Investigation and Analysis Report for the Santa Cruz River Watershed Site 1 Dam Rehabilitation Project

Appendix D

Santa Cruz River Watershed
Rio Arriba County, New Mexico

The purpose of the Investigation and Analysis Report is to present information that supports the formulation, evaluation, and conclusions of the Supplemental Watershed Plan and Environmental Assessment (Plan-EA). The report is required and must be included as an appendix to the Plan-EA.

The procedures, techniques, assumptions, scope and intensity of the investigations for each subject are described in sufficient detail so that a reader not familiar with the watershed/dam or its deficiencies can form an opinion on the adequacy of the Plan-EA document. This report supplements information contained in the Plan-EA and is not intended to replace or duplicate information contained therein.

October 2019

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D.1 Introduction

The information presented in this Investigation and Analysis Report (I&A Report) is based on standard methods, procedures, and computer programs used or approved for use by the United States Department of Agriculture Natural Resources Conservation Service (NRCS). The following information gives a summary of the investigation and analysis for the key studies in the preparation of the Supplemental Watershed Plan and Environmental Assessment (Plan-EA) documentation for the rehabilitation of Santa Cruz River Site 1 Dam. Additional information relevant to each of the sections provided in this report is available as part of the administrative record for the project upon request. Requests for additional information can be sent to the following address:

USDA-NRCS
Attn: State Conservation Engineer
100 Sun Avenue NE, Suite 602
Albuquerque, New Mexico 87109

Santa Cruz River Site 1 Dam (Site 1 Dam) is located within the Santa Cruz River Watershed upstream of the Village of Chimayó, in Rio Arriba County, New Mexico. The dam was designed and constructed by the USDA Soil Conservation Service (SCS) in cooperation with the Pojoaque-Santa Cruz Soil and Water Conservation District (now named Santa Fe-Pojoaque Soil and Water Conservation District [SFPSWCD] in 1962 under the authority of the Watershed Protection and Flood Prevention Act of 1954 (Public Law 83-566). The structure has a contributing drainage area of 8.34 square-miles (sq. mi.) and the basin and upstream drainages are normally dry except during seasonally high runoff and extreme weather events. The current authorized purpose of the structure is flood prevention (flood damage reduction). Existing conditions and structural data are shown in Tables D-1, D-2, and D-3.

Note on Vertical Datum: All elevations provided in this I&A Report are relative to the North American Vertical Datum of 1988 (NAVD88), unless otherwise noted. Some of the elevations provided by historical documents are reported in an unknown vertical datum. When converting As-Built elevations to NAVD88 from the National Geodetic Vertical Datum of 1929 (NGVD29) using the VERTCON program (available at www.ngs.noaa.gov), assuming a latitude of 36° 00’ 35.46’’N and a longitude of 105° 55’ 04.41’’ W, the datum shift is +3.34 feet (ft) from NGVD29 to NAVD88. This shift provides inconsistent results when compared to Light Detection and Ranging (LiDAR) data collected in 2015 and survey data. The conversion is accurate for the dam crest elevation, but not for any other major feature. Therefore, unless otherwise noted, all elevations presented in the I&A Report are obtained from LiDAR (1-meter resolution) and 2010 survey data (URS Corporation survey data provided by NRCS) and are presented in the NAVD 88 vertical datum.

Table D - 1. Existing Conditions Summary Table

Feature	Dimension		
	As-Builts 1962[1]	NRCS 2009[3]	NAVD88 from 2015 LiDAR and/or 2010 Survey
Structural Height (ft)	68.7	57.4	67.0
Total Reservoir Capacity at Auxiliary Spillway Crest (ac-ft)	812	585.0	339.0
Reservoir Capacity at Dam Crest (ac-ft)	Not Given	Not Given	548.7
50-Year Aerated Sediment Storage Elevation (ft)	6,334.8	6334.8	6,336.6
Aerated Sediment Capacity (ft) (2017)	418	Not Given	13.2
Floodwater Retarding Capacity (ac-ft) (2017)	394	Not Given	325.8
Auxiliary Spillway Crest Elevation (ft)	6,346.1	6,346.1	6,349.6
Dam Crest Elevation (ft)	6,350.7 / 6,352.2[2]	6,352.2	6,354.4
Dam Crest Length (ft)	1,082	1,082	1,082
Dam Crest Width (ft)	18	18	18
Retaining Dike Elevation (ft)	6350.7	6,350.7	6,354.0

[1]Values obtained from As-Builts are reported in unknown vertical datum.
[2]Two values of 6,350.7 and 6,352.2 ft are documented as the dam crest elevation in the As-Built drawings (SCS 1962).
[3]No vertical datum is provided in the 2009 NRCS report (NRCS 2009).

Table D - 2. Existing Conditions Structural Data

Item	Unit	Site 1 Dam Existing Conditions
Dam Number	#	924043
Hazard Class of Structure	Design	High Hazard
Seismic Zone	-	1
Total Drainage Area (Uncontrolled)	sq mi	8.34
Runoff Curve N. (1-day)	N/A	76.1
Time of Concentration (Tc)	hr	1.34
Elevation Crest Dam	ft	6,354.4
Elevation Crest Auxiliary Spillway	ft	6,349.6
Elevation Crest High Stage inlet	ft	6,339.5
Elevation Crest Low Stage Inlet	ft	6,333.6
Auxiliary Spillway Type	-	Open Channel (earthen)
Auxiliary Spillway Bottom Width	ft	600
Auxiliary Spillway Exit Slope	%	32.7
Maximum Height of Dam	ft	67.0
Total Capacity at Auxiliary Spillway Crest	ac-ft	339.0
Remaining Aerated Sediment Capacity (2017)	ac-ft	13.2
Sediment Submerged[1]	ac-ft	0
Sediment Aerated[1] (2017)	ac-ft	13.2
Beneficial Use Pool (Irrigation, recreation)	ac-ft	0

Item	Unit	Site 1 Dam Existing Conditions
Floodwater Retarding Pool at Auxiliary Spillway Crest	ac-ft	325.8
Principal Spillway Design		
Rainfall Volume (1-day, 100 yr)	in	0.76
Rainfall Volume (10 day, 100 yr)	in	1.82
Runoff Volume (10 day, 100 yr)	in	1.72
Capacity of Low Stage (Upper) Riser (max)	cfs	20.0
Capacity of High Stage (Lower) Riser (max)	cfs	125.0
Dimension of Conduit (low-level outlet)	in	24 (upper riser), 30 (lower riser)
Type of Conduit (low-level outlet)	N/A	CMP (upper), RCP (lower)
Frequency of Operation Auxiliary Spillway (assumes a full aerated sediment pool)	% chance	>0.1
Auxiliary Spillway Design		
Rainfall Volume	in	4.89
Runoff Volume	in	2.45
Storm Duration	hrs	6 & 24
Velocity of Flow (Ve)	ft/s	7.3
Maximum Aux. Spillway Discharge[2]	cfs	2,157.2
Max. Reservoir Water Surface Elevation[3]	ft	6,351.3
Freeboard Hydrograph		
Rainfall Volume	in	13.25
Runoff Volume	in	10.11
Storm Duration[3]	hrs	6 & 24
Max. Reservoir Water Surface Elevation[3]	ft	6,359.2

1 - This is a dry basin so no sediment is submerged and all sediment is considered aerated.
2 - The 6-hour storm event was determined to be the critical storm event.
3 - Assumes aerated sediment volume is 0 ac-ft.

Table D - 3. Existing Stage-Storage-Discharge Data

Feature	Elevation (ft)	Reservoir Storage (ac-ft)	Discharge[1] (cfs)
Existing Sediment Elevation / Lowest Ungated Inlet	6,333.6	0.0	0.0
	6,335.6	4.3	0.0
Design Sediment Pool	6,336.6	13.2	0.0
	6,337.5	23.7	14.3
	6,338.6	39.4	25.3
Principal Spillway Crest (Lower Riser)	6,336.6	56.3	45.3
	6,341.5	94.3	123.4
	6,343.5	142.7	125.0
	6,345.5	198.6	125.0
	6,347.5	262.4	125.0
Auxiliary Spillway Crest	6,349.6	339.0	125.0
	6,351.0	395.8	1,480.4
	6,353.0	483.2	6,088.7
Dam Embankment Crest	6,354.4	548.7	10,375.6

[1]Discharge values assume a full sediment pool.

D.2 Sedimentation

Site 1 Dam was originally designed to have 418 acre-feet (ac-ft) of sediment storage capacity per the Watershed Work Plan (Pojoaque Soil Conservation District [PSCD] 1959) and the project As-builts (SCS 1962). Additionally, per the watershed work plan, the original design sedimentation rate was 1.2 ac-ft per sq. mi. per year with a reported drainage area of 8.06 sq. mi. This corresponds to an annual sedimentation volume of approximately 9.7 ac-ft per year and an original design life of approximately 43 years. The dam is currently 54 years old and the aerated sediment volume is nearing capacity.

McMillen Jacobs Associates (McMillen Jacobs) conducted a sedimentation study for the watershed above Site 1 Dam (McMillen Jacobs 2018e). Several methods were used to estimate the sedimentation rate including the Pacific South-west Inter Agency Committee (PSIAC) Sediment Yield Method, a review and comparison of previously published sedimentation studies, and a Site Survey of trapped sediment using 2015 LiDAR data. A summary of the sediment yield rates is given in Table D-4.

Table D - 4. Sediment Yield Rates at Site 1 Dam

Sediment Estimation Method	Sedimentation Rate (ac-ft/sq. mi./yr)	Watershed Area (sq. mi.)	Deposition Rate (ac-ft/yr)	Remaining Life of the Basin (yr)
Site Survey	**0.9**	**8.34**	**7.51**	**1.8**
PSIAC Sediment Yield	0.95	8.34	5.78[1]	2.3
USACE Study, 1995	2.57	8.34	15.65[1]	0.8
Watershed Work Plan, 1959	1.2	8.06	9.7	1.4

[1] Deposition rate accounts for the size of the watershed and an estimated trap efficiency of 73%.

It was determined that the Site Survey method was judged to be the superior method due to its dependence on actual measurable data of deposited material rather than the qualitative parameters and regional relationships used by the other methods, which tend to not capture local conditions accurately. For this reason, the design sedimentation rate obtained from the Site Survey method (0.9 ac-ft/sq. mi./yr) will be used for this project. The resulting deposition rate into the basin for this rate is approximately 7.51 ac-ft per year. It should be noted that the sediment deposition rate and remaining life of the dam were calculated based on data collected in June 2015.

D.3 Flooding and Dam Breach Risk Analysis

A flooding and risk analysis was performed by McMillen Jacobs in 2016 as part of the Hydrologic and Inundation Analysis for the Site 1 Dam (McMillen Jacobs 2018c). The analysis was used to develop the Population at Risk (PAR) in the event of a breach, the total Loss of Life (LOL) expected, and the NRCS hazard classification for the dam. Three different breach scenarios were analyzed as described below, with the largest and most conservative event being used to develop the PAR, LOL, and hazard classification.

The first breach scenario analyzed was an event-driven breach resulting from the 6-hour local Probable Maximum Precipitation (PMP) hydrograph. The simulation was modeled as an overtopping failure that was triggered at the point of the maximum overtopping depth. This breach resulted in a peak breach discharge of 130,000 cubic feet per second (cfs).

The second scenario simulated a “sunny day” breach. Per NRCS Technical Release 60 (TR-60) requirements, the dam was breached using the existing stage-storage curve and with the water surface set at the crest elevation of the auxiliary spillway. It was also assumed that there was no concurrent flooding at the time of the breach. This was modeled as a piping failure and resulted in a peak breach discharge of 91,000 cfs.

The third scenario, as requested by New Mexico Office of the State Engineer – Dam Safety Bureau (New Mexico Dam Safety), was an overtopping breach of the auxiliary spillway. This request was made because it was determined that this would be the most likely breach to occur at the Site 1 Dam. This simulation was modeled as an event-driven breach resulting from the 6-hour local PMP and was triggered when the water surface behind the dam was 2 feet above the auxiliary spillway crest. This resulted in a peak breach discharge of 98,000 cfs.

The first scenario resulted in the largest breach and was used for the risk analysis. A summary of the results of the risk analysis is presented in Table D-5.

Table D - 5. Risk Analysis Summary

Breach Event	PAR	Fatality Rate (%)	Failure Index	LOL
6-hour PMP, Overtop	1,038	0.7	122	886

D.4 Geology

The Site 1 Dam is located within the southern portion of the Eastern Espanola Basin near the Village of Chimayo, New Mexico. The Eastern Espanola Basin was formed by the Rio Grande Rift and is characterized by eolian, fluvial, and alluvial sands and gravels from adjacent and upstream mountains. A detailed summary of the geologic conditions and hazards present at and around the dam is included in the Geotechnical Report (McMillen Jacobs 2015).

D.4.1 Seismic Analysis

Seismic analyses of the Site 1 Dam included a description of potential seismic sources, deterministic and probabilistic, liquefaction, and the maximum credible earthquake (MCE). The MCE magnitude is 6.22 with a ground acceleration of 0.14g. A number of seismic sources are located in the vicinity of the dam; however, the Pajarito Fault, located approximately 1 mile southwest of the dam, was determined to be the closest active fault. Refer to the Geotechnical Report (McMillen Jacobs 2015) for more detailed information regarding seismic sources and the analysis performed.

D.4.2 Geologic Hazard Classification

The dam is not a water-retaining structure, but a dry dam that detains and attenuates flood flows during precipitation events. The normal pool condition for the dam was determined to be dry and the normal pool consequence is low. The normal pool hazard classification for the dam is “low hazard”. Refer to the Normal Pool Hazard for Seismic Analysis Technical Memorandum (McMillen Jacobs 2018d) completed for the dam.

D.5 Geotechnical Analysis

The geotechnical analyses and site investigation include information regarding the geologic conditions at the dam, other general site conditions, conditions in the subsurface, and analyses of slope stability, including static and seismic steady state seepage and rapid drawdown. Additionally, information from previous geotechnical work performed at the site is also included. Results from the analyses indicate that factors of safety at the Site 1 Dam meet design criteria and are included in the Geotechnical Report (McMillen Jacobs 2015).

D.6 Water Quality

Because there is no permanent pool or perennial stream associated with the structure, nor is there any municipal or habitat use associated with the water discharged through the dam, water quality is not expected to be an issue at the Site 1 Dam. For the same reasons, there is a dearth of information regarding water quality at the project site.

D.7 Hydrologic Analysis

A hydrologic analysis was completed for the dam and included the identification of three design floods (McMillen Jacobs 2018c). They include the Freeboard Hydrograph (FBH), the Spillway Design Hydrograph (SDH), and the Principal Spillway Hydrograph (PSH). The FBH was defined as the critical storm duration resulting from the 6-hour local PMP. The SDH and FBH were found to activate the auxiliary spillway and the FBH also overtopped the dam. The results of the design storm routing for the PSH, SDH and FBH are provided in Table D-6.

Table D - 6. Design Flood Summary

Storm Event	Storm Duration (Hours)	Peak Inflow (cfs)	Peak Outflow (cfs)	Peak Storage (ac-ft)	Peak Water Surface Elev. (ft)	Depth of Flow Over Aux. Spillway (ft)	Depth of Flow Over Dam Crest (ft)
PSH	240	284.5	124.9	127.2	6,343.4	0.0	0.0
SDH	6	2,549.7	2,282.2	397.7	6,351.3	1.7	0.0
FBH	6	28,451.0	27,029.2	781.1	6,359.2	9.6	4.8

Additional results from the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) model indicated that the peak reservoir inflows for the 24-hour, 100-year and 24-hour, 500-year events were 2,823 cfs and 4,383 cfs, respectively (McMillen Jacobs 2018c). These inflow values were used to model a no dam, existing dam current condition, and rehabilitation condition in a “two-dimensional” FLO2D model for comparison of both flood events.

D.8 Auxiliary Spillway Stability and Integrity Analysis

The existing auxiliary spillway is an approximately 600-ft-wide earthen spillway located on the northwest side of the dam. The control section is approximately 100 ft in length and the exit channel continues for an additional 100 to 120 ft at an approximate grade of 30% to 35% where it meets an adjacent wash. There have been no reports of this spillway activating over the life of the structure; however, the exit channel is currently experiencing significant erosion due to direct rainfall, which has resulted in the formation of gullies more than 8 ft wide and 10 ft deep.

A stability and integrity analysis was conducted for the auxiliary spillway by using the Water Resource Site Analysis (SITES) software package (McMillen Jacobs 2018a). The model showed that the FBH would lead to an erosive headcut that would extend from the downstream extents of the auxiliary spillway all the way upstream to the control section. Because the headcut would extend into the control section, the FBH is considered to lead to a breach of the auxiliary spillway approximately 5.5 hours after the beginning of the hydrograph.

D.9 Induced Flooding Analysis

Because the auxiliary spillway discharges into a natural drainage channel separate from the natural drainage channel, an induced flooding analysis was required. This analysis concluded that there were no properties located downstream of the auxiliary spillway that would be inundated during the FBH that would not have been inundated had the dam not been in place (McMillen Jacobs 2017). Therefore, additional protection against induced flooding will not be required for this project.

D.10 Design Deficiencies

The entities with jurisdiction over this project are New Mexico Dam Safety and NRCS. New Mexico Dam Safety requires compliance with New Mexico's Administrative Code Title 19, Chapter 25, Part 12 (19.25.12; NMDS 2010) – Dam Design, Construction, and Dam Safety, while NRCS requires compliance with Technical Release 60 (TR-60), and the National Engineering Handbook (NEH). The most conservative design criteria outlined in either the New Mexico Administrative Code 19.25.12, TR-60, or NEH will be followed.

Based on a design criteria analyses conducted for this project, design criteria deficiencies were identified for the Site 1 Dam (McMillen Jacobs 2018b). This analysis describes the specific ways in which the existing dam does not meet either state or federal standards and guidelines, and the results are summarized below.

1. **Embankment - Height (NRCS Criteria):** TR-60 requires that the height of the embankment be sufficient to prevent overtopping during passage of either the FBH or SDH, whichever is higher. The FBH overtops the dam by 4.8 feet.
2. **Embankment – Surface Erosion (NRCS and New Mexico Criteria):** TR-60 and New Mexico Dam Safety require that sufficient surface erosion protection be included on the upstream and downstream faces. Embankment surfaces are not currently protected from erosion and surface erosion and gullies have been observed on the upstream and downstream embankment faces.
3. **Embankment - Crest Width (New Mexico Criteria):** New Mexico Dam Safety requires the top width to be equal to the structural height of the dam divided by 5, plus an additional 8 feet (21.4 feet for the Site 1 Dam). The existing embankment has a top width of 18 feet.
4. **Principal Spillway – Trash Racks (NRCS and New Mexico Criteria):** TR-60 and New Mexico Administrative Code 19.25.12.8g require that all intake structures be provided with trash racks or grates to prevent clogging. The risers at the Site 1 Dam do not have trash racks or grates.
5. **Principal Spillway - Structural Design of Risers (NRCS Criteria):** TR-60 requires that all risers be structurally designed to withstand all water, earth, ice, and earthquake loads to which they may be subjected. The existing riser has not been seismically evaluated. This has not been evaluated and should be part of final design.
6. **Principal Spillway – Antivortex Devices (NRCS Criteria):** TR-60 requires that all conduits designed for pressure flow have antivortex devices. The principal spillway is not equipped with an antivortex device.
7. **Principal Spillway – Conduit Material (New Mexico Criteria):** New Mexico Administrative Code 19.25.12.7b states metal conduits are not acceptable for dams classified as high hazard potential or dams classified as significant hazard potential with permanent water storage except as interior forms for cast-in-place concrete conduits. A corrugated metal conduit extends between the upper riser and lower riser structure.
8. **Principal Spillway – Outlet Protection (New Mexico Criteria):** The design of the outlet works terminal structure shall address energy dissipation to prevent erosion. Energy dissipation and erosion protection measures do not appear to currently exist at the principal spillway conduit outlet.

9. **Principal Spillway – Conduit (NRCS and New Mexico Criteria):** The conduit through the dam embankment is required to be watertight to meet both NRCS and New Mexico design standards. Minor cracking and associated leaking was observed along the principal spillway conduit during a video pipe inspection, indicating that the conduit is not currently watertight.
10. **Auxiliary Spillway – Design Storms (NRCS Criteria):** TR-60 requires that auxiliary spillways be proportioned so they will pass the SDH and FBH at safe velocities and at or below the dam crest elevation. The existing auxiliary spillway would experience unsafe velocities, leading to a breach while routing the SDH and FBH. Additionally, the FBH overtops the dam.
11. **Auxiliary Spillway – Stability (NRCS and New Mexico Criteria):** TR-60 requires that auxiliary spillways be able to maintain stability during passage of design flows without blockage or breaching. New Mexico Administrative Code 19.25.12.5 states damage to a spillway during the design flood event is acceptable; however, a breach of the spillway is unacceptable. The existing auxiliary spillway breaches during passage of the design flows (SDH and FBH).
12. **Auxiliary Spillway - Capacity (New Mexico Criteria):** New Mexico Administrative Code 19.25.12.5 states that the spillway must have adequate capacity to pass the spillway design flood without failure of the dam. The existing spillway does not have capacity to pass the spillway design flood without overtopping (failing) the dam.
13. **Retaining Dike (New Mexico Criteria):** The existing retaining dike appears to contain granular materials susceptible to seepage and not consistent with standard embankment materials. New Mexico Dam Safety requires that this retaining dike meet state design standards for a dam embankment because it would be impounding water.

D.11 Inspections

The Site 1 Dam is inspected on an intermittent basis by the New Mexico Office of the State Engineer Dam Safety Bureau. An Informal Dam Safety and O&M Inspection Report conducted on October 13, 2017 identified the following items of concern:

- Difficult to access site due to recent flooding changing the road grade
- Rodent holes and vehicular damage on the dam embankment
- Rill erosion on the east and west groin of the downstream dam embankment
- The trash rack is missing and needs to be replaced on the principal spillway riser
- Rill erosion on the auxiliary spillway
- Small woody plant species are located on the auxiliary spillway
- The drain filter needs repair and cleaning
- Fencing is not adequate, and/or loose or damaged

D.12 Alternatives Evaluation

The formulation process of alternatives for the rehabilitation of the Site 1 Dam followed procedures outlined in the NRCS National Watershed Program Manual (NWPM) (NRCS 2015), Parts 500 through 506; NRCS National Watershed Program Handbook (NWPH) (NRCS 2014), Parts 600 through 606; Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G) (U.S. Water Resources Council [USWRC] 1983); and other NRCS watershed planning policy. Numerous alternatives were developed by the project team based on the ability to address the purpose and need of the project, and were formulated in consideration of four criteria outlined in the P&G (USWRC 1983): completeness, effectiveness, efficiency, and acceptability. Scoping comments received during the scoping period were considered in the formulation process for the initial alternatives.

According to the NWPM, the following alternatives and expected consequences must be evaluated:

1. No Action – Most likely future condition if none of the federally assisted action alternatives are selected.
2. Decommissioning – Removal of the dam and stabilizing the site. If this alternative is unreasonable it can be eliminated from detailed study.
3. Rehabilitation – Rehabilitation of the structure with a sediment storage life for the longest reasonable period practical (no less than 50 years and no greater than 100 years).
4. National Economic Development (NED) Alternative – One of the alternatives, or a combination of them. This is the federally-assisted alternative with the greatest economic benefits.

D.12.1 Alternatives Eliminated From Detailed Study

Alternatives were developed early in the process following the procedures identified above, but were eliminated from detailed study due to environmental impacts, cost, and logistics. A description of the alternatives eliminated from detailed study is included below. Refer to the Plan-EA for a more detailed description of each alternative eliminated from detailed study and reasoning for elimination.

D.12.1.1 Dam Decommissioning Alternative

This alternative would require removal of the storage function of the dam and would reconnect, restore, and stabilize the stream and floodplain functions. Only partial removal of the embankment would be required, which would require excavating a breach in the dam of sufficient size to safely pass the 100-year, 24-hour frequency flood event. This alternative would also require restoration of the natural stream channel grade, vegetation, and geomorphology within the basin per New Mexico and NRCS specifications. The remaining portion of the embankment and sediment pool would be re-contoured to reconnect the stream channel through the sediment pool. Riprap would be installed on the new channel and embankment cut slopes as needed for erosion control and to prevent headcutting. The channel with riprap would extend just beyond the acequia, and the acequia would be piped in this area to allow continued irrigation use. The principal spillway riser would be demolished and removed, and the principal spillway outlet pipe would be capped.

In order to meet the purpose and need of the project and provide flood protection for runoff, erosion, and sediment to communities and infrastructure downstream, equivalent flood protection measures must be provided. To accomplish this, a flood easement could be acquired for the downstream properties, and/or relocation or purchase of properties completed. Downstream residences and properties subject to flooding from a 100-year event would need to be relocated, purchased, or easements would need to be established. The number of homes inundated at a depth greater than 1 foot during the 100-year, 24-hour event under conditions of dam decommissioning is approximately 80 homes. A median home price of $100,000, plus approximately $25,000 per home for demolition or relocation and regrading, was used for cost estimating. Additionally, there is approximately 55 acres of crop and pasture land that would be inundated. An average value of $10,000 per acre was assumed for acquisition costs. Land easement acquisition, relocation, and demolition costs for this alternative would be approximately $10,550,000.

The estimated construction cost for the Dam Decommissioning Alternative is approximately $19,702,400 (see Table D-7). Based on the extreme disturbance to the human environment, logistics, and costs, this alternative was determined to be infeasible and was eliminated from further study.

Table D - 7. Dam Decommissioning Construction Cost Estimate

Item	Quantity	Unit	Unit Price	Estimate
Dam Embankment				
Clearing and Grubbing	25	AC	$275.00	$6,900
Embankment Cut	20,000	CY	$15	$300,000
Sediment Excavation	20,000	CY	$15	$300,000
Riprap Grade Stabilization	15,000	CY	$125	$1,875,000
Principal Spillway Riser Demolition	1	LS	$150,000	$150,000
Cap Principal Spillway Conduit	1	LS	$50.00	$50,000
Acequia Crossing	1	LS	$50.00	$50,000
Access Road	$250,000	1	LS	$250,000
Home Demolition/Relocation and Grading	1	LS	$2,000,000	$2,000,000
Property Acquisition	1	LS	$8,550,000	$8,550,000
Construction Subtotal				$13,531,900
Mobilization (12% of Subtotal)				$1,623,800
Contingency (30%)				$4,546,700
Total:				**$19,702,400**

D.12.1.2 Dam Raise 100-Year Sediment Life Alternative (Maximum Life)

An option to provide 100 years of sediment storage for rehabilitation alternatives was explored. Measures to meet 100 years of sediment life would include all those listed for the Dam Raise 71-Year Sediment Life Alternative (Section D.13.2.2), in addition to approximately 347,675 cubic yards (215 ac-ft) of sediment removal within the basin. The total approximate construction cost for this alternative would be $22,931,000. Based on the logistics associated with excavating and disposing of such a large quantity of sediment, erosive and arid conditions creating issues with sediment stabilization measures, the large environmental impact, and very high cost, this alternative was considered infeasible and eliminated from further study.

D.12.1.3 Dam Raise 88-Year Sediment Life Alternative

The option to provide 88 years of sediment storage for rehabilitation alternatives was explored. Measures to meet 88 years of sediment life would include all those listed for the Dam Raise 71-Year Sediment Life Alternative (Section D.13.2.2), in addition to approximately 211,350 cubic yards (131 ac-ft) of sediment removal within the basin. The total approximate construction cost for this alternative would be $20,006,000. Based on the logistics associated with excavating and disposing of such a large quantity of sediment, erosive and arid conditions creating issues with sediment stabilization measures, the large environmental impact, and very high cost, this alternative was considered infeasible and eliminated from further study.

D.12.1.4 Dam Raise 50-Year Sediment Life Alternative (Minimum Life)

This alternative would include measures similar to those of the Dam Raise 71-Year Sediment Life Alternative (Section D.13.2.2), except the principal spillway, auxiliary spillway, retaining dike, and dam crest would not be raised as high. The estimated construction cost for this alternative is approximately $14,206,000. This alternative was compared to the Dam Raise 71-Year Sediment Life Alternative to compare the cost benefit over a 71-year evaluation period. The comparison concluded that O&M costs for sediment removal (157.7 ac-ft) to extend the life and meet 71 years would be approximately $5,457,000. The construction cost for the project over a 71-year life would be over $4,000,000 more than the Dam Raise 71-Year Sediment Life Alternative. Based on the sediment logistic issues and cost benefit comparison, this alternative was eliminated from further study.

D.12.1.5 Dam Raise Sediment Excavation Combo for 50- to 71-Year Life

This alternative would include measures similar to those of the Dam Raise 50-Year Sediment Life Alternative (Section D.13.1.4.), but sediment excavation in the basin would also be conducted to extend the sediment life of the structure past 50 years. Sediment excavation amounts and construction costs would vary depending on the amount of life added to the structure. Cost analysis determined that the costs associated with raising the structure were far less than those associated with removing sediment from the basin. Based on the logistics with excavating and disposing of sediment, erosive and arid conditions creating issues with sediment stabilization measures, the environmental impact, and high cost associated with any sediment excavation, this alternative was considered infeasible and eliminated from further study.

D.12.1.6 Dam Raise Sediment Excavation Combo for 71- to 88-Year Life

Measures for this alternative would include all those listed for the Dam Raise 71-Year Sediment Life Alternative (Section D.13.2.2), with additional sediment excavation from the basin. Sediment excavation amounts and construction costs would vary depending on the amount of life added to the structure. Cost analysis determined that sediment excavation costs would be excessive due to the extreme stabilization measures that would be required for the arid and erosive conditions. Based on the logistics with excavating and disposing of sediment, erosive and arid conditions creating issues with sediment stabilization measures, the environmental impact, and high cost associated with any sediment excavation, this alternative was considered unreasonable and eliminated from further study.

D.12.1.7 Return Sediment Storage to As-Built Condition Alternative

This alternative would consist of excavating approximately 405 ac-ft (653,400 cubic yards) of sediment from the basin to return it to As-Built sediment capacity. It would also include the same measures identified in the No Action Alternative (Section D.13.2.1). The cost for sediment excavation and relocation alone would be approximately $14,015,000. Total construction cost for this alternative would be approximately $24,525,000. Based on the cost, environmental disturbance associated with sediment excavation and disposal, and logistics of sediment disposal, this alternative was eliminated from further study.

D.12.1.8 Riprap Auxiliary Spillway Alternative

Measures for this alternative would include all those listed for the Dam Raise 71-Year Sediment Life Alternative (Section D.13.2.2), but the auxiliary spillway would be armored with riprap instead of concrete. The added roughness from riprap for this alternative would require the auxiliary spillway to be widened at least four times its existing width to pass the necessary design flows. The logistics and costs associated with widening the auxiliary spillway by this amount were determined to be unreasonable. Costs for auxiliary spillway modifications alone would be greater than $10,000,000. The total cost for this alternative would far exceed the cost of other alternatives analyzed. Based on the logistics and exorbitant costs associated with a riprap auxiliary spillway, this alternative was eliminated from further study.

D.12.2 Alternatives Studied in Detail

This section discusses the evaluation of alternatives for the Site 1 Dam Rehabilitation Project that were studied in detail. Two alternatives were evaluated and include the No Action Alternative and the Dam Raise 71-Year Life Alternative.

Preliminary cost estimates were computed for the alternatives listed above. The following procedures were used:

- Cost estimates were based on 2018 U.S. dollars.
- Rehabilitation costs account for estimated quantities of material and labor.

- Costs associated with mitigation of potential environmental and cultural/historical impacts were not included.

D.12.2.1 No Action

The No Action Alternative, also known as the Future-Without-Project Plan, projects the changes in resource concerns from the current condition to the condition that would exist in the future if no NRCS action were taken (NRCS, 2015). The No Action Alternative for dam rehabilitation projects typically takes one of the following courses (NRCS, 2014):

- The Sponsoring Local Organization (SLO) decides to bring the dam up to current state dam safety criteria for high hazard dams, without meeting NRCS standards, which may be more or less stringent.
- The SLO reconfigures the dam to a lower hazard classification and proceeds to meet state dam safety criteria.
- The SLO or state dam safety office reconfigures the dam so it is no longer classified as a dam (e.g., constructed breach).

The Santa Fe-Pojoaque Soil and Water Conservation District's (Sponsor's) most likely course of action, as indicated in discussions, would be to bring the dam up to current state design standards, and address deficiencies identified in Section D.10. Note that the construction measures to bring the dam into compliance with state standards do not include extending the sediment life of the structure. The Sponsor would need to perform sediment excavation and O&M activities to extend the structure life and ensure proper operation of the dam. The Sponsor would likely perform the measures described below to bring the dam up to current state design standards.

Dam Embankment
The dam crest would be widened to 21.4 feet and level graded to 6,354.4 ft. The dam crest would be graded with a cross slope of no more than 3% to direct water back into the basin. The entire dam embankment would be covered with a gravel blanket (1-ft-thick) for erosion protection. The existing embankment slopes would be maintained.

Auxiliary Spillway
A new reinforced concrete auxiliary spillway would be constructed within the footprint of the existing earthen spillway with a crest elevation of 6,349.6 ft. Riprap would be installed at the downstream toe of the new concrete spillway to provide energy dissipation and erosion protection for flows entering the adjoining drainage.

Retaining Dike
The existing retaining dike would be reconstructed to meet the requirements for a water impounding structure up to a crest elevation matching the dam crest at 6,354.4 ft. The crest would have a minimum width of 10 ft and would be graded with a cross slope of no more than 3% to direct water back into the basin. The entire retaining dike would be covered with a gravel blanket (1-ft-thick) for erosion protection. The upstream embankment would be sloped at 3H:1V and the downstream embankment would be sloped at 2H:1V.

Principal Spillway
The existing principal spillway riser structures would be demolished and replaced with one new principal spillway riser. The crest elevation would be maintained at the existing sediment pool elevation of 6,336.6 ft. The new riser would be constructed of reinforced concrete with a steel trashrack, and designed to meet all current state engineering standards. The riser would be connected to the existing 30-inch reinforced

principal spillway concrete outlet conduit. The outlet conduit would be sliplined to repair any leaks and restore structural stability.

The plunge pool at the principal spillway conduit outlet would be reconstructed with riprap for erosion protection and dissipation before discharging into the downstream channel. To allow connectivity to the existing downstream channel, an approximately 25-ft length of the existing acequia would be piped. An armored channel would extend over the piped section of the acequia and discharge into the existing downstream natural drainage channel.

Access Road and Staging

These measures would be the same as those listed for the Dam Raise 71-Year Life Alternative in Section D.13.2.2.

The construction cost for the No Action Alternative is estimated at $10,510,00 including 10% for mobilization and a 30% contingency, as detailed in Table D-8. The project would also have costs associated with engineering, real property rights, permitting, and project administration estimated at $2,412,300. The estimated installation cost for this alternative is $12,922,300. To evaluate the No Action Alternative for the same duration as the Dam Raise 71-Year Life Alternative, the Sponsor would need to perform sediment excavation O&M activities to ensure proper operation of the dam. Approximately 520 ac-ft of sediment would need to be removed from the basin over the course of the next 71 years. The estimated annual O&M cost that includes sediment excavation would be approximately $257,000, for a total of $18,268,300 over the 71-year evaluation period. These costs would be funded by the Sponsor.

Table D - 8. No Action Alternative Construction Cost Estimate

Item	Unit Price	Quantity	Unit	Estimate
Principal Spillway				
Plunge Pool Excavation	$15	100	CY	$1,500
Riprap Plunge Pool	$125	120	CY	$15,000
Replace Risers with 1 Riser	$65,000	1	LS	$65,000
Acequia Crossing	$50,000	1	LS	$50,000
Trashrack	$200,000	1	LS	$200,000
Slipline Outlet Conduit	$200	600	LF	$120,000
Dam Embankment				
Rock Blanket	$75	6,500	CY	$487,500
Widen and Level Grade	$25	13,250		$331,250
Auxiliary Spillway				
Excavation	$15	8,000	CY	$120,000
Grading	$15	6,000	CY	$90,000
Crushed Rock Base	$40	4,000	CY	$160,000
Concrete	$600	4,000	CY	$2,400,000
Riprap Plunge Pool and Outlet	$100	3,500	CY	$350,000
Retaining Dike				
Remove Existing Retaining Dike	$30	40000	CY	$1,200,000
Reconstruct Retaining Dike	$30	47500	CY	$1,425,000
Rock Blanket on Slopes	$75	1,125	CY	$84,375
Access Road				
Construct New Access Road	$250,000	1	LS	$250,000
			Construction Cost Subtotal	**$7,349,625**
			Mobilization (10%)	$734,963
			Contingency (30%)	$2,425,376
			TOTAL CONSTRUCTION COST	**$10,510,000**

D.12.2.2 Dam Raise 71-Year Sediment Life Alternative

This alternative consists of raising the structure components to the maximum feasible extent allowed by topographic constraints to increase capacity in the basin. The Dam Raise 71-Year Sediment Life Alternative (Rehabilitation Alternative) would consist of the measures described below and also depicted in the Concept Design Drawings included in Attachment 1.

Dam Embankment

The dam crest would be raised approximately 10.6 ft to elevation 6,365.0 ft. The dam crest would be widened to 24 ft and graded with a cross slope of no more than 3% to direct water back into the basin. The entire dam embankment would be covered with a gravel blanket (1-ft-thick) for erosion protection. The upstream embankment slope would be maintained at 3H:1V and the downstream slope would be maintained at 2H:1V for the upper approximately 36 ft, and 2.5H:1V for the lower portion.

Auxiliary Spillway

The auxiliary spillway crest would be raised approximately 11.1 ft to elevation 6,360.7 ft. A new reinforced concrete auxiliary spillway would be constructed within the footprint of the existing earthen spillway. The new concrete spillway would have an approximately 40-ft level control section. Riprap would be installed at the downstream toe of the new concrete spillway to provide energy dissipation and erosion protection for flows entering the adjoining drainage.

Retaining Dike

The existing retaining dike would be reconstructed to meet the requirements for a water impounding structure up to a crest elevation matching the dam crest at 6,365.0 ft. The crest would have a minimum width of 12.5 ft and would be graded with a cross slope of no more than 3% to direct water back into the basin. The entire retaining dike would be covered with a gravel blanket (1-ft-thick) for erosion protection. The upstream embankment would be sloped at 3H:1V and the downstream embankment would be sloped at 2H:1V.

Principal Spillway

The existing principal spillway riser structures would be demolished and replaced with one new principal spillway riser. The crest elevation would be raised approximately 17.8 ft to accommodate capacity for 71 years of sediment accumulation. The new riser would be constructed of reinforced concrete with a steel trashrack, and designed to meet all current state and NRCS engineering standards. The riser would be connected to the existing 30-inch reinforced principal spillway concrete outlet conduit. The outlet conduit would be sliplined to repair any leaks and restore structural stability.

The plunge pool at the principal spillway conduit outlet would be reconstructed with riprap for erosion protection and dissipation before discharging into the downstream channel. To allow connectivity to the existing downstream channel, an approximately 25-ft length of the existing acequia would be piped. An armored channel would extend over the piped section of the acequia and discharge into the existing downstream natural drainage channel.

Access Road and Staging

Two staging areas would be constructed, with one located downstream of the dam embankment and one located upstream of the dam embankment within the basin. A new access road would be constructed at a grade not to exceed 10% along a new alignment to the top of the dam crest. The new access road would be approximately 14 ft wide and 1,200 ft long.

The construction cost estimate for this alternative is approximately $15,473,000, including 10% for mobilization and a 30% contingency, as detailed in Table D-9. The project would also have costs associated with engineering, real property rights, permitting, and project administration estimated at $3,549,900. The estimated installation cost for this alternative is $19,022,900. Annual costs for O&M are estimated at $4,000. These costs would be funded by NRCS and the Sponsor.

Table D - 9. Rehabilitation Alternative Construction Cost Estimate

Item	Unit Price	Quantity	Unit	Estimate
Principal Spillway				
Plunge Pool Excavation	$15	100	CY	$1,500
Riprap Plunge Pool	$125	120	CY	$15,000
Replace Risers with 1 Riser	$65,000	1	LS	$65,000
Acequia Crossing	$50,000	1	LS	$50,000
Trashrack	$200,000	1	LS	$200,000
Slipline Outlet Conduit	$200	600	LF	$120,000
Dam Embankment				
Rock Blanket	$75	16,500	CY	$1,237,500
Widen/Raise Crest and Level Grade	$25	70,000	CY	$1,750,000
Auxiliary Spillway				
Excavation	$15	8,000	CY	$120,000
Grading	$15	6,000	CY	$90,000
Raise Auxiliary Spillway	$25	16,000	CY	$400,000
Crushed Rock Base	$40	4,000	CY	$160,000
Concrete	$600	4,500	CY	$2,700,000
Riprap Plunge Pool and Outlet	$100	3,500	CY	$350,000
Retaining Dike				
Remove Existing Retaining Dike	$30	40000	CY	$1,200,000
Reconstruct Retaining Dike	$30	62,000	CY	$1,860,000
Rock Blanket on Slopes	$75	3,350	CY	$251,250
Access Road				
Construct New Access Road	$250,000	1	LS	$250,000
			Construction Cost Subtotal	**$10,820,250**
			Mobilization (10%)	$1,082,025
			Contingency (30%)	$3,570,683
			TOTAL CONSTRUCTION COST	**$15,473,000**

D.13 Economic Evaluation

The NRCS National Watershed Program Manual (NWPM; NRCS 2015) was used as a reference for the economic analysis along with the Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies (P&G) (U.S. Water Resources Council, 1983). P&G was developed to define a consistent set of project formulation and evaluation instructions for federal agencies that carry out water and related land resource implementation studies. The basic objective of P&G is to determine whether or not benefits from proposed actions exceed project costs for *federally funded projects*. P&G also requires that the "National Economic Development" or NED Alternative, which maximizes monetary net benefits, be selected for implementation unless there is an overriding reason for selecting another alternative based on federal, state, local, or international concerns related to the social and environmental accounts.

The following benefits were analyzed for the Site 1 Dam, per the P&G and the NWPM:

- Floodwater
- Sediment
- Erosion

Each of these benefits is analyzed in the following sub-sections. This economic analysis has been reviewed by a qualified independent technical reviewer.

D.13.1 Damage Reduction Benefits

Reduction benefits were assessed based on the equivalent annual damage reduction expected through implementation of the Rehabilitation Alternative as compared with the No Action Alternative baseline. Equivalent annual damages were calculated using the cumulative probability method as specified in the URB1 manual (SCS, 1990) or damages expected over the 71-year life of the project annualized at a discount rate of 2.75%. Damages are estimated by developing inundation extents of the events using a hydraulic model, overlaying the boundaries of the various events onto aerial maps, determining the structures that intersect the flood event extents, and discretizing the damages based on the severity of exposure for each structure. Note that due to model stability constraints, model grid spacing, and data resolution, the inundation extents appear to cover a larger area than what would be expected for floods of these magnitudes. These model constraints result in flood areas that cover similar extents for varying storm events with little to no difference between the No Action Alternative and Rehabilitation Alternative. Additional modeling with more robust software packages now available and with higher resolution elevation data would need to be performed to determine a more accurate difference in flood extents for a detailed economic analysis to be performed.

Under the No Action Alternative, the auxiliary spillway would activate at the 100-year 24-hour storm event, and the Rehabilitation Alternative would not. The auxiliary spillway would activate more frequently as the basin fills with sediment every year until the sediment would be removed or the structure has no more sediment volume left. This would increase the amount of water flowing downstream into the community for this event for the No Action Alternative and result in increased damages. Damages to property and land from flooding, sediment deposition, and erosion were estimated for both the No Action and Rehabilitation Alternatives. The difference between damages for the alternatives is calculated as the damage reduction. Table D-10 provides the damages estimated for each alternative and the resulting damage reduction benefit.

Table D - 10. Damages and Damage Reduction Benefit

Item	Estimated Average Annual Damage		Damage Reduction Benefit
	No Action Alternative	Preferred Alternative	
Floodwater			
Crop and Pasture	$185	$156	$29
Other Agricultural	$0	$0	$0
Residential	$4,098	$3,626	$473
Commercial	$0	$0	$0
Other	$420	$398	$23
Subtotal	$4,703	$4,179	$524
Sediment			
Overbank Deposition	$0	$0	$0
Erosion			
Channel Scour	$0	$0	$0
Total	**$4,703**	**$4,179**	**$524**

D.13.2 Cost Avoidance Benefit

The cost avoidance benefit represents the costs associated with implementation of the No Action Alternative (if a Dam Rehabilitation alternative was not selected). These costs include installation estimated at $12,922,300 ($416,000 annual) and O&M, estimated at $257,300 annually. Total annual cost for the No Action Alternative sums to approximately $673,300 and would be the total annual cost avoidance benefit for the Rehabilitation Alternative. The total annual cost for the Rehabilitation Alternative including O&M and installation was estimated at $616,400.

D.13.3 Benefit Cost Ratio

Table D-11 summarizes the benefits and costs of the alternatives analyzed for this project.

Table D - 11. Damages and Damage Reduction Benefit

Alternative	Total Annual Benefits	Total Annual Costs	Benefit Cost Ratio	Net Annual Economic Benefit
Rehabilitation Alternative	$673,824	$616,400	1.1	57,424
No Action Alternative	$0	$673,300	0	-$673,300

D.14 Environmental Evaluation

The Environmental Evaluation (EE) is an NRCS planning process as described in the NRCS National Planning Procedures Handbook (NRCS 2015b). The EE identifies and analyzes the economic, environmental, and social concerns for a project. This planning process is then summarized on the CPA-52 Environmental Evaluation form for Conservation Planning. This EE planning process started with the identification of problems and opportunities and continues through the application and evaluation of the project. A CPA-52 Environmental Evaluation is provided in Attachment 2.

D.15 References

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ATTACHMENT 1

CONCEPTUAL DESIGN DRAWINGS

ATTACHMENT 2

CPA-52 ENVIRONMENTAL EVALUATION