1JJ1KK1		W			Z	AA			DD	FF	GG	HH	JJ	KK					
OAE10	OO12OOE12OOX5	OOE10	V0W1X0Y0Z1AA1BB0CC0DD1EE1FF1GG1HH1JJ1KK1		W			Z	AA			DD	FF	GG	HH	JJ	KK					
OAE11	OO13OOE12OOX5	OOE11	V0W1X0Y1Z1AA1BB0CC0DD1EE1FF1GG1HH1JJ1KK1		W		Y	Z	AA			DD	FF	GG	HH	JJ	KK					
OAE12	OO13OOE13OOX5	OOE12	V0W1X1Y1Z1AA1BB0CC0DD1EE1FF1GG1HH1JJ1KK1		W	X	Y	Z	AA			DD	FF	GG	HH	JJ	KK					
OAE13	OO14OOE13OOX5	OOE13	V1W1X1Y1Z1AA1BB0CC0DD1EE1FF1GG1HH1JJ1KK1	V	W	X	Y	Z	AA			DD	FF	GG	HH	JJ	KK					
OAE14	OO15OOE13OOX5	OOX1	LL0MM1NN0PP0QQ0RR0SS0		MM																	
OAE15	OO16OOE13OOX5	OOX2	LL0MM1NN1PP0QQ0RR0SS0		MM	NN																
OAE16	OO17OOE13OOX5	OOX3	LL0MM1NN1PP0QQ0RR0SS1		MM	NN				SS												
OAE17	OO18OOE13OOX5	OOX4	LL1MM1NN1PP0QQ0RR0SS1	LL	MM	NN				SS												
OAE18	OO19OOE13OOX5	OOX5	LL1MM1NN1PP1QQ0RR0SS1	LL	MM	NN	PP			SS												
OAE19	OO19OOE13OOX6	OOX6	LL1MM1NN1PP1QQ0RR1SS1	LL	MM	NN	PP		RR	SS												
		OOX7	LL1MM1NN1PP1QQ1RR1SS1	LL	MM	NN	PP	QQ	RR	SS												
Measures from Table 9	**Coding that describes Measures from Table 7**	**Measures from Table 7**	**Coding that describes Measures from Table 6**	**Measures from Table 6**																		
SA1	SC1SCE0SCM0SCX0	SC1	A0B0C0D0E1F0G0H0J0K0L0M0					E														
SA2	SC2SCE0SCM0SCX0	SC2	A0B0C0D0E1F0G0H0J1K0L0M0					E				J										
SA3	SC2SCE1SCM0SCX0	SC3	A0B0C0D0E1F0G0H0J1K1L0M0					E				J	K									
SA4	SC2SCE1SCM0SCX1	SC4	A0B0C0D1E1F0G0H0J1K1L0M0				D	E				J	K									
SA5	SC3SCE1SCM0SCX1	SC5	A0B0C0D1E1F1G0H0J1K1L0M0				D	E	F			J	K									
SA6	SC4SCE1SCM0SCX1	SC6	A0B0C0D1E1F1G0H1J1K1L0M0				D	E	F		H	J	K									
SA7	SC4SCE1SCM0SCX2	SC7	A0B0C0D1E1F1G1H1J1K1L0M0				D	E	F	G	H	J	K									
SA8	SC4SCE2SCM0SCX2	SC8	A0B1C0D1E1F1G1H1J1K1L0M0		B		D	E	F	G	H	J	K									
SA9	SC4SCE3SCM0SCX2	SC9	A1B1C0D1E1F1G1H1J1K1L0M0	A	B		D	E	F	G	H	J	K									
SA10	SC4SCE3SCM0SCX3	SC10	A1B1C0D1E1F1G1H1J1K1L1M1	A	B		D	E	F	G	H	J	K	L	M							
SA11	SC4SCE3SCM1SCX3	SC11	A1B1C1D1E1F1G1H1J1K1L1M1	A	B	C	D	E	F	G	H	J	K	L	M							
SA12	SC4SCE4SCM1SCX3	SCE1	N0P1Q0R0S0T0U0V0W0X0Y0Z0		P																	
SA13	SC4SCE5SCM1SCX3	SCE2	N0P1Q0R0S0T0U0V0W0X0Y0Z1		P										Z							
SA14	SC4SCE6SCM1SCX3	SCE3	N0P1Q0R0S0T1U0V0W0X0Y0Z1		P				T						Z							
SA15	SC4SCE6SCM1SCX4	SCE4	N0P1Q0R0S0T1U0V0W0X1Y0Z1		P				T				X		Z							
SA16	SC4SCE7SCM1SCX4	SCE5	N0P1Q0R0S0T1U1V0W0X1Y0Z1		P				T	U			X		Z							
SA17	SC4SCE7SCM1SCX5	SCE6	N0P1Q0R0S0T1U1V0W1X1Y0Z1		P				T	U		W	X		Z							
SA18	SC4SCE7SCM1SCX6	SCE7	N0P1Q1R0S0T1U1V0W1X1Y0Z1		P	Q			T	U		W	X		Z							
SA19	SC4SCE7SCM1SCX7	SCE8	N1P1Q1R0S0T1U1V0W1X1Y0Z1	N	P	Q			T	U		W	X		Z							
SAE1	SC4SCE8SCM1SCX7	SCE9	N1P1Q1R0S0T1U1V1W1X1Y0Z1	N	P	Q			T	U	V	W	X		Z							
SAE2	SC4SCE8SCM1SCX8	SCE10	N1P1Q1R0S1T1U1V1W1X1Y0Z1	N	P	Q		S	T	U	V	W	X		Z							
SAE3	SC5SCE8SCM1SCX8	SCE11	N1P1Q1R1S1T1U1V1W1X1Y0Z1	N	P	Q	R	S	T	U	V	W	X		Z							
SAE4	SC6SCE8SCM1SCX8	SCE12	N1P1Q1R1S1T1U1V1W1X1Y1Z1	N	P	Q	R	S	T	U	V	W	X	Y	Z							
SAE5	SC7SCE8SCM1SCX8	SCM1	AA1BB0CC0	AA																		
SAE6	SC8SCE8SCM1SCX8	SCM2	AA1BB0CC1	AA		CC																
SAE7	SC9SCE8SCM1SCX8	SCM3	AA1BB1CC1	AA	BB	CC																
SAE8	SC8SCE8SCM1SCX9	SCX1	DD0EE0FF0GG0HH1JJ0KK0LL0MM0NN0PP0QQ0RR0SS0TT0UU0					HH														
SAE9	SC9SCE8SCM1SCX9	SCX2	DD0EE0FF0GG0HH1JJ0KK0LL0MM0NN0PP1QQ0RR0SS0TT0UU0					HH						PP								
SAE10	SC9SCE9SCM1SCX9	SCX3	DD0EE0FF0GG0HH1JJ0KK0LL0MM0NN0PP1QQ0RR0SS0TT0UU1					HH						PP					UU			
SAE11	SC9SCE10SCM1SCX9	SCX4	DD0EE0FF0GG0HH1JJ0KK0LL0MM0NN1PP1QQ0RR0SS0TT0UU1					HH					NN	PP					UU			
SAE12	SC9SCE10SCM1SCX10	SCX5	DD0EE0FF0GG0HH1JJ0KK0LL0MM0NN1PP1QQ0RR0SS0TT1UU1					HH					NN	PP				TT	UU			
SAE13	SC9SCE11SCM1SCX10	SCX6	DD0EE0FF0GG0HH1JJ0KK0LL0MM0NN1PP1QQ0RR0SS1TT1UU1					HH					NN	PP			SS	TT	UU			
SAE14	SC9SCE11SCM1SCX11	SCX7	DD0EE0FF0GG0HH1JJ0KK0LL0MM0NN1PP1QQ1RR0SS1TT1UU1					HH					NN	PP	QQ		SS	TT	UU			
SAE15	SC9SCE11SCM1SCX12	SCX8	DD0EE0FF0GG0HH1JJ0KK0LL0MM0NN1PP1QQ1RR1SS1TT1UU1					HH					NN	PP	QQ	RR	SS	TT	UU			
SAE16	SC10SCE11SCM1SCX12	SCX9	DD0EE0FF0GG0HH1JJ0KK1LL1MM0NN1PP1QQ1RR1SS1TT1UU1					HH		KK	LL		NN	PP	QQ	RR	SS	TT	UU			
SAE17	SC10SCE11SCM1SCX13	SCX10	DD0EE1FF0GG0HH1JJ0KK1LL1MM0NN1PP1QQ1RR1SS1TT1UU1		EE			HH		KK	LL		NN	PP	QQ	RR	SS	TT	UU			
SAE18	SC11SCE11SCM1SCX13	SCX11	DD1EE1FF0GG0HH1JJ0KK1LL1MM0NN1PP1QQ1RR1SS1TT1UU1	DD	EE			HH		KK	LL		NN	PP	QQ	RR	SS	TT	UU			
SAE19	SC11SCE11SCM1SCX14	SCX12	DD1EE1FF0GG1HH1JJ0KK1LL1MM0NN1PP1QQ1RR1SS1TT1UU1	DD	EE		GG	HH		KK	LL		NN	PP	QQ	RR	SS	TT	UU			
SCAM1	SC11SCE11SCM1SCX15	SCX13	DD1EE1FF1GG1HH1JJ0KK1LL1MM0NN1PP1QQ1RR1SS1TT1UU1	DD	EE	FF	GG	HH		KK	LL		NN	PP	QQ	RR	SS	TT	UU			
SCAM2	SC11SCE11SCM2SCX15	SCX14	DD1EE1FF1GG1HH1JJ1KK1LL1MM0NN1PP1QQ1RR1SS1TT1UU1	DD	EE	FF	GG	HH	JJ	KK	LL		NN	PP	QQ	RR	SS	TT	UU			
SCAM3	SC11SCE11SCM3SCX15	SCX15	DD1EE1FF1GG1HH1JJ1KK1LL1MM1NN1PP1QQ1RR1SS1TT1UU1	DD	EE	FF	GG	HH	JJ	KK	LL	MM	NN	PP	QQ	RR	SS	TT	UU			

4.2.3 Sensitivity Analysis

When the Project Delivery Team (PDT) uses the term increment or incremental in discussing incremental cost analysis, the PDT is using the term to mean a difference, or change, between two solutions. The types of changes the PDT, specifically the economist, are interested in are differences in cost and differences in output between solutions; these differences are referred to as incremental cost and incremental output.

Incremental Cost is the difference in total cost between two solutions, expressed in dollars. For example, if a 40-acre swale costs $100,000, and a 50-acre swale costs $175,000, the increment of cost (or change in cost) between the two swales is $75,000. This incremental cost information simply tells us that the 50-acre swale costs $75,000 more than the 40-acre swale. The example formula is shown below.

Incremental Cost of Solution B = [Total Cost of Solution B] – [Total Cost of Solution A]

Incremental Output is the difference in output between two solutions, expressed in the output’s unit of measurement. Continuing with the swale example, if the 40-acre swale would produce 20 habitat units, and the 50-acre swale would produce 30 habitat units, the increment of output between the two swales is 10 habitat units. In other words, the 50-acre swale provides 10 more habitat units than the 40-acre swale. The example formula is shown below.

Incremental Output of Solution B = [Total Output of Solution B] – [Total Output of Solution A]

Examining the changes in incremental cost per unit across solutions is, in other words, examining how the cost per unit (or average cost) of incremental output changes as the level of output changes. Returning again to the swale example, the incremental cost per unit of the 50-acre swales is $7,500 per habitat unit, based on the following calculation:

($175,000 cost of 50 acre swale - $100,000 cost of 40 acre swale) = $75,000

(30 HU output of 50 acre swale - 20 HU output of 40 acre swale) = 10 HU

= $7,500/HU

This describes that the 10 extra habitat units that the 50-acre swale can provide (over the 20 units provided by the 40-acre swale) cost $7,500 each. Using the average cost equation one can find that the 20 habitat units provided by the 40-acre swale cost $5,000 each. This information tells the PDT that we can get the first 20 habitat units for $5,000 each; if the PDT wants more, for example an additional 10 units, but those will cost $7,500 each. Now the team has the cost and output data in a format that facilitates answering the “is it worth it?” question. Specifically, are 20-habitat units worth $5,000 each, and if so, are 10 more worth $7,500 each?

For this analysis, two scenarios were computed to help identify the NER Plan. The most significant and sensitive management measure was the six grade restoration facilities (GRF’s), also known as channel stabilization features, on Ohkay Owingeh Pueblo. The GRF’s mitigates headcut and channel scour and ensures the river bed doesn’t drop away from the present river banks. GRFs can be expensive (~$20 million on the Ohkay Owingeh Pueblo) and the PDT was concerned that inclusion of this feature may distort identification of other cost effective means to generate habitat outputs in the study area. To accurately capture how the GRFs impact plan selection it was determined, in coordination with the project’s Biologist, to assign the GRFs a high and low unit cost.

The original analysis assumed that the unit cost for the GRFs was high, which moved all cost-effective plans that included the GRFs to the upper right side of the cost and output graph. As a consequence of all plans that included the GRF happening to be significantly far to the right in the cost and output graph, it also limited the number of plans the project team could consider for the selected plan. The GRFs are an integral element for (ecosystem) project success. The team determined the best course of action was to reanalyze the effectiveness of the GRFs. As a result of the sensitivity analysis, the GRFs are shown to have a greater effect on ecosystem measures upstream of the GRF. Therefore, for measures upstream of the GRF, an additional 100 meter buffer was added for benefit calculation. Table 10 displays the original AAHUs and the updated AAHUs after the 100 meter was applied.

In the second, or sensitivity analysis, the new AAHU values for the affected management measures were increased to account for the fact that the GRFs do provide greater benefit for management measures upstream. The new AAHU values, from Table 10 below, were added to the model and the new results showed that when the AAHUs were increased the plans that included 1 or more of the GRFs moved left along the supply curve (shown in Figure 5) and included more management measures within those plans.

By conducting the sensitivity analysis, it was demonstrated that under the original analysis that any plans that included the GRF made those plans extremely expensive and therefore moving those plans up and to the right along the supply curve (see figure 5). When the sensitivity analysis was completed the plans became cheaper and the unit cost became smaller therefore moving plans (that included the GRF) down and to the left (see figure 5), which made those plans more plausible for the PDT and our non-Federal sponsor.

Table 11 - AAHU final analysis

CEICA CODE	Group (location ID)	Measure Description	Updated AAHU(100m buffer) SENSITIVITY ANALYSIS	Target AAHU
A	3101	High-flow channel		28.80
B	3102	High-flow channel		19.38
C	3103	High-flow channel		32.88
D	3107	High-flow channel		35.34
E	3000	Swale	72.74	68.91
F	3002	Vegetation Removal (Invasive plant species removal)		245.26
G	3111	High-flow channel		305.00
H	3115	Terrace lowering		93.04
J	3118	High-flow channel		122.82
K	3129	High-flow channel		95.49
L	3208	Terrace lowering		22.67
M	3202	Swale		12.85
N	3210	Swale		108.33
P	3214	Swale		98.00
Q	3215	Swale		87.89
R	3217	Swale		27.91
S	3218	Swale		22.21
T	3204	High flow channel		226.82
U	3212	Channel Stabilization (URG)	592.55	115.60
V	3001	Swale		155.53
W	3014	Vegetation Removal (Invasive plant species removal)		227.25
X	3105	High-flow channel		27.04
Y	3108	High-flow channel		56.80
Z	3113	High-flow channel		344.62
AA	3116	High-flow channel		533.53
BB	3119	High-flow channel	195.32	185.03
CC	3120	High-flow channel		60.85
DD	3130	High-flow channel		73.65
EE	3140	High-flow channel		55.29
FF	3201	Terrace lowering		80.48
GG	3203	Terrace lowering		140.31
HH	3209	Terrace lowering		119.91
JJ	3213	High flow channel		49.63
KK	3211	Channel Stabilization (URC)	296.51	34.41
LL	3016	Bankline lowering (Contouring)		522.38
MM	3123	Terrace lowering	403.22	381.98
NN	3124	Terrace lowering	224.53	20.56
PP	3125	Terrace lowering	15.27	14.46
QQ	3127	Terrace lowering		4.94
RR	3184	High-Flow channel	155.76	184.43
SS	0/3205	Channel Stabilization (combination of 4 GRF's)	2069.61	1,055.24

4.2.4 Incremental Analysis

As a result of the cost-effectiveness analysis, there were 78 best buy plans carried forward for incremental analysis. Highlighted, inside the darker green box, is the TSP (Best Buy 36) and the 24 Best Buys that were screened using incremental analysis. Plans 1 to 18, inside the red box, were left out of consideration when compared to the other best buys as these plans don't address grade restoration. Plans 44 to 78, inside the lighter green box, were left out of consideration because when compared to other best buys these best buys only obtain only small marginal benefits at a very high cost. Best buy plans 19 through 43 were further screened incrementally and of these 7 plans stood out as a plan of interest to recommend as the TSP. These plans can be easily identified as they are the plan (green square marker) to the right of each "gap" between the cluster of plans, meaning that compared to the previous plan that plan provides much more benefit for very little increase in cost. In addition, each of these plans included all 6 GRF's, which was preferred by the Ohkay Owingeh Pueblo and was also considered by the PDT as necessary for overall project success. These plans also included a wide distribution of measures, particularly near the historic Pueblo of Santa Clara, which was preferred by the Santa Clara Pueblo since the measures within these plans play a significant role in their traditional, cultural and recreational practices.

It is important to emphasize that the reason why the curve doesn't a clear cut breaking point is due to the fact that the preliminary models eliminated the obvious ineffective and inefficient measures, making future measures in future iterations of the modeling process more effective and efficient when combined into plans.

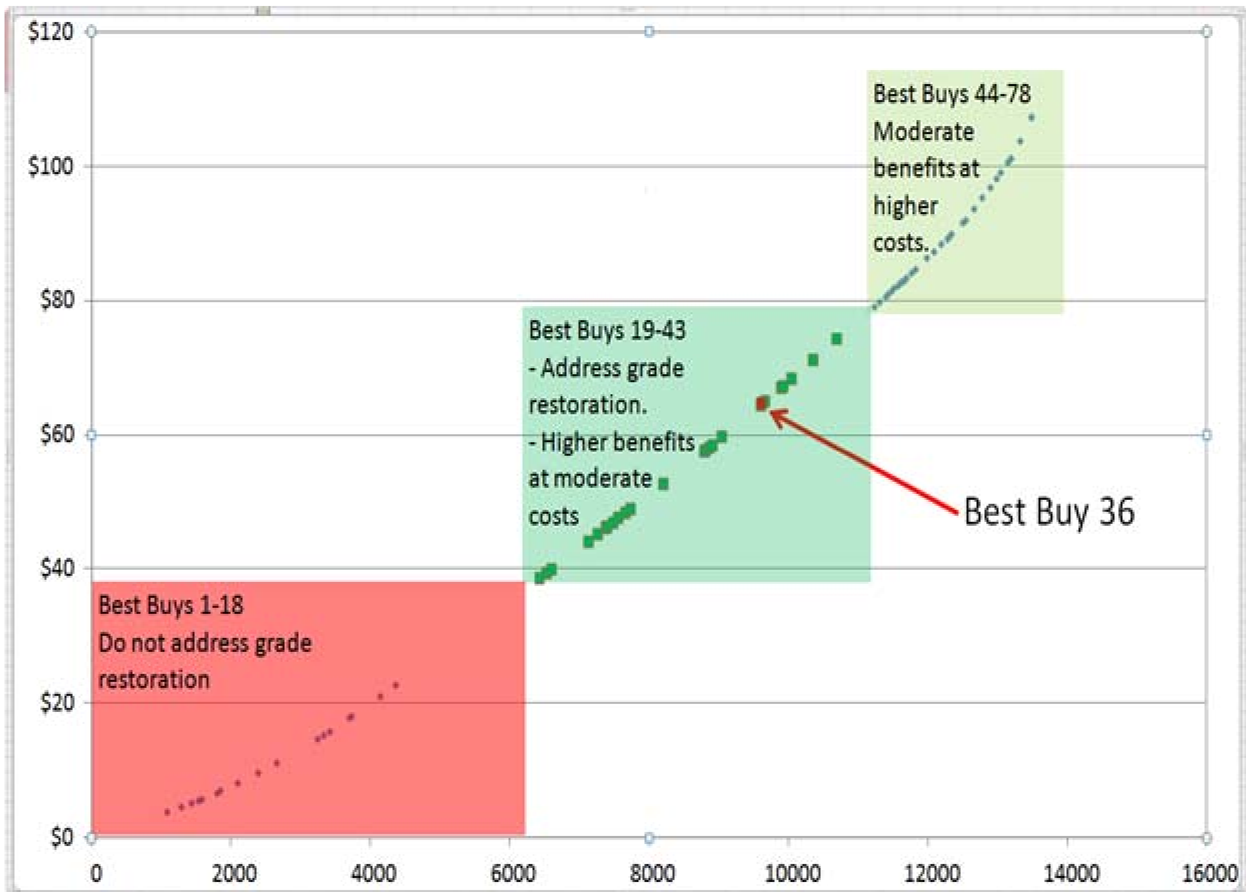


Figure 6 - Incremental cost (in millions) and output

4.2.5 Final Findings

As a result of the CEICA analysis, it was determined by the PDT and Pueblo Sponsors to select best buy (BB) 36. Table 11 below lists the BB36 management measures to be implemented for Santa Clara and Ohkay Owingeh Pueblos. The features in Table 12 are the same features entered into the first model of the IWR planning Suite (Table 6).

Table 12 - Best Buy 36, comprised of measures on Ohkay Owingeh and Santa Clara Pueblos

Best Buy's Ohkay Owingeh Pueblo	Values Sum of Acres	Sum of Cost
F	**9.03245**	**$1,252,520.06**
3002	**9.03245**	**$1,252,520.06**
Vegetation Removal (Invasive plant species removal)	9.03245	$1,252,520.06
245.26	**9.03245**	**$1,252,520.06**
Upper Rio Grande East - Top of study area to confluence (east bank)	9.03245	$1,252,520.06
FF	**2.96384**	**$643,492.45**
3201	**2.96384**	**$643,492.45**
Terrace lowering	2.96384	$643,492.45
80.48	**2.96384**	**$643,492.45**
Rio Chama East - Top of study area to confluence (east bank)	2.96384	$643,492.45
GG	**5.16736**	**$1,116,172.85**
3203	**5.16736**	**$1,116,172.85**
Terrace lowering	5.16736	$1,116,172.85
140.31	**5.16736**	**$1,116,172.85**
Rio Chama East - Top of study area to confluence (east bank)	5.16736	$1,116,172.85
H	**1.67706**	**$367,389.42**
3115	**1.67706**	**$367,389.42**
Terrace lowering	1.67706	$367,389.42
93.04	**1.67706**	**$367,389.42**
Upper Rio Grande East - Top of study area to confluence (east bank)	1.67706	$367,389.42
HH	**4.41582**	**$954,353.48**
3209	**4.41582**	**$954,353.48**
Terrace lowering	4.41582	$954,353.48
119.91	**4.41582**	**$954,353.48**
Rio Chama East - Top of study area to confluence (east bank)	4.41582	$954,353.48
JJ	**1.82759**	**$228,265.53**
3213	**1.82759**	**$228,265.53**
High flow channel	1.82759	$228,265.53
49.63	**1.82759**	**$228,265.53**
Rio Chama East - Top of study area to confluence (east bank)	1.82759	$228,265.53
KK	**14.375573**	**$1,544,843.83**
3211	**14.375573**	**$1,544,843.83**
Channel Stabilization (URC)	14.375573	$1,544,843.83
296.51	**14.375573**	**$1,544,843.83**
Rio Chama East - Top of study area to confluence (east bank)	14.375573	$1,544,843.83
L	**0.83502**	**$186,972.11**
3208	**0.83502**	**$186,972.11**
Terrace lowering	0.83502	$186,972.11
22.67	**0.83502**	**$186,972.11**
Upper Rio Grande East - Top of study area to confluence (east bank)	0.83502	$186,972.11
LL	**19.23791**	**$4,148,736.58**
3016	**19.23791**	**$4,148,736.58**
Bankline lowering (Contouring)	19.23791	$4,148,736.58
522.38	**19.23791**	**$4,148,736.58**
Mid Rio Grande West - Below confluence to End of OO (west bank)	19.23791	$4,148,736.58
MM	**14.06737**	**$3,019,775.42**
3123	**14.06737**	**$3,019,775.42**
Terrace lowering	14.06737	$3,019,775.42
403.22	**14.06737**	**$3,019,775.42**
Mid Rio Grande West - Below confluence to End of OO (west bank)	14.06737	$3,019,775.42
NN	**0.75733**	**$1,700,623.04**
3124	**0.75733**	**$1,700,623.04**
Terrace lowering	0.75733	$1,700,623.04
224.53	**0.75733**	**$1,700,623.04**
Mid Rio Grande West - Below confluence to End of OO (west bank)	0.75733	$1,700,623.04
PP	**0.53268**	**$122,011.60**
3125	**0.53268**	**$122,011.60**
Terrace lowering	0.53268	$122,011.60
15.27	**0.53268**	**$122,011.60**
Mid Rio Grande West - Below confluence to End of OO (west bank)	0.53268	$122,011.60
SS	**0**	**$15,747,353.08**
0	**0**	**$15,747,353.08**
Channel Stabilization (combination of 4 GRF's)	0	$15,747,353.08
2069.61	**0**	**$15,747,353.08**
Mid Rio Grande West - Below confluence to End of OO (west bank)	0	$15,747,353.08
U	**15.818431**	**$3,458,763.20**
3212	**15.818431**	**$3,458,763.20**
Channel Stabilization (URG)	15.818431	$3,458,763.20
592.55	**15.818431**	**$3,458,763.20**
Upper Rio Grande East - Top of study area to confluence (east bank)	15.818431	$3,458,763.20
W	**8.36898**	**$1,031,650.56**
3014	**8.36898**	**$1,031,650.56**
Vegetation Removal (Invasive plant species removal)	8.36898	$1,031,650.56
227.25	**8.36898**	**$1,031,650.56**
Rio Chama East - Top of study area to confluence (east bank)	8.36898	$1,031,650.56
Grand Total	**99.077414**	**$35,522,923.21**

Best Buy's Santa Clara Pueblo	Sum of Acres	Sum of Cost
AA	2.51349	$ 538,865.07
3164	2.51349	$ 538,865.07
High-flow channel	2.51349	$ 538,865.07
68.25067909	2.51349	$ 538,865.07
Santa Cruz - Entire River	2.51349	$ 538,865.07
D	3.33853	$ 617,851.89
3020	3.33853	$ 617,851.89
Bankline lowering (3.5 acre bank lowering next to shrub / scrub & mixed deciduo	3.33853	$ 617,851.89
90.65360899	3.33853	$ 617,851.89
Lower Rio Grande West - Start of SC to end of SC (west bank)	3.33853	$ 617,851.89
E	38.96218	$ 3,886,638.00
3021	38.96218	$ 3,886,638.00
Vegetation Removal (Invasive plant species removal)	38.96218	$ 3,886,638.00
1057.969295	38.96218	$ 3,886,638.00
Lower Rio Grande West - Start of SC to end of SC (west bank)	38.96218	$ 3,886,638.00
HH	1.65732	$ 193,773.48
3032	1.65732	$ 193,773.48
Vegetation Removal (Invasive plant species removal)	1.65732	$ 193,773.48
45.00245295	1.65732	$ 193,773.48
Lower Rio Grande East - Start of SC to end of SC (east bank)	1.65732	$ 193,773.48
J	7.44354	$ 761,946.41
3026	7.44354	$ 761,946.41
Vegetation Removal (Invasive plant species removal)	7.44354	$ 761,946.41
202.1200243	7.44354	$ 761,946.41
Lower Rio Grande West - Start of SC to end of SC (west bank)	7.44354	$ 761,946.41
K	9.53039	$ 1,428,788.12
3035	9.53039	$ 1,428,788.12
Vegetation Removal (Invasive plant species removal)	9.53039	$ 1,428,788.12
258.7858275	9.53039	$ 1,428,788.12
Lower Rio Grande West - Start of SC to end of SC (west bank)	9.53039	$ 1,428,788.12
N	20.58576	$ 4,691,348.11
3046	20.58576	$ 4,691,348.11
Swale	20.58576	$ 4,691,348.11
558.9805806	20.58576	$ 4,691,348.11
Lower Rio Grande West - Start of SC to end of SC (west bank)	20.58576	$ 4,691,348.11
NN	17.00987	$ 3,775,364.44
3054	17.00987	$ 3,775,364.44
Swale (Wetland / marsh / wet meadow swale)	17.00987	$ 3,775,364.44
461.8817575	17.00987	$ 3,775,364.44
Lower Rio Grande East - Start of SC to end of SC (east bank)	17.00987	$ 3,775,364.44
P	5.75432	$ 594,079.45
3047	5.75432	$ 594,079.45
Vegetation Removal (Invasive plant species removal)	5.75432	$ 594,079.45
156.2513667	5.75432	$ 594,079.45
Lower Rio Grande West - Start of SC to end of SC (west bank)	5.75432	$ 594,079.45
PP	3.15832	$ 585,935.00
3144	3.15832	$ 585,935.00
Bankline lowering (Remove spoil bank)	3.15832	$ 585,935.00
85.7602317	3.15832	$ 585,935.00
Lower Rio Grande East - Start of SC to end of SC (east bank)	3.15832	$ 585,935.00
Q	21.7556	$ 4,847,540.17
3049	21.7556	$ 4,847,540.17
Swale	21.7556	$ 4,847,540.17
590.7461235	21.7556	$ 4,847,540.17
Lower Rio Grande West - Start of SC to end of SC (west bank)	21.7556	$ 4,847,540.17
QQ	5.1945	$ 1,173,214.01
3146	5.1945	$ 1,173,214.01
Swale	5.1945	$ 1,173,214.01
141.0501544	5.1945	$ 1,173,214.01
Lower Rio Grande East - Start of SC to end of SC (east bank)	5.1945	$ 1,173,214.01
SS	1.62941	$ 366,359.02
3154	1.62941	$ 366,359.02
High-flow channel	1.62941	$ 366,359.02
44.24459179	1.62941	$ 366,359.02
Lower Rio Grande East - Start of SC to end of SC (east bank)	1.62941	$ 366,359.02
T	1.20849	$ 242,253.36
3145	1.20849	$ 242,253.36
Bank destabilization (Bank destabilization along shrub / scrub)	1.20849	$ 242,253.36
32.81503534	1.20849	$ 242,253.36
Lower Rio Grande West - Start of SC to end of SC (west bank)	1.20849	$ 242,253.36
TT	1.75004	$ 392,829.19
3155	1.75004	$ 392,829.19
High-flow channel	1.75004	$ 392,829.19
47.52014865	1.75004	$ 392,829.19
Lower Rio Grande East - Start of SC to end of SC (east bank)	1.75004	$ 392,829.19
U	3.32798	$ 729,208.01
3151	3.32798	$ 729,208.01
High-flow channel	3.32798	$ 729,208.01
90.36713693	3.32798	$ 729,208.01
Lower Rio Grande West - Start of SC to end of SC (west bank)	3.32798	$ 729,208.01
UU	3.7857	$ 793,756.55
3161	3.7857	$ 793,756.55
High-flow channel	3.7857	$ 793,756.55
102.7959514	3.7857	$ 793,756.55
Lower Rio Grande East - Start of SC to end of SC (east bank)	3.7857	$ 793,756.55

(continued)

W	**3.10427**	**$**	**688,438.50**
3158	**3.10427**	**$**	**688,438.50**
High-flow channel	3.10427	$	688,438.50
84.29257151	**3.10427**	**$**	**688,438.50**
Lower Rio Grande West - Start of SC to end of SC (west bank)	3.10427	$	688,438.50
X	**3.0912**	**$**	**672,541.78**
3159	**3.0912**	**$**	**672,541.78**
High-flow channel	3.0912	$	672,541.78
83.937672	**3.0912**	**$**	**672,541.78**
Lower Rio Grande West - Start of SC to end of SC (west bank)	3.0912	$	672,541.78
Z	**10.27807**	**$**	**2,015,843.98**
3034	**10.27807**	**$**	**2,015,843.98**
Vegetation Removal (Invasive plant species removal)	10.27807	$	2,015,843.98
279.0881433	**10.27807**	**$**	**2,015,843.98**
Lower Rio Grande West - Start of SC to end of SC (west bank)	10.27807	$	2,015,843.98
Grand Total	**165.07898**	**$**	**28,996,574.54**

*****NOTE***** *Some of the terminology/cost in Table 12 is different from the terminology in Appendix J. The change was made during detailed design.*

The results show that the total cost for the project is expected to be $64.5 million. Of that, the management measures for Ohkay Owingeh are expected to cost $35.5 million and the management measures for Santa Clara are expected to cost $29.9 million. Within Ohkay Owingeh Pueblo, the management measures include: 6 GRFs (1 located along the Rio Chama, 1 located along the Rio Grande upstream of the Rio Grande/Rio Chama confluence, and 4 located below the Rio Grande/Rio Chama confluence), terrace lowering, non-native vegetation removal and high flow channels. For the Santa Clara Pueblo management measures include: vegetation removal, high-flow channels, swales, vegetation removal and bank line lowering. This plan was the first plan that meets the study objectives and sponsor goals for the study (detailed in the incremental cost section of this appendix).

5 - Recreation Analysis

5.1 Recreation Plan

The recreation plan for the Espanola Valley General Investigation study was derived from a 2014 recreation master plan prepared by USACE for Santa Clara Pueblo. At the time of this analysis, Ohkay Owingeh Pueblo wished not to include a recreation plan as a part of their portion of the study. The recreation amenities should compliment and not detract from the ecosystem restoration components. Recreational amenities would include formalized gravel trails, informational kiosk and shade structures, and wildlife blinds for bird and wildlife observations. An amphitheater would also be included in the recreation plan. The proposed recreation plan selected those amenities that complement the restoration features without detracting from habitat. Where possible, gravel trails would follow existing primitive trails or access road alignments. Kiosks and benches would be placed at strategic locations along improved trails.

USACE performed additional analysis to identify the benefit-cost ratio for the selected recreation plan. This analysis is presented below.

5.1.1 Recreation Overview

The current supplies of recreation facilities located in the Española/Santa Clara Pueblo area are very limited. Currently no recreation infrastructure exists.

This recreation analysis follows the NED benefit evaluation procedures contained in ER 1105-2-100, Appendix E, Section VII. Because the recreation features identified in the proposed project are of a small scale and incidental to the project purpose, USACE selected the unit day value (UDV) method of benefit evaluation for this analysis. The UDV calculations require an estimation of five criteria, obtained from Economic Guidance Memorandum (EGM) 15-3, when evaluating the without- and with-project recreation experience. A discussion of each of the five criteria for the without-project condition, as well as the reason(s) for the proposed point boost, follows:

- Recreation experience – This criterion tries to explore the recreation opportunities that exist at the site. The proposed recreation plan would improve the trails within the project site by adding kiosks and adding viewing blinds (to view wildlife).

- Availability of opportunity – This criterion evaluates the uniqueness of the recreation experience by identifying the number and proximity of available substitutes. In the project area, there are 2-3 recreation facilities located within one hour's travel time. The proposed recreation plan significantly increases the availability of opportunity.

- Carrying capacity – This criterion evaluates the ability of the recreation facilities to handle the existing and projected demand. Excessively crowded facilities diminish the recreation experience for users. The proposed recreation plan includes adding formal gravel trails to guide users through the natural environment and to provide extra facilities for recreation visitors.

- Accessibility – This criterion examines the relative ease by which users can get to and through the recreation site. Currently, access is limited by the lack of roads and the lack of parking space. The proposed recreation plan includes an expanded trail system.

- Environmental – This criterion measures the aesthetic value of the recreation experience. The proposed recreation plan includes efforts to increase the amount of vegetated area and improve wildlife viewing through an increase in wildlife abundance and diversity.

5.1.2 UDV Evaluation of the Existing Project Condition

EGM 15-3 outlines the general and specialized recreation valuation for UDV point values for fiscal year 2015 and outlines the value of the recreation experience per visit based upon the point values assessed. The previous discussion of the five criteria used for establishing a value of the recreation experience afforded by the Española/Santa Clara Pueblo area indicates that the proposed project would touch most of these criteria in a beneficial direction. What is unclear is the qualitative improvement's translation to the UDV point values. Therefore, multiple scenarios were developed to evaluate the impact of the proposed project on the existing recreation facilities. One scenario assumes the existing facilities have relatively low point values (the "minimum points" scenario), and the proposed recreation features provide a significant boost to the quality of the recreation experience. Another scenario assumes the recreation experience has a relatively high starting value (the "most likely" scenario) and the proposed recreation features are somewhat less beneficial than described in the "minimum points" scenario. Based on EGM 15-3, Table 13 below presents an estimate of the minimum, most likely, and maximum UDV computed for the without-project condition. Converting these point values into dollars per EGM 15-3, the without-project condition is worth $3.91 per visit (at the minimum), $3.91 per visit (at the most likely), and $4.64 per visit (at the maximum). The difference between the minimum and the maximum is $0.73.

Table 13 - Without-project values for recreation analysis.

	Minimum Pts	**Most Likely Pts**	**Maximum Pts**	**Judgment factors used for Most Likely Pts.**
Recreation Experience	0	1	4	Few trails and limited fishing activities
Availability of Opportunity	4	5	6	2-3 activities within an hour of the site
Carrying Capacity	0	1	2	Minimum facilities. No basic facilities to conduct activities
Accessibility	0	1	3	Limited access near or at site
Environmental Quality	0	1	2	Low aesthetic factors that lower quality

5.1.3 UDV Evaluation of the Proposed Project Condition

USACE expects that the restoration efforts in the Española/Santa Clara Pueblo area will improve the environmental aesthetic. With no current recreation infrastructure, the features of the recreation plan include formalized gravel trails, informational kiosk and shade structures, wildlife blinds for bird and wildlife observations and an amphitheater, which are expected to touch each of the other criteria in the UDV assessment in a positive fashion. The Rio Grande bosque is unique due to the fact that it encompasses a small percentage of the surrounding area. Based on EGM 15-3, Table 14 below presents an estimate of the minimum, most likely, and maximum UDV computed for the with-project condition. Converting these point values into dollars per EGM 15-3, the without-project condition is worth $7.32 per visit (at the minimum), $8.30 per visit (at the most likely), and $9.03 per visit (at the maximum). The difference between the minimum and the maximum is $1.71.

Table 14 - With-project values for recreation analysis

	Minimum Pts	**Most Likely Pts**	**Maximum Pts**	**Judgment factors used for Most Likely Pts.**
Recreation Experience	11	14	16	Improved trails, kiosk, wildlife observations (blinds/decks) and an amphitheater
Availability of Opportunity	11	12	14	No similar activities within an hour of the recreation site
Carrying Capacity	6	7	8	Adequate facilities w/o deterioration of the activity experience
Accessibility	11	13	14	Improved trails and access to site
Environmental Quality	7	9	10	Above average aesthetic quality and any limiting factors can be easily rectified.

5.1.4 Benefit Determination of the Proposed Recreation Features

Hiking and interpretive recreation areas exist near the Espanola study area within 8 to 20 miles. These areas include; Puye Cliff Dwellings, Bandelier National Monument, Nambe Lake and numerous trails and day use areas in the Santa Fe National Forest. These areas include formal trails in the canyons and mountainous landscapes surrounding the Espanola Valley, however the nearest recreation sites within the Rio Grande Bosque occur in Albuquerque approximately 60 miles away. This project will provide the only formal recreation in the Rio Grande Bosque which provides a unique experience in the river riparian habitat. The visitation estimate was derived by determining the visitation rates of the similar recreation facilities along the Rio Grande Bosque in Albuquerque, NM. Not only is the Bosque Trail in Albuquerque offer the similar experience, the City open space division tracks visitor numbers. Reliable visitation rates for facilities closer to the study area were not available. In consultation with the City of Albuquerque's Open Space Division, it was determined that in FY 09, the last year they had accurate information,143,300 visitors per year use the types of recreational facilities proposed for the Espanola GI Project.[1] In Albuquerque, the 2010 population is 556,500; meaning that about 25% of Albuquerque's population used the Open Space trails. Applying the 25% figure to the population of study area, approximately 32,200 visitors are expected to visit the proposed recreation site.

According to EGM 15-03, converting the point values to dollars, for the without-project condition the point value of 9 points would be converted to $3.91. Converting the point values to dollars, for the with-project condition the point value of 55 points would be converted to $8.30. The difference between the two values is $4.39. Multiplying $4.39 by the number of individuals visiting the proposed recreation facilities, the result is $164,684. The recreation plan is estimated to cost $284,000. A $284,000 recreation plan, with a period of analysis of 50 years and an interest rate of 3.375%, the total annual cost is $11,836. Dividing the benefit of the proposed recreation facilities ($164,864) by the annual cost of the proposed project ($11,836) the benefit cost ratio (BCR) exceeds 10 to 1.

[1] Data obtained from the Rio Grande Nature Center State Park Management Plan 2010 for the NM State Parks Division.

6 - Impact of Addressing Flood Risk in Four Accounts (NED, NER, OSE, RED)

The *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies* (March 10, 1983) establishes four accounts to facilitate the evaluation and display of effects of alternative plans. They are described in ER 1105-2-100, Planning Guidance Notebook, paragraph 2-3. The evaluation of the recommended plan against those accounts follows:

- The National Economic Development (NED) account displays changes in the economic value of the national output of goods and services. The damages and benefits described in this appendix describe NED impacts of Flood Risk Management in the study area.

- The Environmental Quality (EQ) account displays non-monetary effects on ecological, cultural, and aesthetic resources including the positive and adverse effects of ecosystem restoration plans. The arrays of plans described in this appendix have ecosystem restoration as their stated goals. EQ benefits or impacts are identified within the Environmental Appendix and evaluated relative to the cost of restoration alternatives in Section 4. of this appendix..

  All of the best buy plans would contribute to the EQ account by increasing the amount and quality of high value habitat in the study area by their respective quantity of outputs. All best buy plans provide an increase in habitat and therefore benefits to the EQ account as quantified by AAHU's in Table 4.10. Benefits to the EQ account increase with plan outputs as does the costs for the project and incremental costs for each AAHU. As described earlier only plans 7 and above will meet the improvement objective of the study. Benefits would increase in the following criteria as the amount and quality of habitat increases.

  Water Quality – Reconnection of the river channel to overbank area would provide some improvements to water quality through natural filtration in riparian areas. An increase in wetland area particularly those located at storm water outfalls would filtration of water and beak down of some pollutants through biologic processes.

  Air Quality – An increase in the number and acres of plants would contribute to absorption of carbon dioxide and release of oxygen in this urbanized area. The Bosque also acts as a heat sink during warmer months providing a corridor of shady, relatively moist environment that contrasts the urban asphalt and concrete.

  Wildlife – The increase in habitat diversity would provide for an increase diversity and density of wildlife species.

  Essentially the larger the project is the more benefits to this account would be. This is quantified both in total AAHU and incremental costs per AAHU in Table 4.10. The cost effective analysis has provided a measure of efficiency to determine what the cost of incremental of these outputs would be.

- The Regional Economic Development (RED) account displays changes in the distribution of regional economic activity (e.g., income and employment). This account is typically used to capture the regional impacts of a large capital infusion of project implementation dollars on income and employment throughout the study area through the use of income and employment multipliers. A recent study for the Nuclear Watch of New Mexico suggests that public sector multipliers tend to be below 1.5, while the Department of Energy claimed multipliers of 2.4 to 3.5

in fiscal year 1998[2]. The important point to be made here is that a large infrastructure project in the Española Valley will have a positive impact on local income and employment.

- The Other Social Effects (OSE) account displays plan effects on social aspects such as community impacts, health and safety, displacement, energy conservation and others. In most cases, impacts of proposed projects not covered in other accounts are described and evaluated here. Primary affects to OSE from the proposed restoration would benefit health, standard of living and education by providing a public area of improved aesthetics, air quality and providing recreational and educational opportunities. There would be significant benefits to the community from the facilities provided from the recreation component of the project, increase in quality of the recreational experience and educational opportunities within the project area.

  The proposed project would improve existing trails, create additional access, as well as provide amenities such as benches or picnic tables for an improved recreational experience. Habitat improvements would also enhance the recreational experience through those criteria listed under the EQ account and the aesthetic quality of the Bosque. The relatively open cottonwood gallery forest or view over a wetland is generally more pleasing than a view obstructed by thick brush 10-20 feet high. Habitat improvements would also provide the opportunity to view wildlife considered rare outside this Bosque.

  The opportunity for this area to become a destination for recreational and educational activities, as well as the improved experience, increase the overall standard or living for the entire community in the Espanola Valley.

[2] Dumas, L.J., *Economic Multipliers and the Economic Impact of DOE Spending in New Mexico*, March 2003.

Economic Attachment of Tables

Table B - 1 - Depth damage relationships (expressed as a proportion of property value).

	Stage (ft.)									
	1	2	3	4	5	6	7	8	9	10
Structures										
1 story no bsmt.	0.23	0.32	0.40	0.47	0.53	0.59	0.63	0.67	0.71	0.73
STD DEV	0.016	0.016	0.018	0.019	0.02	0.021	0.022	0.023	0.024	0.027
1 story no bsmt. (comm./public)	0.14	0.21	0.26	0.29	0.30	0.41	0.43	0.44	0.45	0.46
1 story w/ bsmt.	0.32	0.39	0.46	0.52	0.59	0.65	0.70	0.74	0.78	0.80
STD DEV	0.0096	0.0114	0.0137	0.0163	0.0189	0.0214	0.0235	0.0252	0.0266	0.0277
2 story no bsmt.	0.15	0.21	0.26	0.31	0.36	0.41	0.45	0.49	0.52	0.56
STD DEV	0.03	0.028	0.029	0.032	0.034	0.037	0.039	0.04	0.041	0.042
2 story no bsmt. (comm./public)	0.16	0.28	0.37	0.43	0.47	0.49	0.50	0.51	0.55	0.58
2 story w/ bsmt.	0.22	0.27	0.32	0.37	0.42	0.47	0.52	0.56	0.61	0.65
STD DEV	0.0135	0.015	0.0175	0.0204	0.0234	0.0263	0.0289	0.0313	0.0338	0.0371
Mobile home	0.44	0.64	0.73	0.78	0.80	0.81	0.82	0.84	0.86	0.88
Metal	0.07	0.10	0.15	0.18	0.20	0.23	0.28	0.33	0.37	0.40
Outbuilding	0.25	0.35	0.41	0.46	0.54	0.65	0.71	0.80	0.85	0.90
Contents										
1 story no bsmt. (Residential)*	0.13	0.18	0.22	0.26	0.29	0.32	0.34	0.36	0.37	0.38
STD DEV	0.012	0.012	0.014	0.015	0.016	0.016	0.017	0.018	0.019	0.021
2 story no bsmt. (Residential)*	0.09	0.12	0.16	0.19	0.21	0.24	0.26	0.28	0.30	0.32
STD DEV	0.026	0.025	0.025	0.027	0.03	0.032	0.033	0.034	0.035	0.035
1 story w/ bsmt. (Residential)*	0.19	0.22	0.25	0.27	0.30	0.32	0.35	0.36	0.38	0.39
STD DEV	0.0083	0.0098	0.0117	0.0139	0.016	0.0181	0.0199	0.0213	0.0225	0.0235
2 story w/ bsmt. (Residential)*	0.14	0.16	0.18	0.20	0.22	0.24	0.27	0.29	0.32	0.34
STD DEV	0.0111	0.0123	0.0143	0.0167	0.0192	0.0215	0.0236	0.0256	0.0276	0.0304
Mobile home (Residential)**	0.27	0.50	0.64	0.70	0.76	0.78	0.79	0.81	0.83	0.92
Motel, Office, Church (1 story)**	0.35	0.50	0.60	0.68	0.74	0.78	0.81	0.83	0.85	0.87
Motel, Office, Church (2 story)**	0.26	0.39	0.48	0.55	0.61	0.67	0.73	0.78	0.83	0.87
Food Related**	0.55	0.70	0.85	0.90	0.95	0.95	0.95	0.95	0.95	0.95
Gas Station, Car Service**	0.22	0.43	0.70	0.92	0.95	0.95	0.95	0.95	0.95	0.95
Retail (1 story)**	0.18	0.30	0.59	0.70	0.90	0.95	0.95	0.95	0.95	0.95
Retail (2 story)**	0.12	0.22	0.34	0.54	0.74	0.83	0.87	0.91	0.93	0.95
Clothing Store**	0.35	0.45	0.67	0.83	0.95	0.95	0.95	0.95	0.95	0.95
Car Dealership**	0.10	0.72	0.80	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Furniture Store**	0.75	0.85	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Outbuilding Contents**	0.30	0.51	0.62	0.67	0.69	0.71	0.80	0.85	0.90	0.95
Roads	0.11	0.22	0.35	0.50	0.66	0.76	0.76	0.76	0.76	0.76
Utilities	0.06	0.13	0.22	0.32	0.42	0.52	0.63	0.76	0.88	0.92
Railroad	0.03	0.04	0.12	0.15	0.18	0.21	0.31	0.64	0.76	0.82
Vehicles	0.05	0.17	0.20	0.75	0.80	0.85	0.90	0.95	0.95	0.95

* Content stage-damage function expressed as a percentage of structure value.

** Content stage-damage function expressed as a percentage of content value.

Table B - 2 - Number of structures, existing without-project conditions.

Land Use Category	EVENT							
	10%		2%		1%		0.20%	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Residential	172.00		297.00		352.00		460.00	
Commercial	4.00		8.00		19.00		48.00	
Public	0.00		1.00		8.00		10.00	
Apartments	9.00		9.00		10.00		10.00	
Outbuildings	0.00		0.00		0.00		0.00	
TOTAL STR.	185.00		315.00		389.00		528.00	

Table B - 3 - Number of structures, future without-project conditions.

Land Use Category	EVENT							
	10%		2%		1%		0.20%	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Residential	165.00		311.00		325.00		452.00	
Commercial	4.00		8.00		12.00		48.00	
Public	0.00		1.00		5.00		10.00	
Apartments	9.00		9.00		9.00		10.00	
Outbuildings	0.00		0.00		0.00		0.00	
TOTAL STR.	178.00		329.00		351.00		520.00	

Table B - 4 - Value of damageable property, existing without-project conditions. (Oct, 2014 price level)

Land Use Category	(x $1,000) EVENT							
	10%		2%		1%		0.20%	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
$/str	$29.80		$36.31		$34.90		$36.16	
Residential	5,125		10,784		12,286		16,632	
Res. Content	2,608		5,507		6,266		8,451	
$/str	$56.39		$86.25		$36.33		$302.61	
Commercial	226		690		7242		14,526	
Comm. Content	133		377		1,894		6,873	
$/str	$0.00		$105.00		$552.29		$454.01	
Public	0		105		4,418		4,540	
Pub. Content	0		53		3,008		3,059	
$/str	$22.56		$22.56		$30.60		$30.60	
Apartments	203		203		306		306	
Apt. Contents	102		102		153		153	
	$0.00		$0.00		$0.00		$0.00	
Outbuildings	0		0		0		0	
TOTAL	8,397		17,821		35,573		54,540	

Table B - 5 - Value of damageable property, future without-project conditions. (Oct, 2014 price level)

Land Use Category	(x $1,000) EVENT							
	10%		2%		1%		0.20%	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
$/str Residential	$30.17 4,978		$35.64 11,084		$35.67 11,594		$36.57 16,530	
Res. Content	2,525		5,660		5,915		8,401	
$/str Commercial	$56.31 225		$86.27 690		$80.47 7242		$302.61 14,526	
Comm. Content	133		377		716		6,873	
$/str Public	$0.00 0		$105.00 105		$227.00 1,135		$455.00 4,550	
Pub. Content	0		53		468		3,059	
$/str Apartments	$22.56 203		$22.56 203		$22.56 203		$30.50 305	
Apt. Contents	102		102		102		102	
Outbuildings	$0.00 0		$0.00 0		$0.00 0		$0.00 0	
TOTAL	8,166		18,274		27,375		54,346	

Table B - 6 - Single occurrence damages, existing without-project conditions. (Oct, 2014 price level)

Land Use Category	(x $1,000) EVENT							
	10%		2%		1%		0.20%	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Residential	556		1,531		2,140		4,178	
Res. Content	171		462		639		1,244	
Commercial	30		110		700		2,351	
Comm. Content	41		145		335		2,219	
Public	0		11		301		615	
Pub. Content	0		9		273		676	
Apartment	13		31		40		73	
Apt. Content	4		9		12		20	
Outbuildings	0		0		0		0	
TOTAL	259		777		2,300		7,198	

Table B - 7 - Single occurrence damages, future without-project conditions. (Oct, 2014 price level)

Land Use Category	(x $1,000) EVENT							
	10%		2%		1%		0.20%	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Residential	430		1,424		1,997		3,836	
Res. Content	136		437		601		1,144	
Commercial	17		99		454		2,386	
Comm. Content	14		119		204		2,350	
Public	0		11		120		602	
Pub. Content	0		9		98		660	
Apartment	14		31		39		70	
Apt. Content	4		9		11		20	
TOTAL	615		2,139		3,524		11,068	

Table B - 8 - Existing conditions, average annual damage by damage categories, reaches and Tribal entity. (Oct, 2014 price level)

Tribal Entity	Stream	Reaches	Damage Categories ($1,000's)					
			Apartment	Commercia	Outbuilding	Public	Residential	Total
Ohkay Owingeh	Rio Chama	3 & 4	0.00	0.00	0.00	0.00	0.00	
	Sub-total Stream		0.00	0.00	0.00	0.00	0.00	0.00
	RG, Upstream	7 & 8	0.00	0.00	0.00	25.20	52.89	
	Sub-total Stream		0.00	0.00	0.00	25.20	52.89	78.09
	RG, Downstream	9 & 10	0.00	0.00	0.00	0.00	1.79	
	Sub-total Stream		0.00	0.00	0.00	0.00	1.79	1.79
TOTAL			0.00	0.00	0.00	25.20	54.68	79.88
Santa Clara	RG, Downstream	13 & 14	0.07	0.47	0.00	0.55	30.04	
	Sub-total Stream		0.07	0.47	0.00	0.55	30.04	31.13
	Guahupangue	25 & 26	0.00	0.00	0.00	0.00	11.46	
	Guahupangue	27 & 28	0.00	42.86	0.00	29.78	19.95	
	Sub-total Stream		0.00	42.86	0.00	29.78	31.41	104.05
	Santa Cruz	29 & 30	2.24	12.44	0.01	3.99	24.04	
	Santa Cruz	31 & 32	2.59	43.93	0.05	0.00	48.96	
	Santa Cruz	33 & 34	1.30	0.00	0.01	0.00	0.50	
	Santa Cruz	35 & 36	0.00	20.97	0.00	0.00	38.10	
	Sub-total Stream		6.13	77.34	0.07	3.99	111.60	199.13
	Santa Clara	37 & 38	-	-	-	-	-	-
	Santa Clara	39 & 40	-	-	-	-	-	-
	Sub-total Stream		-	-	-	-	-	-
TOTAL			6.20	120.67	0.07	34.32	173.05	334.31
San Illdefonso	RG, Downstream	15 & 16	0.00	0.00	0.00	0.00	38.63	
	Sub-total Stream		0.00	0.00	0.00	0.00	38.63	38.63
	Rio Pojoaque	17 & 18	0.00	28.82	0.00	13.92	17.18	
	Rio Pojoaque	19 & 20	0.00	0.00	0.03	0.00	39.22	
	Rio Pojoaque	21 & 22	0.00	0.00	0.01	0.00	9.23	
	Rio Pojoaque	23 & 24	0.00	0.00	0.01	0.00	30.48	
	Sub-total Stream		0.00	28.82	0.05	13.92	96.11	138.90
TOTAL			0.00	28.82	0.05	13.92	134.74	177.53
Non-Tribal	Rio Chama	1 & 2	0.00	0.00	0.00	0.00	2.07	
	Sub-total Stream		0.00	0.00	0.00	0.00	2.07	2.07
	RG, Upstream	5 & 6	0.00	0.00	0.00	0.00	2.98	
	Sub-total Stream		0.00	0.00	0.00	0.00	2.98	2.98
	RG, Downstream	11 & 12	0.00	0.00	0.00	0.00	0.00	
	Sub-total Stream		0.00	0.00	0.00	0.00	0.00	0.00
TOTAL			0.00	0.00	0.00	0.00	5.05	5.05
TOTAL STUDY AREA			**6.20**	**149.49**	**0.12**	**73.44**	**367.52**	**596.77**

Table B - 9 - Future without-project conditions, average annual damage by damage categories, reaches and Tribal entity. (Oct, 2014 price level)

Tribal Entity	Stream	Reaches	Damage Categories ($1,000's)					
			Apartment	Commercia	Outbuilding	Public	Residential	Total
Ohkay Owingeh	Rio Chama	3 & 4	0.00	0.00	0.00	0.00	0.00	
	Sub-total Stream		0.00	0.00	0.00	0.00	0.00	0.00
	RG, Upstream	7 & 8	0.00	0.00	0.00	22.81	52.66	
	Sub-total Stream		0.00	0.00	0.00	22.81	52.66	75.47
	RG, Downstream	9 & 10	0.00	0.00	0.00	0.00	1.28	
	Sub-total Stream		0.00	0.00	0.00	0.00	1.28	1.28
TOTAL			0.00	0.00	0.00	22.81	53.94	76.75
Santa Clara	RG, Downstream	13 & 14	0.05	0.13	0.00	0.42	24.74	
	Sub-total Stream		0.05	0.13	0.00	0.42	24.74	25.34
	Guahupangue	25 & 26	0.00	0.00	0.00	0.00	5.64	
	Guahupangue	27 & 28	0.00	32.32	0.00	22.58	14.11	
	Sub-total Stream		0.00	32.32	0.00	22.58	19.75	74.65
	Santa Cruz	29 & 30	2.12	11.37	0.01	3.81	22.36	
	Santa Cruz	31 & 32	2.85	47.63	0.05	0.00	53.95	
	Santa Cruz	33 & 34	1.22	0.00	0.01	0.00	0.45	
	Santa Cruz	35 & 36	0.00	8.33	0.00	0.00	12.56	
	Sub-total Stream		6.19	67.33	0.07	3.81	89.32	166.72
	Santa Clara	37 & 38	-	-	-	-	-	-
	Santa Clara	39 & 40	-	-	-	-	-	-
	Sub-total Stream		-	-	-	-	-	-
TOTAL			6.24	99.78	0.07	26.81	133.81	266.71
San Illdefonso	RG, Downstream	15 & 16	0.00	0.00	0.00	0.00	9.30	
	Sub-total Stream		0.00	0.00	0.00	0.00	9.30	9.30
	Rio Pojoaque	17 & 18	0.00	28.08	0.00	13.53	16.75	
	Rio Pojoaque	19 & 20	0.00	0.00	0.03	0.00	38.37	
	Rio Pojoaque	21 & 22	0.00	0.00	0.01	0.00	8.17	
	Rio Pojoaque	23 & 24	0.00	0.00	0.01	0.00	33.45	
	Sub-total Stream		0.00	28.08	0.05	13.53	96.74	138.40
TOTAL			0.00	28.08	0.05	13.53	106.04	147.70
Non-Tribal	Rio Chama	1 & 2	0.00	0.00	0.00	0.00	4.43	
	Sub-total Stream		0.00	0.00	0.00	0.00	4.43	4.43
	RG, Upstream	5 & 6	0.00	0.00	0.00	0.00	2.99	
	Sub-total Stream		0.00	0.00	0.00	0.00	2.99	2.99
	RG, Downstream	11 & 12	0.00	0.00	0.00	0.00	0.00	
	Sub-total Stream		0.00	0.00	0.00	0.00	0.00	0.00
TOTAL			0.00	0.00	0.00	0.00	7.42	7.42
TOTAL STUDY AREA			**6.24**	**127.86**	**0.12**	**63.15**	**301.21**	**498.58**

Table B - 10 - Existing conditions, average annual damage by damage categories, river bank and reaches. (Oct, 2014 price level)

Stream	River Bank	Reaches	Damage Categories ($1,000's)					
			Apartment	Commercial	Outbuilding	Public	Residential	Total
Rio Chama	Left	1	0.00	0.00	0.00	0.00	0.00	
	Left	3	0.00	0.00	0.00	0.00	0.00	
	Sub-Total		0.00	0.00	0.00	0.00	0.00	0.00
	Right	2	0.00	0.00	0.00	0.00	2.07	
	Right	4	0.00	0.00	0.00	0.00	0.00	
	Sub-Total		0.00	0.00	0.00	0.00	2.07	2.07
TOTAL			0.00	0.00	0.00	0.00	2.07	2.07
RG-Upstream	Left	5	0.00	0.00	0.00	0.00	2.98	
	Left	7	0.00	0.00	0.00	25.20	52.89	
	Sub-Total		0.00	0.00	0.00	25.20	55.87	81.07
	Right	6	0.00	0.00	0.00	0.00	0.00	
	Right	8	0.00	0.00	0.00	0.00	0.00	
	Sub-Total		0.00	0.00	0.00	0.00	0.00	0.00
TOTAL			0.00	0.00	0.00	25.20	55.87	81.07
RG-Downstream	Left	9	0.00	0.00	0.00	0.00	0.00	
	Left	11	0.00	0.00	0.00	0.00	0.00	
	Left	13	0.00	0.00	0.00	0.00	28.25	
	Left	15	0.00	0.00	0.00	0.00	0.00	
	Sub-Total		0.00	0.00	0.00	0.00	28.25	28.25
	Right	10	0.00	0.00	0.00	0.00	1.79	
	Right	12	0.00	0.00	0.00	0.00	0.00	
	Right	14	0.07	0.47	0.00	0.55	1.79	
	Right	16	0.00	0.00	0.00	0.00	38.63	
	Sub-Total		0.07	0.47	0.00	0.55	42.21	43.30
TOTAL			0.07	0.47	0.00	0.55	70.46	71.55
Rio Pojoaque	Left	17	0.00	28.82	0.00	13.92	17.00	
	Left	19	0.00	0.00	0.03	0.00	39.22	
	Left	21	0.00	0.00	0.01	0.00	8.59	
	Left	23	0.00	0.00	0.01	0.00	19.60	
	Sub-Total		0.00	28.82	0.05	13.92	84.41	127.20
	Right	18	0.00	0.00	0.00	0.00	0.18	
	Right	20	0.00	0.00	0.00	0.00	0.00	
	Right	22	0.00	0.00	0.00	0.00	0.64	
	Right	24	0.00	0.00	0.00	0.00	10.88	
	Sub-Total		0.00	0.00	0.00	0.00	11.70	11.70
TOTAL			0.00	28.82	0.05	13.92	96.11	138.90
Guachapungue	Left	25	0.00	0.00	0.00	0.00	11.46	
	Left	27	0.00	42.86	0.00	29.78	19.70	
	Sub-Total		0.00	42.86	0.00	29.78	31.16	103.80
	Right	26	0.00	0.00	0.00	0.00	0.00	
	Right	28	0.00	0.00	0.00	0.00	0.25	
	Sub-Total		0.00	0.00	0.00	0.00	0.25	0.25
TOTAL			0.00	42.86	0.00	29.78	31.41	104.05
Santa Cruz	Left	29	0.00	0.00	0.00	0.00	1.74	
	Left	31	0.00	0.00	0.00	0.00	0.03	
	Left	33	0.00	0.00	0.01	0.00	0.29	
	Left	35	0.00	7.97	0.00	0.00	22.68	
	Sub-Total		0.00	7.97	0.01	0.00	24.74	32.72
	Right	30	2.24	12.44	0.01	3.99	22.30	
	Right	32	2.59	43.93	0.05	0.00	48.93	
	Right	34	1.30	0.00	0.00	0.00	0.21	
	Right	36	0.00	13.00	0.00	0.00	15.42	
	Sub-Total		6.13	69.37	0.06	3.99	86.86	166.41
TOTAL			6.13	77.34	0.07	3.99	111.60	199.13
Santa Clara	Left	37	-	-	-	-	-	-
	Left	39	-	-	-	-	-	-
	Sub-Total			-	-	-	-	-
	Right	38	-	-	-	-	-	-
	Right	40	-	-	-	-	-	-
	Sub-Total		-	-	-	-	-	-
TOTAL			-	-	-	-	-	-
Grand Total			**6.20**	**149.49**	**0.12**	**73.44**	**367.52**	**596.77**

Table B - 11 – Future, without-project conditions, average annual damage by damage categories, river bank and reaches. (Oct, 2014 price level)

Stream	River Bank	Reach	Damage Categories ($1,000's)					
			Apartment	Commercial	Outbuilding	Public	Residential	Total
Rio Chama	Left	1	0.00	0.00	0.00	0.00	0.00	
	Left	3	0.00	0.00	0.00	0.00	0.00	
	Sub-Total		0.00	0.00	0.00	0.00	0.00	0.00
	Right	2	0.00	0.00	0.00	0.00	4.43	
	Right	4		0.00	0.00	0.00	0.00	
	Sub-Total		0.00	0.00	0.00	0.00	4.43	4.43
TOTAL			0.00	0.00	0.00	0.00	4.43	4.43
RG-Upstream	Left	5	0.00	0.00	0.00	0.00	2.99	
	Left	7	0.00	0.00	0.00	22.81	52.66	
	Sub-Total		0.00	0.00	0.00	22.81	55.65	78.46
	Right	6	0.00	0.00	0.00	0.00	0.00	
	Right	8	0.00	0.00	0.00	0.00	0.00	
	Sub-Total		0.00	0.00	0.00	0.00	0.00	0.00
TOTAL			0.00	0.00	0.00	22.81	55.65	78.46
RG-Downstream	Left	9	0.00	0.00	0.00	0.00	0.00	
	Left	11	0.00	0.00	0.00	0.00	0.00	
	Left	13	0.00	0.00	0.00	0.00	23.35	
	Left	15	0.00	0.00	0.00	0.00	0.00	
	Sub-Total		0.00	0.00	0.00	0.00	23.35	23.35
	Right	10	0.00	0.00	0.00	0.00	1.28	
	Right	12	0.00	0.00	0.00	0.00	0.00	
	Right	14	0.05	0.13	0.00	0.42	1.39	
	Right	16	0.00	0.00	0.00	0.00	9.30	
	Sub-Total		0.05	0.13	0.00	0.42	11.97	12.57
TOTAL			0.05	0.13	0.00	0.42	35.32	35.92
Rio Pojoaque	Left	17	0.00	28.08	0.00	13.53	16.57	
	Left	19	0.00	0.00	0.03	0.00	38.37	
	Left	21	0.00	0.00	0.01	0.00	7.60	
	Left	23	0.00	0.00	0.01	0.00	22.34	
	Sub-Total		0.00	28.08	0.05	13.53	84.88	126.54
	Right	18	0.00	0.00	0.00	0.00	0.18	
	Right	20	0.00	0.00	0.00	0.00	0.00	
	Right	22	0.00	0.00	0.00	0.00	0.57	
	Right	24	0.00	0.00	0.00	0.00	11.11	
	Sub-Total		0.00	0.00	0.00	0.00	11.86	11.86
TOTAL			0.00	28.08	0.05	13.53	96.74	138.40
Guachapungue	Left	25	0.00	0.00	0.00	0.00	5.64	
	Left	27	0.00	32.32	0.00	22.58	13.93	
	Sub-Total		0.00	32.32	0.00	22.58	19.57	74.47
	Right	26	0.00	0.00	0.00	0.00	0.00	
	Right	28	0.00	0.00	0.00	0.00	0.18	
	Sub-Total		0.00	0.00	0.00	0.00	0.18	0.18
TOTAL			0.00	32.32	0.00	22.58	19.75	74.65
Santa Cruz	Left	29	0.00	0.00	0.00	0.00	1.68	
	Left	31	0.00	0.00	0.00	0.00	0.04	
	Left	33	0.00	0.00	0.01	0.00	0.25	
	Left	35	0.00	3.26	0.00	0.00	7.80	
	Sub-Total		0.00	3.26	0.01	0.00	9.77	13.04
	Right	30	2.12	11.37	0.01	3.81	20.68	
	Right	32	2.85	47.63	0.05	0.00	53.91	
	Right	34	1.22	0.00	0.00	0.00	0.20	
	Right	36	0.00	5.07	0.00	0.00	4.76	
	Sub-Total		6.19	64.07	0.06	3.81	79.55	153.68
TOTAL			6.19	67.33	0.07	3.81	89.32	166.72
Santa Clara	Left	37	-	-	-	-	-	-
	Left	39	-	-	-	-	-	-
	Sub-Total			-	-	-	-	-
	Right	38	-	-	-	-	-	-
	Right	40	-	-	-	-	-	-
	Sub-Total		-	-	-	-	-	-
TOTAL			-	-	-	-	-	-
Grand Total			**6.24**	**127.86**	**0.12**	**63.15**	**301.21**	**498.58**

Table B - 12 - Equivalent annual damages by damage categories by land use category and Tribal entity. (Oct, 2014 price level)

(Damage in $1,000's)					
LAND USE CATEGORY		**Tribal Entity**			
		Non-tribal	**Ohkay Owingeh**	**Santa Clara**	**San Ildefonso**
Apartment		0.00	0.00	6.23	0.00
Commercial		0.00	0.00	107.13	28.34
Outbuilding		0.00	0.00	0.07	0.05
Public		0.00	23.65	29.45	13.67
Residential		6.59	54.20	147.65	116.16
Sub-total Structures and Contents		**6.59**	**77.85**	**290.53**	**158.22**
Streets, Roads		11.80	73.99	209.97	38.09
Utilities		0.02	0.03	0.08	0.04
Vehicles		2.09	7.80	13.13	9.45
Agriculture		0.05	0.08	0.05	0.02
Emergency Cost		0.00	0.10	1.17	4.36
TOTAL		**20.55**	**159.85**	**551.66**	**210.37**

Table B - 13 - Equivalent annual damages by land use category and rivers/tributaries. (Oct, 2014 price level)

		(Damage in $1,000's)					
LAND USE CATEGORY		**Streams**					
	Rio Chama	**DS Rio Grande**	**US Rio Grande**	**Rio Pojoaque**	**Guachupangue**	**Santa Cruz**	**Santa Clara**
Apartment	0.00	0.06	0.00	0.00	0.00	6.17	-
Commercial	0.00	0.25	0.00	28.34	36.04	70.84	-
Outbuilding	0.00	0.00	0.00	0.05	0.00	0.07	-
Public	0.00	0.46	23.65	13.67	25.12	3.87	-
Residential	3.60	47.71	55.73	96.52	23.86	97.18	-
Sub-total Structures and Contents	**3.60**	**48.48**	**79.38**	**138.58**	**85.02**	**178.13**	**-**
Streets, Roads	0.00	85.60	73.99	38.28	65.14	70.84	-
Utilities	0.00	0.03	0.10	0.04	0.01	0.01	-
Vehicles	0.09	4.25	6.84	9.45	0.21	11.63	-
Agriculture	0.040	0.080	0.069	0.000	0.000	0.003	-
Emergency Cost	0.05	0.73	1.19	2.08	1.28	2.67	-
TOTAL	**3.78**	**126.17**	**252.74**	**189.78**	**151.66**	**263.28**	**-**