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Draft Gila River Conceptual Diversion Assessment

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1. Introduction

This report describes and evaluates conceptual diversion design project alternatives and components related to the diversion, delivery and storage of water from the Upper Gila River at the Gila Gage Diversion site (USGS Gage No. 09430500-Gila River Near Gila, NM). Under the Arizona Water Settlements Act (AWSA), the New Mexico Central Arizona Project Entity (NMCAP) seeks to divert an annual average of 14,000 acre-feet[1] of water for the benefit of agricultural, environmental, municipal, and industrial uses. This report outlines site conditions, field observations, key design criteria, concept alternatives and recommendations as they pertain to the suitability of the Gila Gage Diversion site to achieve the desired project goals. Additional study is needed to verify many of the observations and hypotheses presented in this report. This work will inform the ongoing design of proposed water diversion and storage strategies as proposed by the NMCAP to the U.S. Bureau of Reclamation on July 15, 2016.

The following items, described in this report, have been completed in fulfillment of this Task 2 Scope of Work:

- Site visit and evaluation;
- Conceptual engineering design for diversion alternatives located near Gila Gage site;
- Preliminary site access roads design for operations and maintenance activities; and
- Establishment of diversion elevations and locations for Gila Gage site.

2. Project Area and Description

The Gila River originates in the Mogollon Mountains of southwestern New Mexico, within the Gila National Forest. It flows generally south and then westerly toward New Mexico's border with Arizona. Along this route, it passes through portions of Catron, Grant, and Hidalgo counties. Being located in the transition zone between the two distinct physiographic provinces, the geology of this region is characterized by the Basin and Range province and the Colorado Plateau province. The Basin and Range is dominated by faulting, volcanism, magma intrusion, erosion and sedimentation whereas the Colorado Plateau is defined by flat lying, undeformed sedimentary rocks (NRCS, 2016). Within these physiographic provinces the river course transitions between zones dominated by structural bedrock confinement and more elongated alluvial valleys.

The upper most alluvial valley encountered by the Gila River, downstream of the Gila National Forest boundary is the Cliff-Gila Valley. This alluvial valley spans from the mouth of the Upper Gila Box Canyon downstream for a distance of approximately 10 miles to the Town of Cliff, NM (Figure 1). Settled in 1884, the towns of Cliff and Gila, NM are both located high above the active channel of the Gila River on ancient alluvial terraces and have traditionally functioned as ranching and farming communities. Beginning in the later part of the 19th century, the practice of converting these floodplain terraces to irrigated agricultural fields began in the region. By the mid-20th century more significant channel modifications including channel straightening and channel leveeing were actively occurring throughout the Cliff-Gila Valley.

Future water supply projects are proposed within the Upper Gila River Basin to benefit municipal, industrial, agricultural and environmental uses within southwestern New Mexico. To meet this need various diversion, conveyance, and storage alternatives are being considered. For this report, three conceptual diversion design alternatives for the Gila Gage Diversion Site (Gila Gage) have been developed. It is anticipated that the selected diversion alternatives will initiate the diversions and exchange provisions in the Consumptive Use and Forbearance Agreement (CUFA) as ratified by Congress in the 2004 AWSA. Our conceptual design meets the flow parameters as defined in the CUFA and associated documentation.

AECOM's preferred location for the diversion is within the vicinity of the Gila Gage due to its physiographic setting, access, channel width, and channel stability. This diversion site is located high enough in the watershed to provide a gravity flow option to some components of the project. It is also anticipated that the proposed Aquifer Storage and Recovery (ASR) storage alternative could be supplied from this location. This diversion location provides lateral stability to the channel due to confining bedrock located along both banks as compared to potential diversions located

[1] An Acre-Foot is a unit of volume equal to the volume of a sheet of water one acre (0.405 hectare) in area and one foot (30.48 cm) in depth; 43,560 cubic feet (1233.5 cu m).

further downstream in the more expansive Cliff-Gila Valley. Existing access to the diversion site was also identified prior to and confirmed by a field investigation conducted in the fall of 2016.

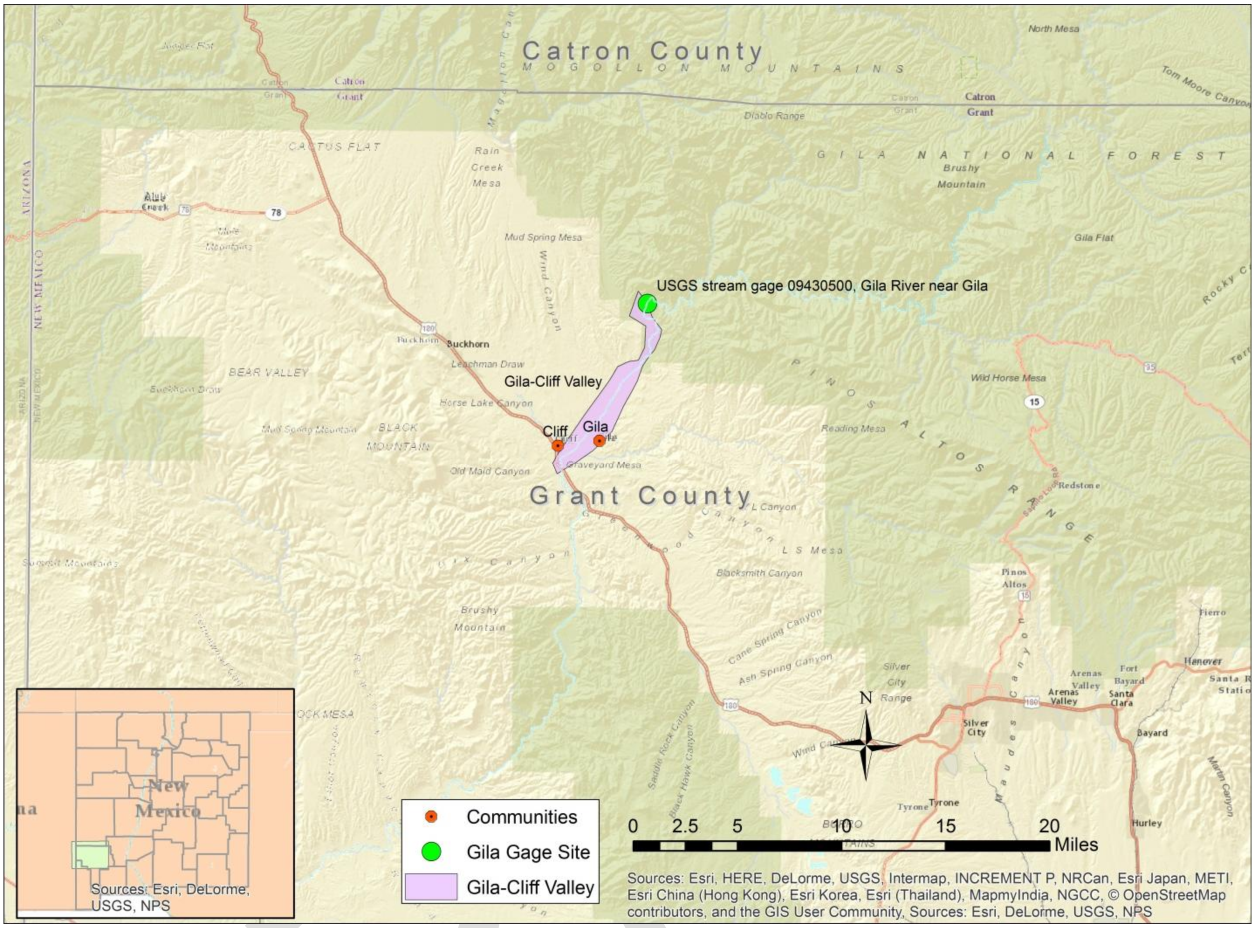

Figure 1 Location of Cliff-Gila Valley and Gila Gage

The proposed location for the Gila Gage diversion is at the existing USGS stream gage 09430500, Gila River near Gila, NM (Gila Gage) approximately 10 miles northeast of the Town of Cliff. The datum of the Gila Gage is 4654.80 feet NGVD29 (USGS, 2016). This report primarily focuses on the reach of the Gila River from the Gila Gage downstream to its confluence with Mogollon Creek. The majority of the reach is located within the Gila River Riparian Preserve, on lands co-owned by The Nature Conservancy of New Mexico Inc. et al (TNC) in conjunction with the State of New Mexico pursuant to the Natural Lands Protection Act (NLPA). Additional surrounding uplands and discrete portions of the valley bottom are located on lands managed by the US Forest Service (USFS). Figure 2 describes land ownership in the reach.

In total, the TNC manages more than 1,200 acres of land within the Gila River Riparian Preserve. The long term vision of the preserve is to “let the river rediscover its natural floodplain and enable new cottonwoods and willows to spring up, providing habitat for neotropical migratory songbirds, especially southwest willow flycatcher—a species whose population is in trouble” (The Nature Conservancy, 2016).

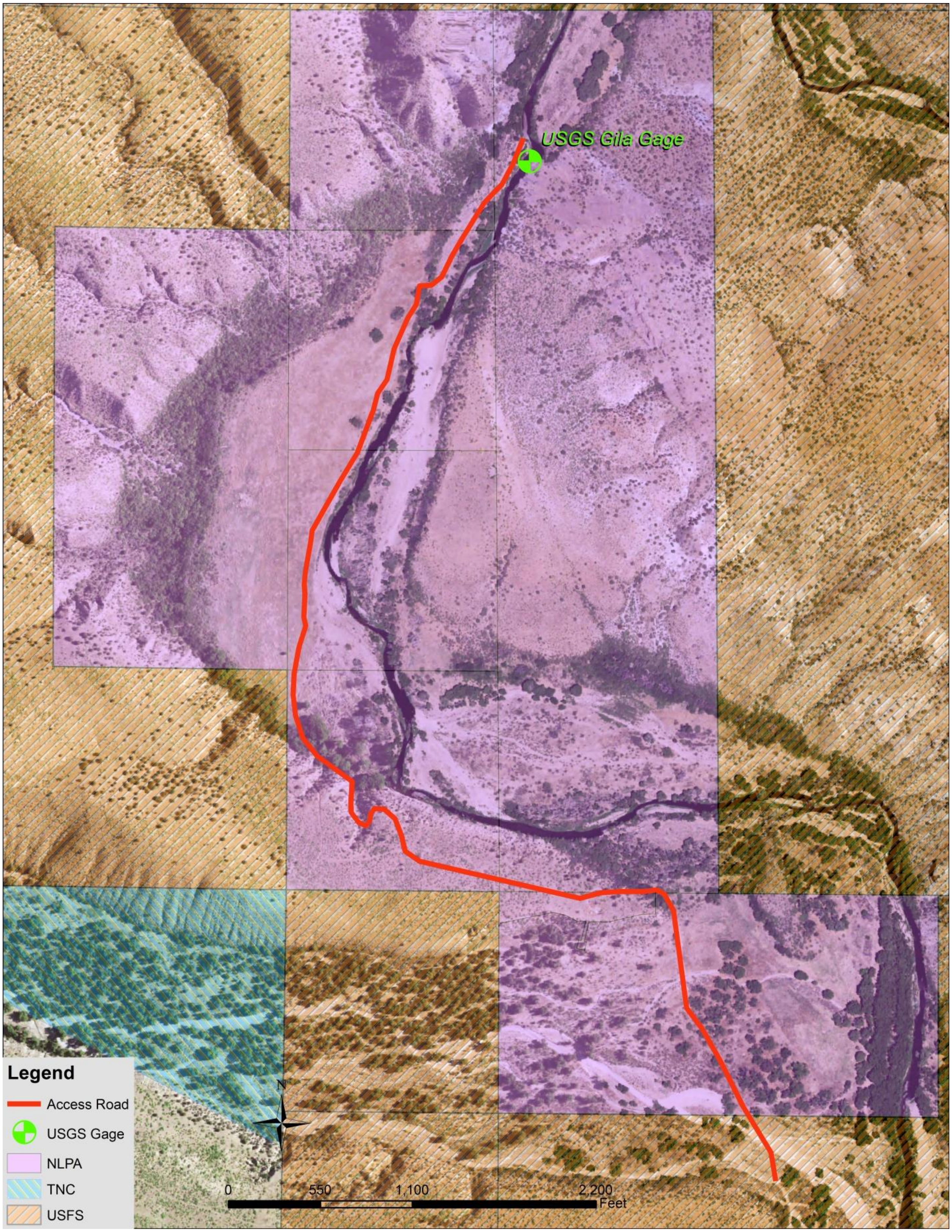

Figure 2 Land Ownership of the River Reach between the Gila Gage Diversion Site and the Confluence with Mogollon Creek

2.1 Upper Gila Watershed

The Upper Gila River watershed (HUC8-15040001) measures 1,864 square miles (USGS, 2016) as delineated at the Gila Gage (Figure 3). The watershed drains much of the southeastern flank of the Mogollon Mountains of southwestern New Mexico, within portions of Catron, Grant, and Sierra counties. At the highest point in the watershed, Willow Mountain rises to an elevation 10,895 feet.

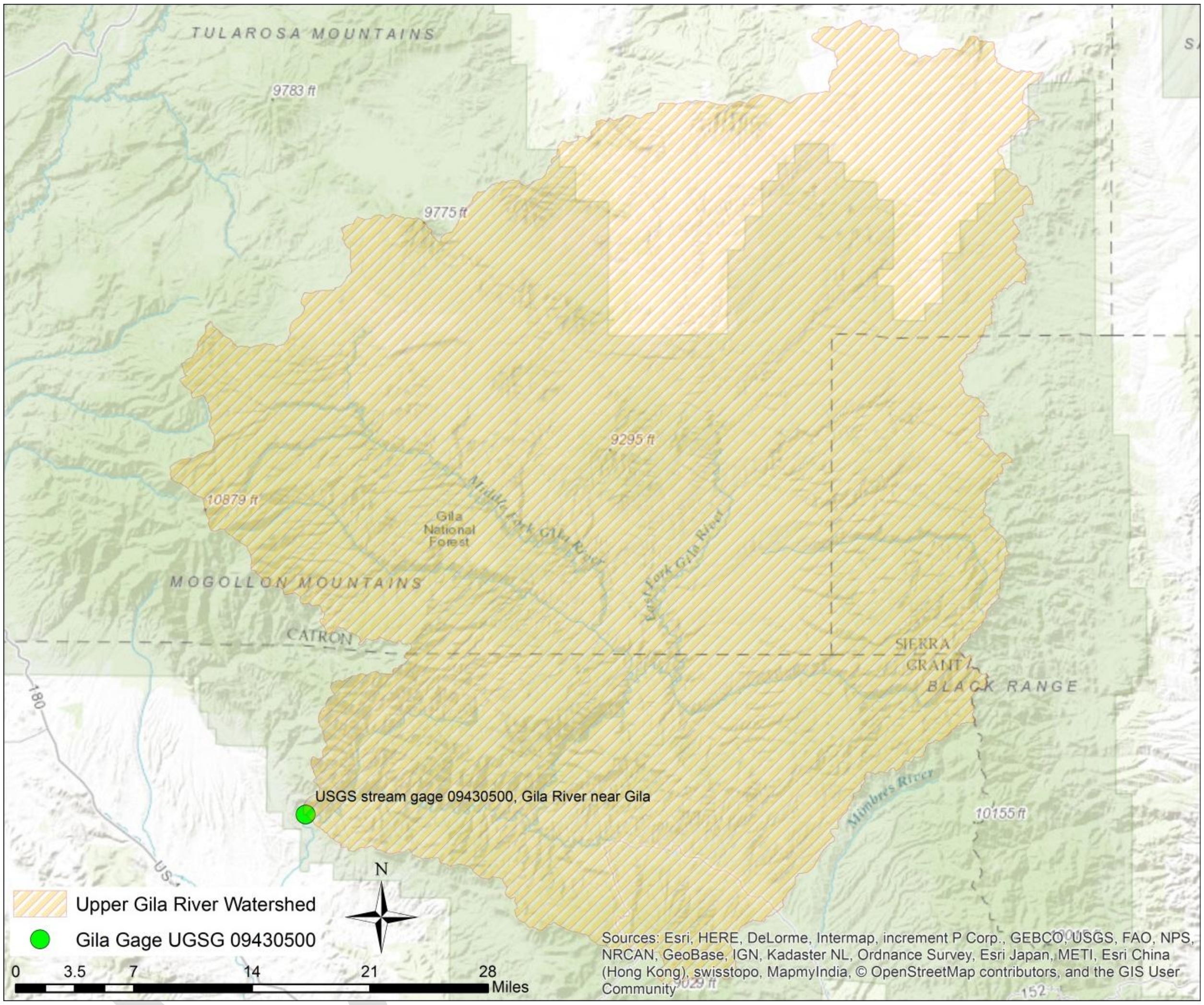

Figure 3 Upper Gila River Watershed Boundary (HUC8-15040001) Measured at the Gila Gage (09430500)

2.2 Climate

Annual precipitation in the basin ranges from 41 inches at the peak of Willow Mountain to 15 inches in the volcanic highlands found in the northeastern portion of the watershed (NRCS, 2016). The distribution of precipitation in the Upper Gila River watershed experiences distinct seasonal and annual variability. In general, elevated periods of precipitation in the watershed occur around the monsoonal convective thunderstorm season between July and October and frontal winter storm activity occurring between November and March.

Table 1 describes the average high and low temperatures and mean monthly precipitation measured at Gila Hot Springs, NM (5600 feet).

Table 1 Gila Hot Springs Climate Data

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Average Max. Temperature (F)	54.8	58.6	64.2	72.2	80.2	88.7	88.7	85.8	81.7	73.7	63.1	54.9	72.2
Average Min. Temperature (F)	18.4	21.2	24.9	30.1	36.3	44	53.7	53.2	45.5	34.1	23.8	18.5	33.7
Average Total Precipitation (in.)	0.93	0.91	0.78	0.45	0.47	0.65	2.76	3.03	1.96	1.53	0.88	1.33	15.69

2.3 Hydrology

The purpose of this hydrologic summary is to describe how the hydrology affects the geomorphology of the Gila River and the design of the diversion structure. It is not intended to be a comprehensive hydrologic review for water supply.

The mean daily discharge for the Gila gage based on the 89 year period of record is shown in Figure 4. A notable aspect of the figure is the change in day-to-day variability throughout the year. Between mid-March and the end of August, the mean daily flows recorded over the period of record vary only gradually from one day to the next. During the period from September through the end of February; however, recorded mean daily streamflow vary greatly. Compared to river and streams across the continental US, the Gila River has unusually large, infrequent floods relatively to the magnitude of the more frequent annual peak flows. For example, the ratio of the estimated 100 year flood of 47,000 cfs, is approximately 25 times the mean annual peak of 1,800 cfs on the Gila River. Across the Central Rocky Mountains of Colorado and Wyoming, this ratio is typically 3-4. In Pacific coastal river basins, the ratio is larger, ~ 10 times, due to the prevalence of intense rainfall, though still well less than half of ratio recorded in the Gila River Basin. Nineteen annual peak flows greater than 6,100 cfs have been recorded at the Gila River near Gila gage. The random occurrence of one of the unusually large floods on a given day is sufficient to increase the average over the entire period of record by 100 to 150 cfs. For example, the peak flow during the 1995 water year of 16,700 occurred on Nov. 12, 1994. The daily mean discharge on the day was 9,970 cfs. Thus, this one flood increased the mean daily discharge for Nov 12th for the entire period of record by approximately 113 cfs. As will be discussed in more detail later in this report, the unusually large flood peaks every 5 to 10 years or so, on average has significant implications for the fluvial geomorphology of the Cliff-Gila Valley and the stability of any structure built within the channel. It should also be noted in Figure 4 that annually, the lowest flows, in the range from 40 to 50 cfs typically occur during the middle of the irrigation season the last two weeks of June and the first two weeks of July.

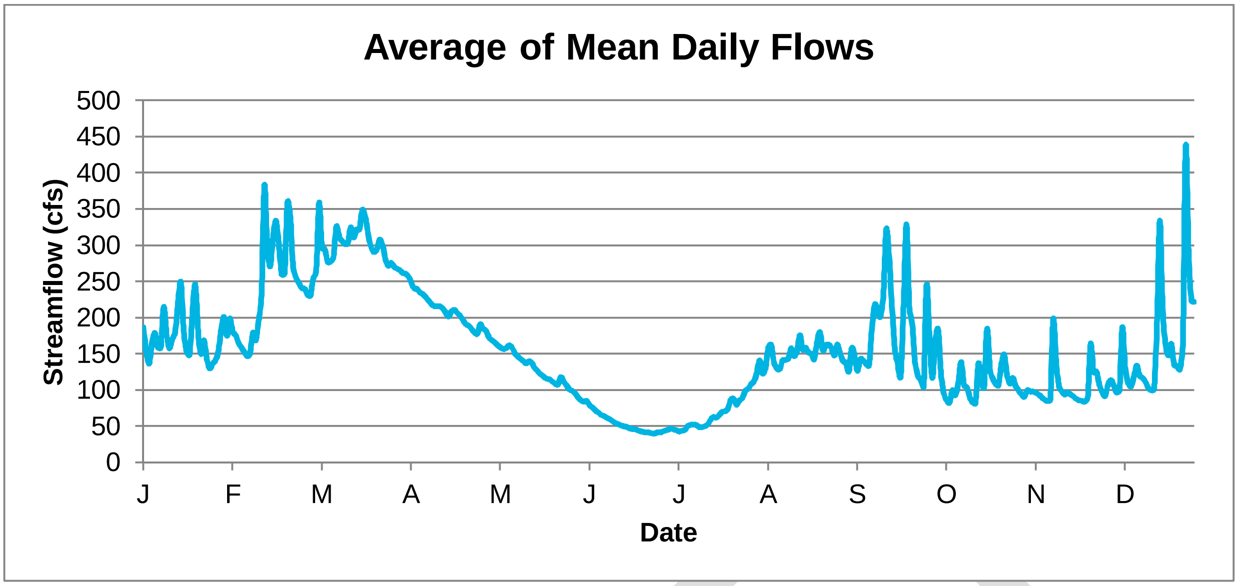

Figure 4 Average of Mean Daily Flow Data Determined from a Continuous Period of Record Between 1927 and 2016, Obtained from the Gila Gage 09430500 (Gila River near Gila, NM)

The magnitude of flooding at the Gila Gage varies extensively from year to year and season to season. The largest flood on record occurred on December 28th, 1984 with a discharge of 35,200 cfs. In contrast, the smallest annual peak discharge of 105 cfs, was measured on March 11th, 1951. Flood frequency analysis was calculated using Weibull plotting position formula from annual maximum series data describing discrete peak flow events measured at the Gila Gage (Figure 5). Stream gaging of the site began in December of 1927 and continues through today, with a few disruptions due to extreme flooding events.

Figure 6 describes the magnitude and range of annual peak flows observed between 1927 and 2016. It can be seen that the vast majority (83%) of peak flows ranged from 105 to 6,750 cfs while only a few (17%) ranged from 9,130 to 35,200 cfs. These more extreme floods are of particular interest to this analysis as their influence on the planform[2] of the river channel is the greatest. This relationship can be inferred from analyses of historical aerial imagery where visible evidence of these events can be seen and compared to the date and magnitude of measured flood events in the river.

[2] The outline of an object viewed from above.

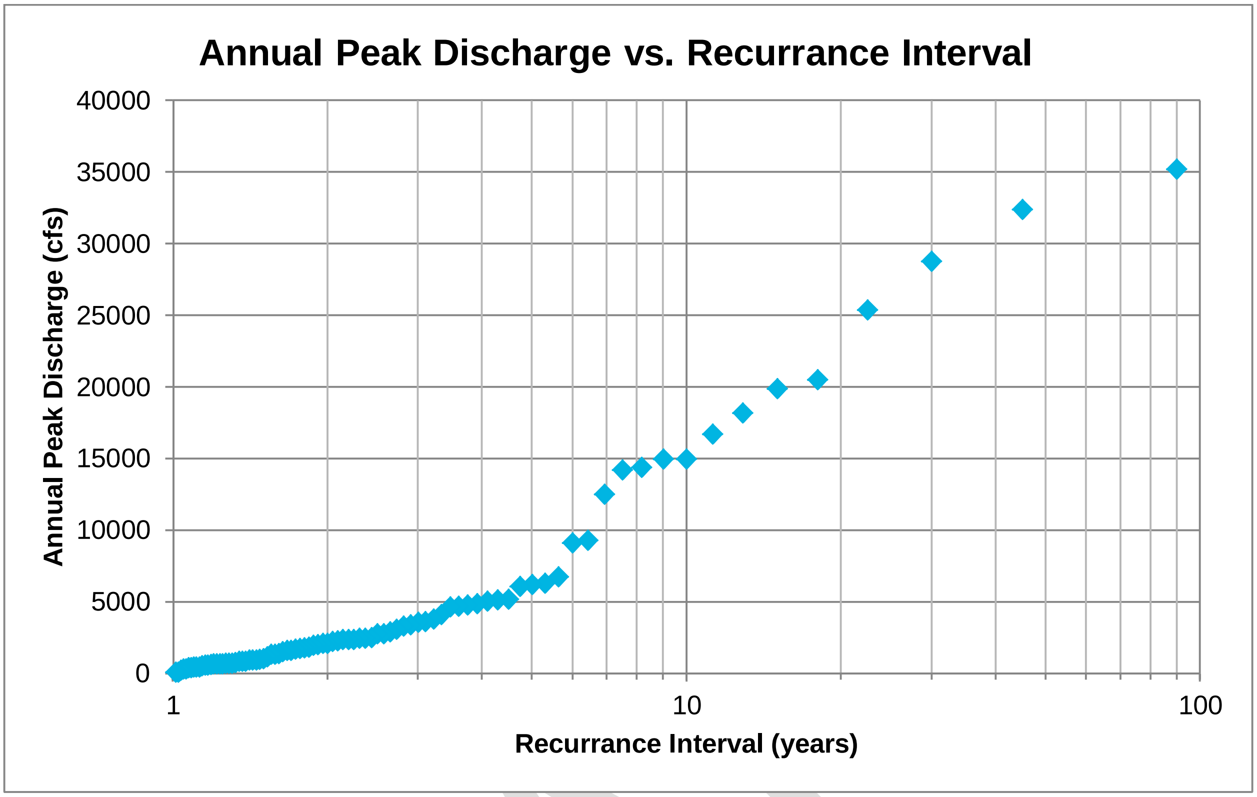

Figure 5 Flood Frequency Analysis Generated Using the Weibull Plotting Position Formula from Annual Peak Flow Values Obtained from the Gila Gage 09430500

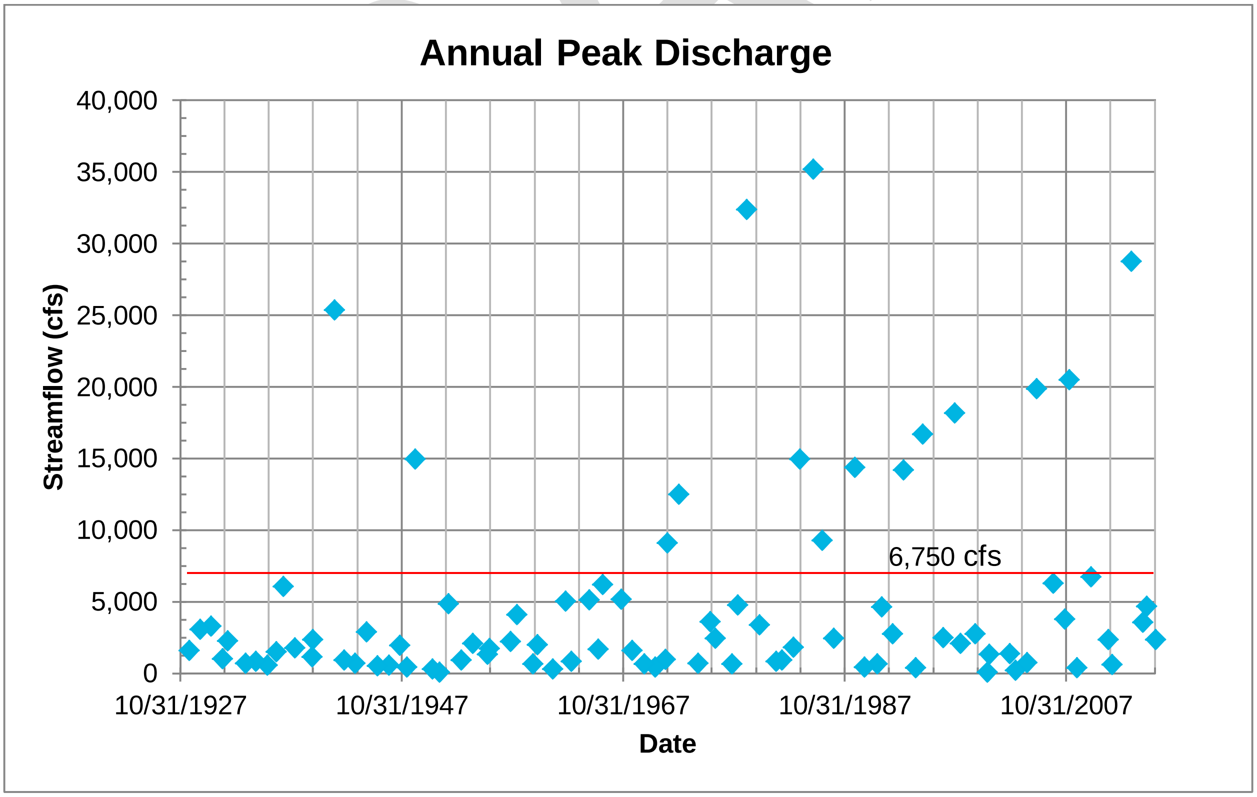

Figure 6 Annual Peak Flow Values Measured at the Gila Gage 09430500 between 1927 and 2016

2.4 Sedimentology

A Wolman pebble count was conducted along the riffle located immediately below the USGS stream gage to characterize the riverbed surface sediment. The D_{50} particle size was calculated to be 40 mm, while the D_{16} and D_{84} were determined to be 7 mm and 88.7 mm respectively (Figure 7). The composition of the streambed and banks is key to understanding the character of the stream system and how it influences the form of the channel.

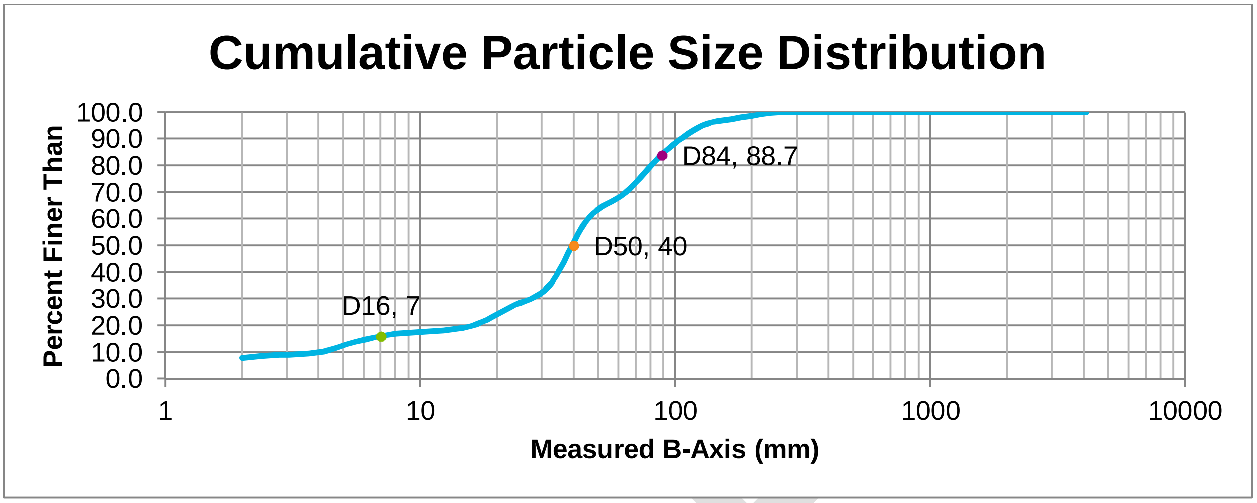

Figure 7 Cumulative Particle Size Distribution of Wolman Pebble Count Data Collected at the Gila Gage

2.5 Cliff-Gila Valley Geomorphology

A preliminary investigation into the geomorphology of the Upper Gila River within the Cliff-Gila Valley was conducted by AECOM to better understand the extent and possible causes of instabilities within the project reach and their implications to the configuration and success of the proposed diversion alternatives. Over the past century, land use and flooding has fundamentally modified the Gila River. An annotated bibliography outlining numerous studies and accounts related to the hydrology, geology, biology, flood and precipitation history, channel morphology, links between flood records and climate, land use planning documents, water quality studies, and ground water studies of the Upper Gila River was developed by the Bureau of Reclamation (Klawon & Wittler, 2001). The hydrology, geomorphology, and aquatic ecology of the Gila River through the Cliff-Gila Valley has been studied extensively including Klawon & Witler (2001), Mussetter Engineering (2006), NRCS (2016), Soles (2003), The Nature Conservancy (2016), USBR (1969), and Wittler and Levish (2004). These reports were reviewed for information relevant to this project. The following outlines the results of three of these reports.

A fluvial geomorphic study of the Upper Gila River was conducted by the Bureau of Reclamation (USBR) in 2004 to “understand the long-term behavior of the Gila River with emphasis on understanding historical changes in terms of expected behavior” (Wittler & Levish, 2004). This study included the Cliff-Gila Valley well as the Upper Box, upstream of the USGS gage. The investigations indicated that the Upper Box, in the vicinity of the Turkey Creek confluence, is geomorphically stable and has been for the 100 to 200 years (Klawon & Wittler, 2001). The report also presents a geomorphic analysis that indicates Gila-Cliff Valley has not been subject to system-wide changes in sediment yield[3] or hydrology and that human disturbance led to the geomorphic change observed downstream of the Upper Box. Specifically, a key conclusion of this report is that:

“The primary cause of geomorphic change of the Gila River in the Cliff-Gila is due to levee construction and subsequent failure. The banks of the Gila River are generally constructed of vertically accreted flood plain deposits, allowing rapid levee failure resulting in dramatic property loss. The effect of levee failure and exaggerated meandering of the Gila River will propagate downstream resulting in repeated levee failure and unexpected widespread laterally instability of the channel. This results in property loss and an unexpected pattern of large

[3] Total quantity of sediment moving out of a watershed in a given time interval, expressed in units of mass per unit time.

asymmetrical meanders. This is not a pattern that would be expected for the Gila River under pre-disturbance conditions" (Wittler & Levish, 2004).

Mussetter Engineering (MEI) conducted a separate study of the geomorphology of the Upper Gila River in 2006 for the purposes of determining the geomorphic impacts of annual diversion of up to 14,000 acre feet of water. Similar to the USBR report, MEI looked at several reaches of the Upper Gila River, some of which nearly extended to the border with Arizona. Of interest to this report, MEI looked at two separate sites bounding the Gila Gage site, within the Cliff-Gila Valley. The upper site, identified as the Turkey Creek Site, is located approximately three miles upstream of the Gila Gage, while the lower site identified as the TNC Site is located about five miles downstream. This report reaches a different conclusion from the USBR report stating:

"The primary determinant of the channel morphology in the alluvial reaches of the upper Gila River is the occurrence of infrequent, large magnitude floods (≥15,000 cfs) of long duration (1941, 1979, 1984, 1985, 1995, 1997, and 2005) that cause lateral erosion and widening of the channel. Between large floods, channel narrowing occurs. Man-made features such as diversions, bank protection and levees have local effects only" (MEI, 2006).

Since the completion of this report, the following two large magnitude floods of long duration have occurred:

- January 1, 2008 (20,500 cfs); and
- September 15, 2013 (28,800 cfs).

It is important to note that a review of aerial photography collected in July of 2006, May of 2009, and June of 2014, within the river reach between the Gila Gage and Mogollon Creek shows no measurable channel widening despite the fact that the magnitude and duration of the 2008 and 2013 floods met the criteria established by MEI. Furthermore, the only observable planform change occurred in a reach that was identified as incised[4] during field reconnaissance. Following these floods, the channel width visibly decreased and a narrow band of riparian vegetation encroached laterally on the channel, though no other visible recruitment of riparian vegetation was observed in the reach.

Soles completed a study in 2003 in which she used a combination of quantitative and anecdotal methods to attempt to separate morphological changes within a 12 mile reach of the Cliff-Gila Valley resulting from extreme flooding events and human induced change. Of particular interest to this study were her findings related to the chronological progression of change to the river channel from the first settlers in the 1870s through the completion of her study in 2000. Early accounts of the region suggest that "in the late 1800's the Gila River in southwestern New Mexico occupied a single deep channel with thickly vegetated banks" (Soles, 2003). Over the course of the next 110 years, the river channel experienced significant lateral and vertical erosion resulting in an extensive loss of riparian vegetation along the active banks and side channels.

Soles observes that lateral erosion was accompanied by continued channel incision through the 1990s (Soles, 2003). Her analysis suggests upwards of 11 feet of degradation within certain reaches occurring between 1935 and 1995. Soles also notes that this incision was not isolated to the lower Cliff-Gila Valley, it occurred for a number of miles upstream. She also notes impacts to the riparian vegetation that point to incision. The impacts to the riparian vegetation, resulting from the incision, were also described:

"Along most of the study reach in 2000, the river channel was wide. Except for an intermittent, narrow band of riparian growth hugging the active channel, its cobble and gravel floodplain for a hundred feet or more on either side of the stream was frequently devoid of all but sparse upland vegetation like catclaw and broom snakeweed. While a few younger stands of cottonwood were evident, most obvious were enormous and isolated older trees on terraces above the active floodplain. In some reach segments, the channel was composed of large cobbles, slippery with algae; in other segments, sand and silt covered the channel bed to a depth of a foot or more. Active cutbanks of unconsolidated silt and gravel, sometimes ten feet high, lined long stretches of the river" (Soles, 2003).

AECOM used a combination of aerial imagery, survey data, and field observation to piece together the recent geomorphic history of the Gila River, within the study reach. Available aerial imagery from 1935, 1945, 1953, 1964,

[4] The term Incised refers to when a river has cut downward through its riverbed. The river begins at one elevation and incises downward through its bed while leaving its floodplain behind (higher).

1973, 1980, 1987, 1996, 2006, 2009 and 2014, provides insight into land use practices, changes to the rivers planform and riparian ecology, and the magnitude of disturbance associated with recorded flood events. Light Detection and Ranging (LiDAR) data, collected by the ISC in 2014, was used to identify relic fluvial[5] and agricultural landforms and provide insight into historic hydraulic conditions within the reach. Stream gaging data obtained from the Gila River Gage (USGS 09430500) provides historic discharge records.

The results of this analysis support Soles findings that the river channel in the upper portions of the Cliff-Gila Valley has degraded and is currently incised. Observations conducted by AECOM as well as numerous reports suggest channel degradation on the order of five to six feet within the reach. It is believed that headcutting[6] in this reach began in between 1973 and 1980 and continued through 2006.

Today, the incised channel actively prevents recruitment of riparian vegetation on the abandoned floodplain, particularly cottonwood, which requires very precise hydrologic and groundwater conditions for germination and growth. Incision of the main river channel also retards the reestablishment of bank-side vegetation that would serve to trap fine sediments during floods and prevent bank erosion. Additionally the incision of the channel lowers the water surface of the river as well as the adjacent groundwater table. The lowering of the water table also changes the composition of vegetation on the floodplain resulting in a reduction in the extent and diversity of riparian vegetation.

2.5.1 Cliff-Gila Valley Study Reach

The study reach shown in Figure 8 is approximately 10 miles in length and is located between the crossing of the Gila River by US Highway 180 West (US Highway 180) and the Gila Gage. The study reach was broken into three separate sub-reaches distinguished by differences in channel confinement, river function, and land use. The lower sub-reach, extending upstream from the US-180 W crossing to the Fort West diversion, is generally characterized by a broad valley floor, history of sediment deposition, and extensive manipulation of the channel and floodplain. The middle reach, extending upstream from the Fort West irrigation diversion to the confluence with Mogollon Creek is typically characterized by moderate lateral confinement of the channel, high sediment transport rates, and limited manipulation of the channel and floodplain. The upper sub-reach, extending upstream from the confluence of Mogollon Creek to the Gila River Gage, is generally characterized by moderate lateral confinement of the channel, a history of both erosional and depositional flooding events, and moderate manipulation of the channel and floodplain.

[5] Produced by the action of a stream
[6] A headcut is an erosional feature of some intermittent and perennial streams where an abrupt vertical drop, also known as a knickpoint in the stream bed occurs.

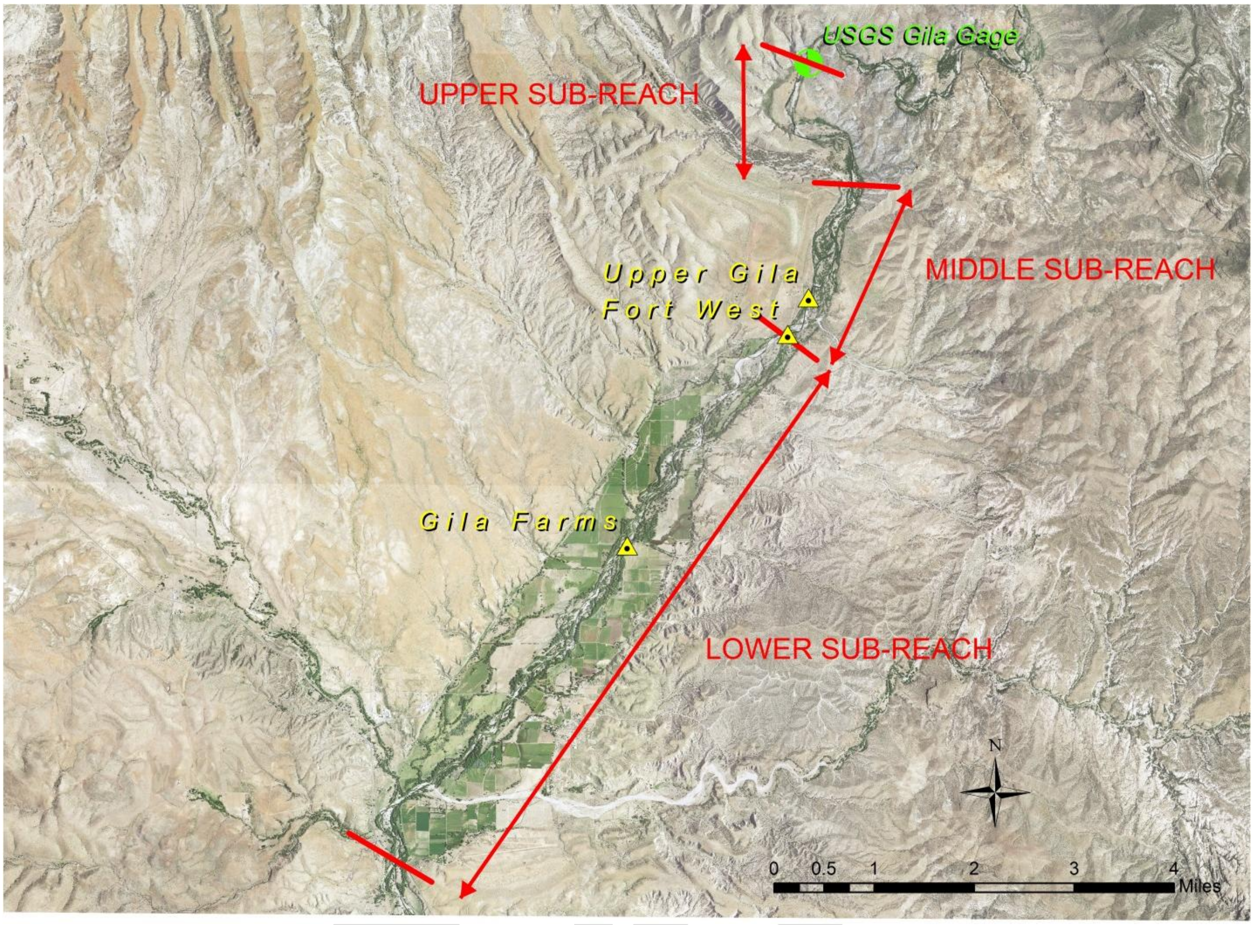

Figure 8 Shows the Upper, Middle, and Lower Sub-Reaches Comprising the Overall Cliff-Gila Valley Study Reach Along with Active Irrigation Diversions within the Reach

2.5.2 Bridges and Roads

There are two bridge crossings within the study reach. The downstream crossing is on US Highway 180. The upper crossing occurs approximately 2.5 miles upstream along New Mexico State Highway 211 North (State Highway 211). Bridge abutments at both crossings appear to encroach laterally into the historic and active floodplains, contracting and accelerating overbank flows through the bridge opening. Bank stabilization activities immediately upstream of US Highway 180 crossing were observed, where failing gabion baskets are located along the river left bank. These issues are currently being studied through a research project funded through the NMDOT Research Bureau.

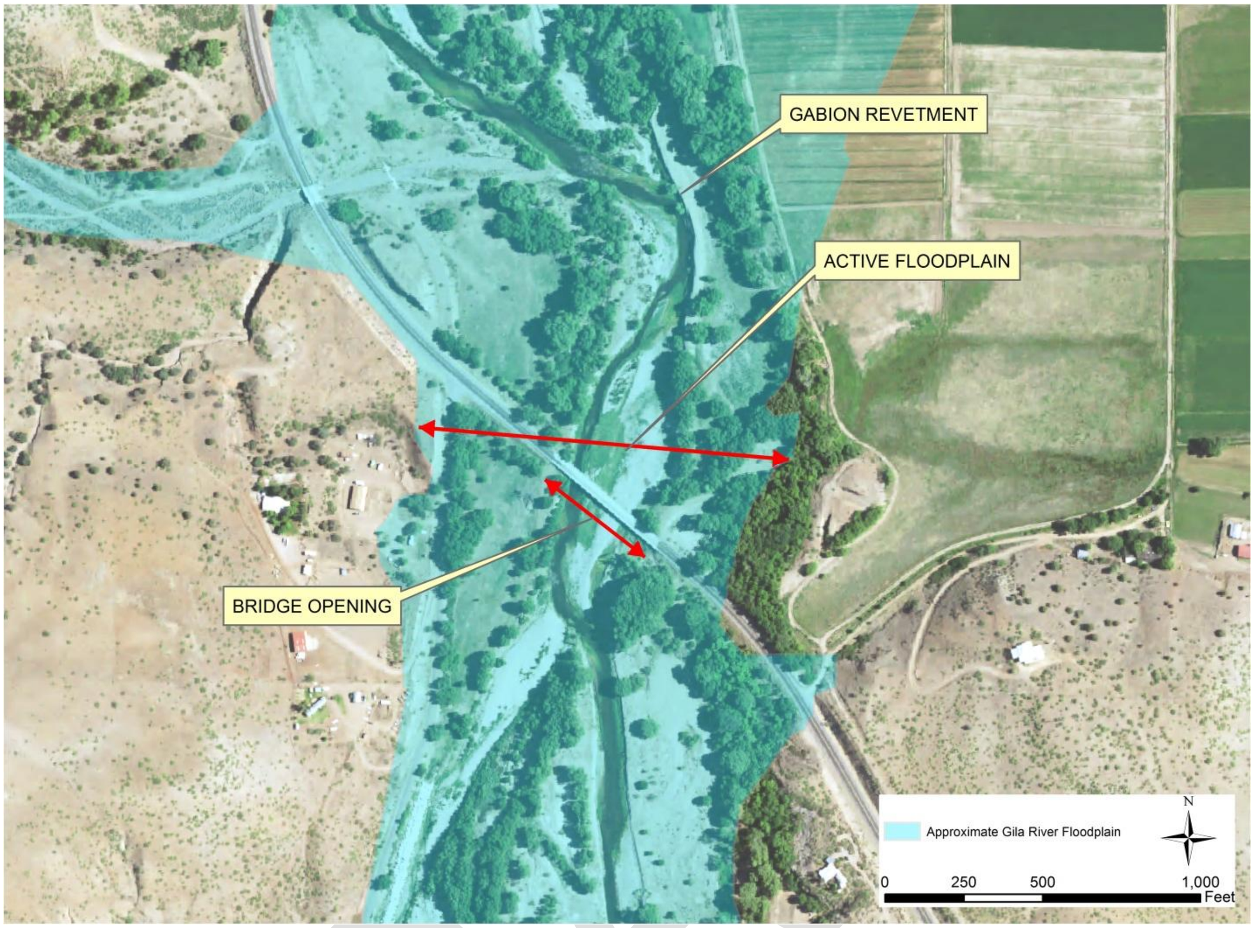

Figure 9 Floodplain Contraction at US 180 Bridge Crossing

2.5.3 Diversion and Irrigation

Irrigation diversions and agricultural activities within the study reach have altered both the form and function of the river system. Irrigated agriculture on the alluvial floodplain terraces of the Cliff-Gila Valley began in the late 19th century. Aerial imagery taken in 1945 shows fields plowed to the edge of the active channel, many of which are still in use today. There are three active diversions within the study reach (Figure 8), although other diversions may have been used historically. The active irrigation diversions from downstream to upstream are as follows:

- Gila Farms Diversion;
- Fort West Diversion; and
- Upper Gila Diversion.

Evidence of abandoned diversions and ditch lines can be seen in the historic aerial imagery as well as the periodic relocation and reconstruction of the active diversions. Maintenance of these alluvial push up dams creates local instabilities within the channel and alters the reaches ability to convey sediment loads.

These diversions also influence the availability of water within the river. During certain times of year, when available flows in the Gila River are exceeded by irrigation demands, the three active diversions may entirely dewater the channel. These conditions significantly impact aquatic and riparian ecosystem health and can greatly affect channel stability.

2.5.4 Channelization

Channelization activities, including both straightening and leveeing of the historically meandering river, have been conducted multiple times in the Cliff-Gila Valley over roughly the past 65 years. Aerial imagery taken between 1945 and 1953 shows the period in which channelization of the Gila River began, between the Gila Farms and Fort West diversions began (Figure 10). Aerial imagery taken between 1953 and 1964 also suggests channelization between the Gila Gage and the confluence of Mogollon Creek (Figure 11). Expansion and repair of the levee systems within the Cliff-Gila Valley was also performed following the flood of 1979, which is the second largest on record.

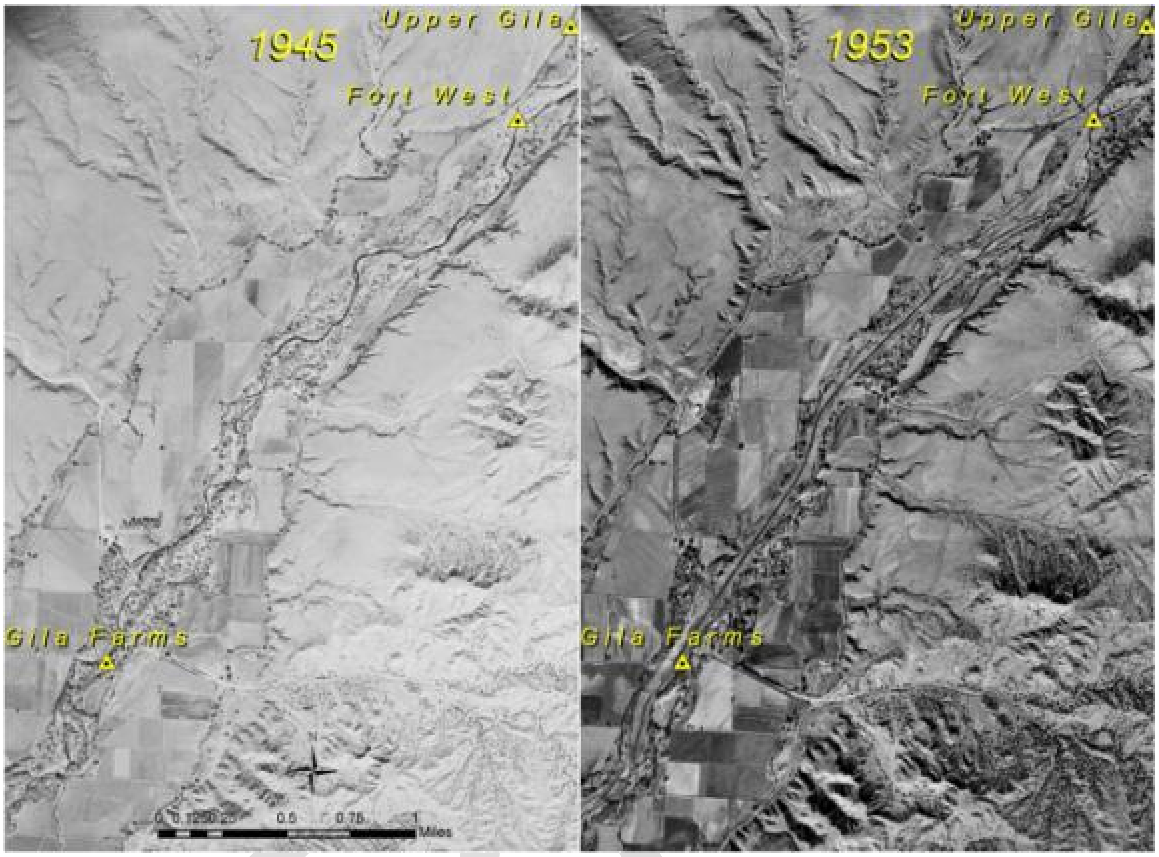

Figure 10 Channelization of the Reach between Gila Farms Diversion and Fort West Diversion (1945-1953)

Channel straightening steepens the river bed slope and increases stream competence to mobilize and convey sediments, resulting in greater sediment transport rates and coarser sediment loads. It can also reduce channel boundary roughness and drag through the removal of large boulders, riparian vegetation, and woody debris. Energy losses are also minimized through the reduction of the planform sinuosity, channel bedforms, or pool/riffle sequencing. Leveeing often results in greater flow depths and stream velocities coupled with reduced flow widths and overbank storage.

Channelization[7] activities typically result in deeper, higher velocity flows with higher bed shear stresses and lower thresholds for incipient motion. As the net transport capacity of the reach increases, the available incoming sediment supply remains temporarily unchanged. The resulting imbalance produces erosive conditions in which the river channel can adjust vertically through the progressive upstream flattening of its bed. The typical mechanism is through a headcut, which starts off as a knickpoint, then moves upstream through a reach reestablishing equilibrium with regard to the hydrology and sediment supply. Headcuts can progress tens of miles or more depending on the erodibility of the channel substrates and the existence of structural controls in the channel that can limit their upstream migration (e.g. bedrock, large alluvium).

[7] Channelization is the practice of dredging and straightening stream channels to increase flow rates and carrying capacities. This practice is often accompanied with levee building to further contain flood flows and to locally store excavated channel materials.

Figure 11 Channelization of the Reach between Mogollon Creek and the Gila Gage (1953-1964)

The impacts of headcutting are particularly evident from the standpoint of bank stability and changes in riparian vegetation. The reduction of the channel thalweg elevation produces taller and subsequently steeper river banks, which are less stable and often subject to erosion and geotechnical failure. In these incised conditions, historic riparian communities are often abandoned by the lowering of the water table resulting in a progressive decline in the extent and diversity of riparian species. The most susceptible vegetation includes species with shallow root systems or those that require very specific hydraulic/hydrologic conditions for germination. Conversely, larger species with established deeper root systems can persist indefinitely, resulting in perched riparian trees such as Cottonwood and Sycamore, which do not match their hydrologic setting.

In time the incised channel may attain a new quasi-equilibrium state as the channel width and slope come back into balance with the background sediment supply and hydrologic regime. New riparian vegetation, such as willow, may also begin to stabilize and protect the active channel margins from erosion. However, the lower elevation channel produces less frequent floodplain inundation resulting in reduced riparian species diversity, health and extents. The loss of riparian vegetation quantity and quality further destabilizes the historic floodplain during larger flood events when more erosive flows go out of the banks. Under these conditions significant damage to the channel can follow extreme flooding events as more robust and extensive riparian vegetation acts to protect the channel and floodplain. This vegetative buffer reduces flood velocities, stabilizes soils, and attenuates flood flows, thereby reducing the magnitude and severity of flood damages.

3. Field Inspection

Inspection of the area surrounding the Gila Gage was conducted to assess the suitability of this location for the proposed diversion structure. The stream gage is located on the left (east) river bank, opposite the end of the two-track access road. The gage consists of a stilling well made from Corrugated Metal Pipe (CMP) mounted to the face of a roughly 15 foot tall cast concrete wall, founded on a large bedrock outcrop (Photo 1). Telemetry equipment was also observed at the site along with a staff gage and cable car.

Several photographs, Photos 1-17, were taken showing various aspect of the river reach in the vicinity of the Gila gage as well as geomorphic features that will influence the location and design of the proposed diversion structure. The location and orientation of the photographs taken during the site visit are described in Figure 12.

Photo 1 Looking Upstream (North) at the Gila Gage

Observations of the staff gage further corroborate channel degradation in the reach. The staff gage is discontinuous with a secondary staff bolted onto the face of the original stilling well to reach the water surface. A review of the notes related to the establishment and maintenance of the Gila Gage, obtained from the USGS Las Cruces Field Office, also identify that in 1994 the datum was lowered by 1.00 ft and the staff was reset. Channelization work needed to divert the river flow back to the gage was also noted to have occurred in 1971.

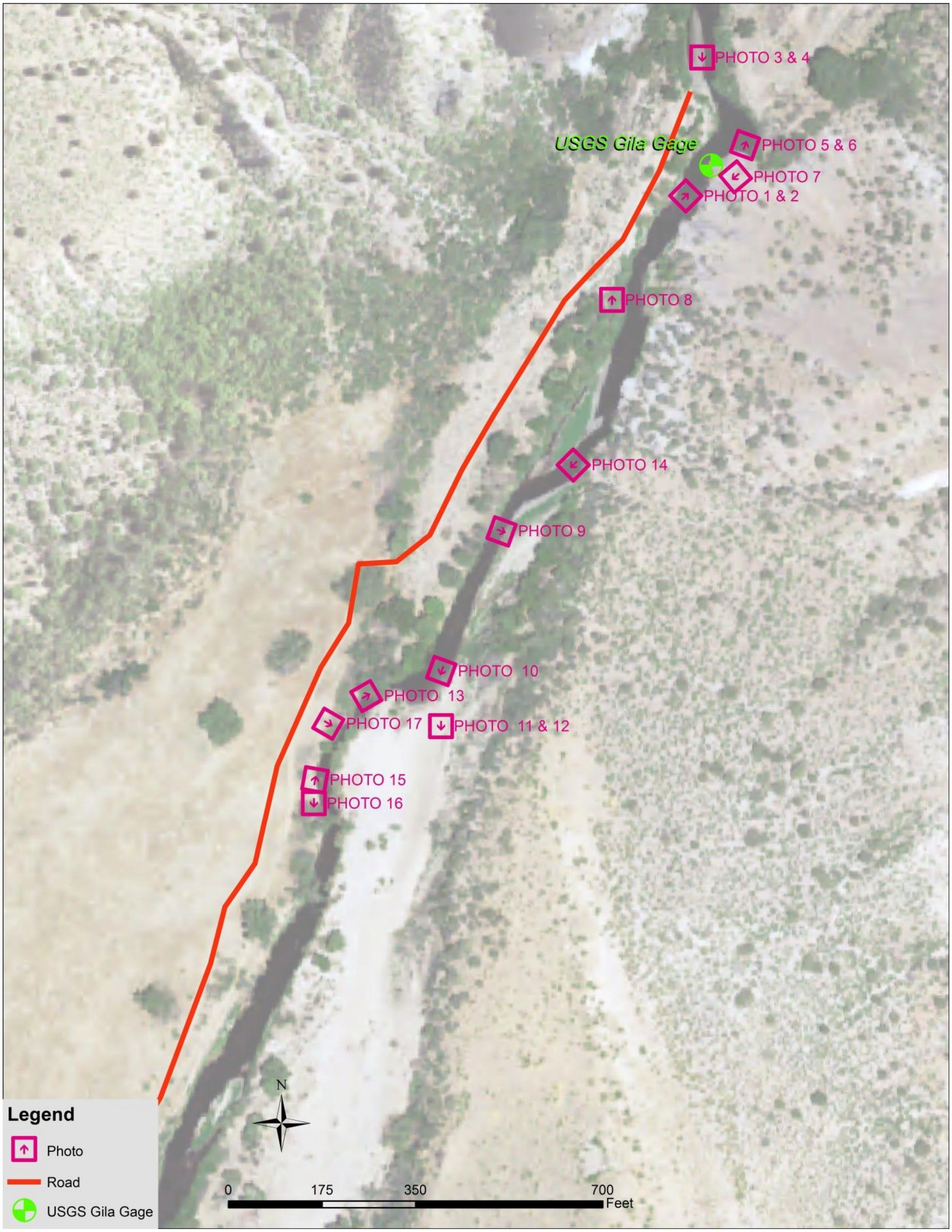

Figure 12 Map Describing the Location and Orientation of the Photographs Taken During the Site Visit

Photo 2 shows a close up of the 18 inch thick concrete wall, stilling well and staff gage. It can be seen that the bottom of the cast in place wall was originally formed by the native alluvium when the river channel was at a higher elevation. As this material washed away through the processes of degradation and channel widening the bottom of the wall was exposed and now hangs in the air, out over the bedrock shelf. A steel plate has since been bolted onto the face of the concrete wall presumably to protect the stilling well and staff gage from damage during high water events.

Photo 2 Looking Across the Channel (Northeast) at a Close-up of the Gila Gaging Station

Approximately 75 feet upstream of the Gila Gage, along river right (west), an active mid-channel alluvial bar was observed. This bar was predominantly composed of cobbles, gravels, and sands and had a sparse cover of riparian grasses and shrubs, which had been laid down by a recent overbank flooding event of approximately 1,290 cfs (Photo 3). The downstream end of this bar marks the approximate location of the proposed surface water diversion intake alternative. A relatively low secondary flow channel, which showed evidence of a recent overbank flooding event, was also observed at this location (Photo 4).

The entrance to this secondary channel connected to what appeared to be an elevated trench with intermittent earthen berms running along both sides. This is possibly the historic ditch used to deliver water to an abandoned agricultural field that was located on the alluvial terrace. Today however, the relative elevations of the Gila River channel and the ditch invert[8] would not allow for the capture of water during lower flows in the river. Streamflow in the channel on the day of the field visit was 75 cfs. At this time the observed water surface elevation in the channel appeared between 1.5 to 2 feet too low to allow spilling into the elevated ditch.

[8] The invert is the lowest flow line of a pipe, trench or tunnel; it can be considered the "floor" level.

Photo 3 Overview of the Gravel/Cobble Bar Located Along the Right (West) River Bank

Photo 4 Looking Downstream (Southeast) at the Downstream Extent of the Cobble/Gravel Bar and the Secondary Channel Inlet on River Right

Upstream of the Gila Gage, along the left (east) side of the channel, an abandoned alluvial terrace was observed (Photo 5). Similar to two downstream alluvial terraces, an apparent secondary overflow channel could be identified along the perimeter of the floodplain, at the toe of the adjoining hill slope. This channel was differentiated from the remainder of the terrace surface by a distinct change in vegetation species and type.

Photo 5 Looking Upstream (North) at the Abandoned Terrace Located Along the Left (East) River Bank

Photo 6 Looking Upstream (Northwest) from the Top of the Concrete Wall at the Gila Gage

Upstream of the stream gage, at the outfall of the elevated secondary channel, evidence of ongoing erosion/sedimentation was also observed (Photo 6). Here sandy deposits were observed below the water surface and evidence of ongoing erosion was identified at the outfall of the secondary channel. A distinct elevation difference, estimated between five and seven feet, was also observed between the invert of the river channel and the outfall of the elevated secondary channel. A Wolman pebble count was conducted on the riffle downstream of the stream gage (Photo 7), near the cross section established by the USGS cable car.

Photo 7 Looking Downstream (Southwest) at the Riffle Where the Wolman Pebble Count Was Performed

The stream channel was walked downstream of the Gila Gage for approximately 1/3 of a mile to assess the condition of the river bed and banks. Numerous bedrock outcrops were identified on river left in this reach along with more recent active channel bar formations. Along river right, the floodplain of the river was significantly elevated above the active channel and predominantly composed of upland vegetation species (Photo 8).

Photo 8 Looking Upstream (North) at the Floodplain along the Right Bank Downstream of the Gila Gage

Photo 8 shows one of the abandoned terraces on the left of the photo. Upland vegetation, such as rabbit brush, is evident in this field, along with dead riparian trees, indicating that the hydrology at this location has changed. The active channel is apparent on the right side of the photo. Growing along the active channel margin, a narrow band of thick riparian vegetation was observed. Evidence of the recent 1,290 cfs flooding event, occurring on September 9th 2016, could be seen by the laid down riparian vegetation (Photo 9), though this event did not achieve the stage of the adjoining floodplain. Willow and smaller (~12 inch diameter) cottonwood were observed growing near the water's edge, while larger (~24-48 inch diameter) Cottonwood and Sycamore were observed at the elevation of the historic floodplain. Construction scars from historic levee activity were also seen on the floodplain along with abandoned corrals for livestock and fencing.

Photo 9 Looking to the West at Recently Laid Down Vegetation along Active Chanel Margin

Photo 10 Looking Downstream (South) at Channel Bifurcation with the Elevated Historic Channel Alignment on Left Half of Image and Current Head of Incised Channel on the Right Half of the Image

Nearing the downstream end of the investigated reach, evidence of a historic channel avulsion[9] and headcutting was observed. Here, the active channel bifurcates, making an abrupt 45 degree angle turn to the southwest away from what appears to have been a historic alignment of the channel (Photo 10). The difference in elevation between the active channel and the historic channel is estimated at between three and four feet. The composition of the historic channel bed appeared similar to that observed at the location of the Wolman Pebble Count at the Gila Gage (Photo 11). It could also be seen that a recent high flow event accessed the historic channel, as evidenced by recently deposited sediments and ponding (Photo 12).

[9] A sudden cutting off of land by flood, currents, or change in course of a body of water; especially : one separating land from one person's property and joining it to another's

Photo 11 Looking at the Composition of the Dry Bed of the Historic Channel

Photo 12 Looking Downstream (South) at the Historic Channel Alignment of the Gila River, with the Active Channel Located Approximately 20 feet to the Right of the Photo

Below the entrance of the active channel at the bifurcation point a pseudo-stable headcut was observed. This headcut was identified by a locally over-steepened riffle, composed of uncharacteristically coarse sediments, which created an audible sound as the river rapidly descended approximately two feet over small boulders (Photo 13). At this location, the right bank is being impinged upon by the flowing channel and actively eroding below a large Sycamore tree. Undercutting of the tree has become so severe, the main trunk of the tree has fallen over creating a bridge over the channel and several smaller suckers now grow vertically from its base.

Photo 13 Looking North from Above at the Pseudo-Stable Head of the Incised Channel

Upstream of this avulsion the flowing channel ranged from 30 to 50 feet in width and one to three feet in depth at the time of the field visit (Photo 14). However, downstream in the incised reach the channel narrowed to roughly 20 to 30 feet in width and the depths increased to between two and four feet (Photo 15).

Photo 14 Looking Downstream at the Reach Just Upstream of the Bifurcation Point

Photo 15 Looking Upstream at the Incised Reach from Downstream of the Bifurcation Point

The banks within the incised reach also appeared excessively steep and unstable, particularly on the right where the bank is approximately 15 feet in height. Here, mature deciduous Sycamore trees were perched along the top of the right bank, overhanging the channel with undercut exposed roots (Photo 16). Several smaller Cottonwood trees and willow were also observed at the toe of the slope, although the majority of the bank was failing.

Photo 16 Looking Downstream at the Incised Reach from Downstream of the Bifurcation Point

Along the left (east) bank a smaller two foot bank was observed, stepping down from the elevation of the historic channel. Outside the active channel margin, the floodplain is composed of imbricated cobble and vegetated predominantly by upland species (Photo 17).

Photo 17 Looking East across the Incised Reach at the Historic Channel Bed that Today Composes the Active Channel Floodplain

The evidence obtained through this field investigation further supports the theory that channelization through the Cliff-Gila Valley together with large, infrequent flood events has resulted in the formation of one or more knickpoints, which have migrated as headcuts through the middle and upper sub-reaches. Over time riparian vegetation has reestablished along the incised channel, resulting in some bank stabilization. However, remnants of the headcuts are still visible in the upper sub-reach today. The river channel is incised and numerous unstable banks were identified. Riparian vegetation has reestablished along most of the active channel margins. However, many historic floodplains have been abandoned and are not inundated frequently enough to support hydrophilic vegetation. Large remnant trees are found on both the historic floodplain and ancient alluvial terraces. On the bank many of these trees are actively being undercut by the incised channel.

4. Diversion Structure Design

The following three conceptual diversion design alternatives have been developed, based on AECOM's review of the hydrologic and geomorphic conditions, sediment availability and supply and channel stability within the reach below the Gila Gage:

- Engineered riffle diversion;
- Obermeyer pneumatic gate diversion; and
- Combination Coanda screen and Obermeyer pneumatic gate diversion.

The following sections outline the alternatives assessment.

4.1 Identified Key Design Criteria

Based on AECOM's field inspection of the Gila Gage site and our experience designing diversion structures, the following key design criteria have been established for the conceptual design alternatives:

- All weather access;
- Available hydraulic head;
- Lateral and vertical channel stability;

- Structural stability;
- Accurate flow measurement:
- Sediment exclusion and continuity;
- Upstream fish passage; and
- Downstream recreational navigation.

The following sections discuss these key criteria.

4.1.1 All Weather Access

Access to the site is achieved via an existing 1.6 mile unimproved two-track road located at the end of County Rd 293. The current condition of the road is poor and vehicular travel is limited to high clearance off-road vehicles capable of navigating road grades in excess of 18% and hair pin turns with limiting turning radii of up to 25 feet. It is anticipated that future improvements to the road will be necessary to facilitate access for various construction, operations, and maintenance vehicles. Preliminary analysis of these improvements has been conducted to verify their feasibility.

Access to the site is further complicated by an unimproved crossing of Mogollon Creek, which is capable of producing large discharge events and is prone to severe bank erosion and channel avulsion. During the fall of 2016 the banks of Mogollon Creek were two to four feet in height and vertical at the crossing (Figure 13). Gage records of Mogollon Creek indicate peak discharges up to 10,800 cfs. During typical flow conditions the channel is often dry and an at-grade crossing with access improvements along the banks may be sufficient for future site access, however access during high flows will be impractical.

Figure 13 Vertical Bank at the Existing Crossing of Mogollon Creek

4.1.2 Available Hydraulic Head

This site is desirable for the diversion of flows from the Gila due to its elevation relative to proposed downstream storage facilities. Though other diversion locations upstream of this site exist, the Gila Gage site represents the highest diversion point below the boundary of the Gila National Forest. A diversion at this location would not be high enough to provide gravity flow to all of the proposed reservoirs, however, various pumping scenarios may be considered to deliver water to the higher elevation storage alternatives.

4.1.3 Lateral and Vertical Channel Stability

The geological and hydrological setting at the Gila Gage is favorable for a surface water diversion from a vertical and horizontal stability standpoint. The prominent bedrock outcrops limit the lateral mobility of the channel and establish relatively narrow bounds on its ability to migrate. Though the occurrence of bedrock is not uncommon upstream from this location, downstream the alluvial floodplains of the Cliff-Gila Valley tend to open to more expansive, less confined conditions. Because of the proximity to bedrock along both river banks lateral cutoff walls can be extended to key into the canyon walls, preventing the lateral flanking of the diversion structure during future flooding events.

Field observations of the vertical channel stability of the Gila Gage site suggest historic channel degradation of the reach. The following evidence of channel degradation was identified:

- Abandoned side channel immediately upstream of the USGS gage;
- Upland vegetation taking over alluvial terraces and bars;
- Observed active knickpoint at head of an incised reach;
- Steep unstable banks immediately downstream of the active knickpoint;
- Perched and undercut riparian vegetation (Sycamore): and
- An extension staff gage bolted to the historic USGS staff gage.

Addressing this historic and ongoing channel incision is critical to the design of the various conceptual project alternatives as well as the protection and restoration of the riverine ecology throughout the study reach.

4.1.4 Structural Stability

The bedrock found at the Gila Gage is hard durable volcanic rock that should provide adequate foundation for the diversion structure when in close proximity to the surface (US Bureau of Reclamation , 1969). Geological investigations conducted by the USBR, approximately 250 feet upstream of the gage site suggest the channel is composed of deep (~80 feet) alluvial deposits. Further investigation into the composition of the channel and depth to bedrock will guide the design of the diversion structure at this location. If bedrock is found to be in close proximity to the surface then the conceptual diversion structure alternatives can be keyed to bedrock. If the depths to bedrock are similar to those identified just upstream, vertical cutoff walls will need to be installed to sufficient depth to eliminate the potential for piping and compaction of the subgrade will be required to prevent settlement.

4.1.5 Accurate Flow Measurement

Accurate measurement of flows in both the river and the conveyance lines will be critical to meeting requirements set forth by the CUFA. It is recommended that acoustic Doppler flow meters be included in the designs at control sections to ensure accurate measurement of depth and velocity for precise stream gaging. The construction of the diversion structure will provide a more stable cross-section at this location providing the opportunity to enhance the accuracy of existing stream gaging activities at the site. Additional coordination with the USGS is anticipated as part of future phases of the project.

4.1.6 Sediment Exclusion and Continuity

AECOM's conceptual level analysis indicates that sediment transport rates may be quite high during annual and even semiannual flood events. It is also believed that relatively low discharge events on the order of 150 cfs will be sufficient to mobilize the smaller silt and sand sized fractions of the bed, while gravels and cobbles are likely to be entrained during flows around 1,200 cfs (AECOM, 2016). Due to the relatively high mobility of the bed during these various flow events, it will be critical to exclude as much of the background sediment supply from this intake and bypass it within the reach. Intake facilities must be capable of excluding the larger bedload material while smaller suspended sediments must actively be sluiced. Configurations including bedload deflector sills and screens should be coupled with sediment sluices to prevent siltation of the intake and conveyance lines. This will be critical to various conveyance, storage, and pumping scenarios to minimize future maintenance requirements.

To ensure the long-term function of the diversion structure sediment continuity within the reach must also be taken into consideration. Aggradation of the bed, both upstream and downstream of the diversion structure, can affect the diversion of flows and require future maintenance activities. For this reason, the structure must anticipate and actively prevent the accumulation of background and sediments derived locally from within the reach. Achieving sediment continuity will be critical in establishing a durable structure capable of providing continued operations into the future.

4.1.7 Upstream Fish Passage

Federally listed aquatic species may be affected by construction of a diversion or other activities in or adjacent to the Gila River. Impacts from diversions typically include changes to the timing or amount of surface water flows or the creation of physical barriers to upstream movement. In general, factors affecting the upstream passage of fish include both depth and velocity limiting conditions. The diversion structure's ability to meet explicit published criteria for upstream fish passage will be critical to the evaluation of potential environmental impacts to aquatic habitat.

Various methods have been shown to successfully move fish over passage barriers. The proposed conceptual alternatives described herein are intended to generate hydraulic conditions that do not create velocity or depth limiting conditions for the species of interest. Additional modeling will be critical to demonstrating the conceptual project alternatives ability to meet published standards for burst speeds and minimum required depths.

4.1.8 Downstream Recreational Navigability

American Whitewater (2016) provides a description of the recreational rafting run through this reach (see "Visitor to Mogollon Creek"). This run is a remote wilderness rafting trip measuring 39 miles in length. This run is rated as a class II-III suggesting minimal to moderate difficulty though emergency evacuation opportunities are limited, requiring a multi-mile hike out on foot. The section is typically run when flows at the Gila Gage range between 200 and 1,200 cfs. The typical put-in is at the Highway 15 bridge crossing approximately 39 miles upstream. An alternate put-in at the Grapevine campground on the East Fork also exists, pending available flows. The normal take-out for this run is at the Mogollon Creek Campground located just past the confluence of Mogollon Creek and the Gila River. (American Whitewater, 2016)

Instream recreational activities in the Upper Gila River are typically performed using inflatable rafts, hard-shell and inflatable kayaks, and whitewater canoes. The run is usually boated in the spring on average snowpack years during peak runoff or for an extended season during years with above-average snowpack. It would also be possible to navigate the run during the summer-fall monsoon season, though the extreme variability of flows would require more precise trip planning and timing. Due to the remoteness of the area, this section of river is typically run as a self-supported multi-day trip with overnight stays occurring at various unimproved campsites along the way. In general river users of this run are knowledgeable of safe river practices and navigation, though some private trips may include less experienced group members.

Historically, man-made diversion structures limited the recreational use of many rivers by creating dangerous hydraulics below a diversion structure. To protect this existing use and create additional recreational benefits, instream structures shall be designed to provide safe passage to whitewater rafts and other forms of river craft by establishing clear and obvious lines through which to navigate throughout the range of flows anticipated in these reaches as well as limiting the formation of dangerous hydraulic jumps along the downstream edge of the structure. Various design guidelines have been developed by the Colorado Water Conservation Board (CWCB) and other groups to assist in the "planning, design and construction of structures such as low-head dams, drops, chutes, bridges and armoring mandate a standard of care consistent with common sense safety concerns for the public that responsibly uses the rivers and waterways" (CWCB, 2008). AECOM engineers have specific experience designing diversion structures for safe boat passage.

4.2 Conceptual Project Alternatives

All three conceptual alternatives meet the key design criteria established for this project; however variations in the design, adjustability and configuration affect the degree to which these alternatives can function. It is assumed that all three diversion alternatives will require external power supplies to regulate various components of the diversions and intakes allowing for automation of the diversion structure. Preliminary, conceptual engineering drawings for each of the alternatives are presented in Appendix A.

4.2.1 Engineered Riffle Diversion

The first conceptual project alternative is an engineered riffle diversion (Figure 14). The invert of this diversion structure has been set to an elevation ranging from 4662 to 4666 feet and could be constructed of either boulder or cast concrete while providing the similar function. The final elevation will depend on the outcome of hydrogeological analyses, hydraulic modeling, sediment transport modeling, and incorporation of the stream channel restoration alternative that would elevate the river channel within the project reach.

Components of the diversion structure will include:

- Grouted boulder or cast concrete sill;
- Cast concrete headwalls and wing walls;
- Grouted boulder or cast concrete cutoff walls;
- Riprap bank protection;
- Flow measurement equipment; and
- Elongated alluvial rundowns.

Components of the intake structure will include:

- A bedload deflector sill;
- A debris exclusion trash rack;
- A fish exclusion screen;
- An automated headgate;
- A suspended sediment sluice;
- Flow measurement equipment; and
- A Surface conveyance canal.

Figure 14 Engineered Riffle Diversion Kremmling, CO

The primary benefit of the engineered riffle diversion alternative is its lower cost to construct as compared to pneumatically adjustable gates and Coanda screen intakes. This configuration also has fewer mechanical systems to maintain and reduced associated infrastructure and power supply requirements. This diversion configuration is also the most conducive to downstream recreational navigation and visual aesthetics. This conceptual diversion alternative is also beneficial in the creation of aquatic habitats and provides opportunities for upstream fish passage for a range of species and life stages.

The primary disadvantage associated with this diversion type is its inability to adjust vertically, based on diversion requirements and externally imposed sediment inputs. More detailed hydraulic design will ensure fish passage opportunities with this configuration. A primary goal of all structures will be to balance depth and velocity limiting conditions to ensure fish passage. To achieve this goal, further analysis and design of hydraulic conditions created by the structure will be critical to fish mobility in the reach. This diversion type will also be less conducive to flood conveyance and will generate higher headwater elevations as compared to at-grade and adjustable diversion configurations. Under more extreme flooding scenarios, this structure may be more prone to sedimentation challenges and require greater degrees of in-channel maintenance to ensure continued future operations.

4.2.2 Obermeyer Pneumatic Gate Diversion

The second conceptual project alternative is an Obermeyer pneumatic gate diversion (Figure 15). The base concrete pad for this diversion structure alternative is set roughly at grade with the existing bed of the river channel (4660 feet) or at a maximum anticipated channel elevation (4664 feet). The height of the gates when elevated is assumed to be two feet (24 inches), raising the diversion elevation to between 4662 to 4666 feet, sufficient to achieve an equivalent headwater condition as compared to the engineered riffle alternative. Ultimately the selection of the diversion height will depend on the outcome of hydrogeological analyses, hydraulic modeling, sediment transport modeling, and incorporation of the stream channel restoration alternative that would elevate the river channel within the project reach.

Components of the diversion structure will include:

- Cast concrete sill;
- Cast concrete headwalls and wing walls;
- Cast concrete cutoff walls;

- Riprap bank protection;
- Flow measurement equipment;
- Adjustable steel gates; and
- Supporting mechanical infrastructure.

The intake structure will include:

- A bedload deflector sill;
- A debris exclusion trash rack;
- A fish exclusion screen;
- An automated headgate;
- A suspended sediment sluice;
- Flow measurement equipment; and
- A Surface conveyance canal.

Figure 15 Albuquerque Diversion Dam (http://mapio.net/pic/p-5170793/)

The primary advantage of the Obermeyer pneumatic gate diversion compared to the engineered riffle diversion is the adjustability of the invert to meet diversion requirements and external sediment inputs. Because of the diversion structure's ability to raise and lower the headwater elevations as needed to supply the intake facilities, the sill of the structure can be set at grade with the surrounding bed as compared to the engineered riffle which must be elevated above the surrounding bed. In this way the gates can be lowered to promote sediment flushing and fish passage at flows below 150 cfs when diversion activities are not occurring. Conversely, the gates can be raised to elevate the headwater in the channel sufficient for diversion then lowered again as the channel stage naturally achieves the intake elevation or during flood scenarios when bypass of sediment laden flows is critical. This dynamically adjustable configuration can also be varied laterally across the structure alternating raising and lowering different gates to create a break in the gates to promote fish passage, recreational navigation, and sediment flushing.

The primary disadvantages to the Obermeyer pneumatic gate diversion configuration are related to its cost of construction and maintenance requirements. Due to the added mechanical infrastructure, including hinged steel gates, pneumatic bladders and lines, redundant power supply, compressor systems, electronic operations controls, and mechanical systems housing facilities the cost associated with this configuration are significantly greater than that of a more typical fixed invert configuration. Moreover, maintenance of these mechanical systems will also be required, though the added cost must also take into account the reduction in the site maintenance requirements created by the sediment flushing capabilities of the system. Additional anticipated components of the pneumatic gates system will be a secondary power supply to ensure operations of the gates even during severe weather and flooding events that could impact primary power supplies to the site. Diesel generators are often used for redundant power supply ensuring the proper all weather function of these facilities.

4.2.3 Combination Coanda Screen and Obermeyer Pneumatic Gate Diversion

The third conceptual project alternative is a combination of an at-grade Obermeyer pneumatic gate diversion and a partially elevated Coanda[10] screen diversion (Figure 16). The invert of this diversion structure is also set roughly at grade with the existing channel bed (4660 feet) or maximum proposed channel bed (4664 feet). A secondary, stepped section of diversion will be elevated roughly one to two feet above the channel invert. This elevated portion of the diversion will house the Coanda screens, and provide self-cleaning sediment screening from the channel bed. Similar to the Obermeyer pneumatic gate diversion, the final diversion invert height can be set at any point within this range depending on the outcome of hydrogeological analyses, hydraulic modeling, sediment transport modeling, and opportunities for stream channel restoration. The height of the gates when elevated is also assumed to be two feet (24 inches) and will be capable of producing an equivalent headwater condition as compared to the engineered riffle alternative or standalone Obermeyer pneumatic gate diversion.

Components of the diversion structure will include:

- Cast concrete sill;
- Cast concrete headwalls and wing walls;
- Cast concrete cutoff walls;
- Riprap bank protection;
- Flow measurement equipment;
- Approx. 1 mm Coanda screens; and
- Supporting mechanical infrastructure.

The intake structure will be set below grade and will include:

- Water collection vaults;
- Suspended sediment settling facilities;
- An automated headgate;
- Flow measurement equipment; and
- A subgrade conveyance culvert.

[10] "Coanda-effect screens offer an economical means for removing debris at small…intakes. The screens remove debris from a supercritical flow that passes over a wedge wire screen panel installed with wires oriented horizontally, perpendicular to the flow direction. Individual wires are tilted so that the leading edge of each wire projects into the flow, causing the screen to shear a thin layer of the flow from the bottom of the water column at each slot opening. The screens are largely self-cleaning, with a high flow capacity and minimal need for routine maintenance. This makes them especially useful for remote sites. Capacity of Coanda-effect screens has been related in the past to basic hydraulic parameters, such as the Froude, Reynolds, and Weber numbers of the flow over the screen." (Wahl, 2013). See US Bureau of Reclamation Coanda-Effects Research page for additional information: https://www.usbr.gov/tsc/techreferences/computer%20software/software/coanda/index.html

Figure 16 Coanda Screen Diversion on Brandywine Creek British Columbia[11]

The primary advantage of the combination Coanda screen and Obermeyer pneumatic gate diversion is in its ability to actively exclude coarse sands, gravels, and cobbles, fish, and debris from intake facilities. As sediment laden water flows over the approximately 1 mm screen openings, the coarser sand sized fraction of the suspended load and bedload will be excluded from water entering the collection vaults. However, smaller sand sized particles along with silts and clays will pass through the screen. This diversion is also well suited for fish passage and recreational navigation. By including an Obermeyer pneumatic gate configuration as part of the diversion infrastructure, the invert elevation will be adjustable to respond to diversion requirements and external sediment inputs. The invert of the structure will also be set at grade with the surrounding bed to promote sediment flushing and fish passage when the diversion is not in operation. During diversion operations, the gates can be raised incrementally to increase the headwater in the channel forcing flows over the Coanda screens. However, once flows naturally inundate the Coanda screens, the gates can again be lowered to facilitate fish passage, flood conveyance, and recreational navigation. This dynamic adjustability can again be implemented laterally across the gate array, within the at-grade invert, for added sediment flushing capabilities.

The primary disadvantages of the combination Coanda screen and Obermeyer pneumatic gate diversion configuration are again related to its cost of construction and maintenance requirements. Due to the added Coanda screen componentry coupled with the requirements for all mechanical infrastructure associated with the Obermeyer pneumatic gates, this alternative is believed to be the most expensive to construct and has additional maintenance requirements beyond those of just the pneumatic gates. The fixed Coanda screen invert elevations provide less

[11] (http://www.elginindustries.com/equipment_group/norris_screen/products/product_line/Norris_Screen/stainless_steel_screening_systems/coanda_screen)

adjustability as compared to the full pneumatic gate array and may also trigger additional in-channel sediment management requirements. Moreover, sediment management within the water collection vaults will pose logistical challenges and the lower elevation of the delivery lines will also reduce available head. Secondary power supplies are also anticipated for this diversion, to ensure all weather adjustability of the structure even during extreme flooding and weather events.

4.3 Alternative Stream Restoration Component

Today the Gila River is actively evolving toward a new stable channel form that is in balance with its background sediment supply and hydrologic regime. However, this new degraded form has produced an incised channel with steep unstable banks and numerous disconnected floodplains and subsequently reduced riparian vegetation extents and health. Though new native riparian vegetation is recovering in the Gila Gage reach, its extent is limited to the active channel margins due to the reduced rates of floodplain inundation and accelerated rates of groundwater decline and availability. The incised channel condition actively limits the recovery of critical avian and aquatic habitats, and reduces the river channels resiliency during future flooding scenarios. For this reason restoration of the river is being considered to enhance the function of the diversion and the stability of the channel as well as to benefit aquatic and riparian habitats.

Restoration of the Gila River downstream of the Gila Gage would include the installation of discrete structures to re-elevate the river channel to a less incised condition to reconnect the stream to the abandoned floodplain. The configuration and downstream extent of the restoration activities will be based on additional analyses. The stream restoration activities will be designed to function within the natural pool rifle morphology of the channel and provide opportunities for fish passage and recreational navigation. Replanting of native riparian vegetation to stabilize the channel banks and revegetate the newly reconnected floodplains that have been lost to the channel incision.

Restoration of the river below the Gila Gage would provide the opportunity to partially reverse the morphological change in the river channel that has occurred over the past century. Extensive grazing, agriculture, diversion, and channelization have altered the historic form of the Gila River, creating an incised condition that has disconnected the river from large portions of its historic floodplain. Though sufficiently large flood events still inundate these floodplains, it does not occur frequently enough and groundwater conditions do not persist long enough to recruit new riparian vegetation that is sensitive to rates of groundwater decline, except in limited areas along the active channel margin or on side channels. Moreover, the lowered primary channel actively dewaters historic floodplains and side channels reducing the prevalence of saturated conditions and promoting the transition from riparian to upland species observed throughout the reach.

Reestablishment of more robust and expansive riparian communities along the river will produce a more stable river channel that is less susceptible to erosion, bank failure and avulsion during future flooding events. These benefits are realized through floodwave attenuation, overbank flood storage, and the reduction of shear stresses both in the channel and on the banks and floodplain.

Threatened and endangered species in the region will also benefit from aquatic and riparian habitats improvements. Existing failing banks create reduced water quality and siltation issues. Diminished floodplain area reduces opportunities for critical nesting habitat for migratory birds. Persistent erosion of the banks is actively threatening several mature Sycamore trees in the reach and creating a scenario for significant bank exposure and damage pending a catastrophic failure.

5. Recommended Path Forward

AECOM believes a reliable diversion can be constructed at the Gila Gage site to deliver CUFA water. It is recommended that additional investigations and analyses be conducted to further refine the conceptual level designs as part of future project tasks. Final design configurations will be dependent on the outcomes of these investigations.

5.1 Fluvial Geomorphology

Additional fluvial geomorphic analysis will be critical to understanding the mechanisms of observed vertical instabilities within the diversion reach and their implications on the configuration and location of the various project alternatives and components. These studies will inform the understanding how the current form of the river has been influenced by past hydrologic and sediment transport events as well as channel modifications. Understanding the stability of the present day channel will be paramount to the selection of appropriate engineering methods for diversion, conveyance and water storage. Selection of appropriate techniques will be critical to ensuring the long term function of the conceptual project alternatives and their components.

5.2 Hydraulic Modeling

Hydraulic modeling will provide estimates of water surface elevations throughout the diversion reach and specifically at the diversion structure and intake. These analyses are critical to predicting the function of the diversion throughout the range of desired flows as well as understanding the implications of the diversion to overbank flooding and structural stability. Additional multidimensional hydraulic modeling will further inform the structure design for navigation and fish passage. These conditions require more complex three dimensional hydrodynamic analyses, which govern the formation and subsequent character of hydraulic jumps potentially created below the structure as well as limiting velocities and depths related to the upstream passage of fish.

5.3 Sediment Transport Modeling

Sediment transport modeling will provide increased understanding to reach-wide sediment continuity of the proposed conditions designs as well as more localized erosion and sedimentation in and around the facilities. Additional analysis will be critical to predicting thresholds for incipient motion, channel and bank stability, particle mobility and exclusion, maintenance requirements and channel aggradation/degradation.

5.4 Foundation Investigation

An existing geotechnical study near the Gila Gage site was conducted by the USBR as part of a feasibility analysis for the Hooker Dam. Additional geotechnical and geophysical site investigations will be needed to further characterize the composition of the river bed for the design of the diversion foundation and cutoff walls. It is anticipated that these studies will entail geotechnical drilling, geophysical testing, geotechnical samplings, and desktop seepage and stability modeling.

5.5 ASR Investigations

Continued investigation into the applicability of ASR below the Gila Gage site will further inform the design of the diversion structures. Hydrogeologic testing of the alluvial terraces will dictate configurations for water delivery and infiltrations systems. The current design alternatives present a range of invert elevations and subsequent water surface elevations at the diversion intake structure. Depending on the implementation of the alternative stream restoration project component, the corresponding water surface elevations may be increased up to as much as four feet, which will affect the design of delivery and infiltration systems within the ASR fields and the elevation to which the water will need to be delivered.

5.6 Stream Restoration Evaluation

The ability to re-elevate the incised channel will create opportunities to:

– Restore stable channel geometries;
– Reduce the height and slope of over-steepened banks;
– Reconnect abandoned floodplains;
– Raise the shallow water table; and

– Reestablish native riparian communities.

The benefits of restoration are to improve overall river function and diversion operations through the enhancement of vertical and lateral channel stability and the promotion of sediment continuity within the reach. These enhancements will directly benefit both federal and state listed species through the restoration of aquatic and riparian habitats in the reach. Benefits to river based recreation in the reach will also be obtained through the management of existing hazards observed downstream in the reach.

Further evaluation into the feasibility of stream restoration activities will provide critical detail into the final configuration and anticipated function of the Gila Gage diversion. Instabilities identified in the reach described herein present challenges to the successful design and implementation of the conceptual projected alternatives. Ecological restoration of the river channel will address these instabilities and improve diversion function. Additionally, significant benefits to the river function, aquatic and riparian ecology, and recreational navigation will also be realized. AECOM recommends further investigation into the benefits of an alternative stream restoration project component.

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Appendix A Diversion Concept Alternatives

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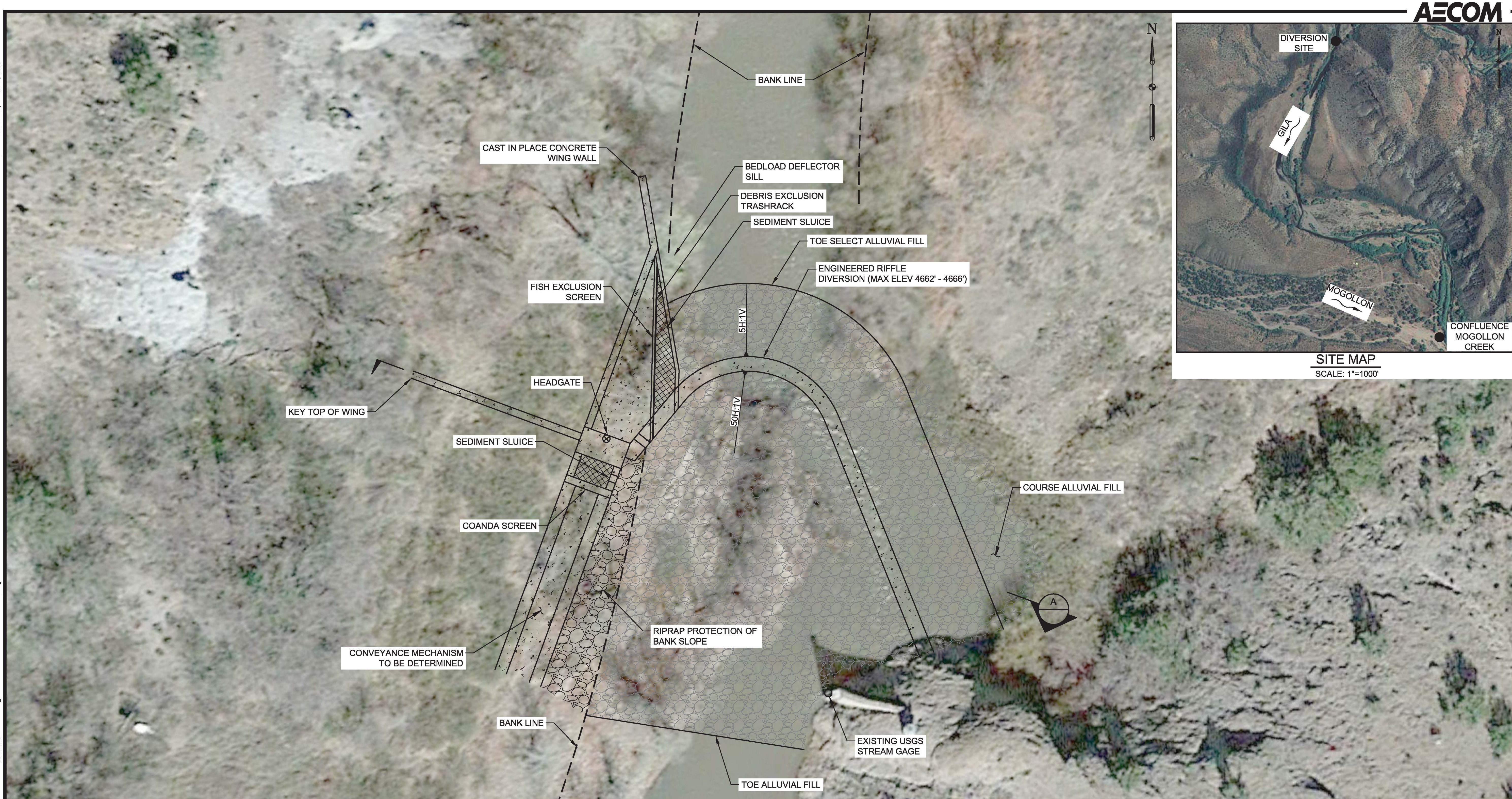
AECOM



PLAN

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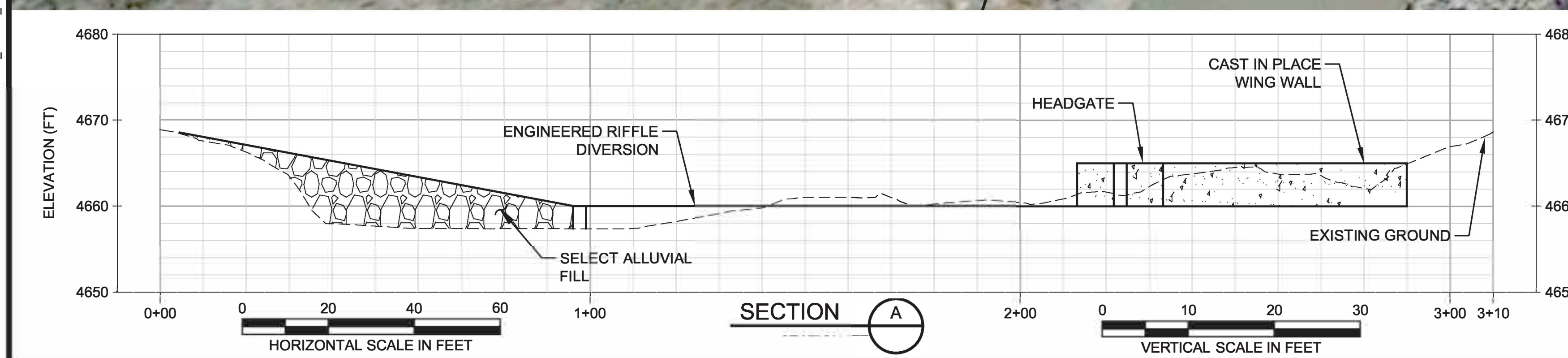
HORIZONTAL SCALE IN FEET



SECTION A

Note: All designs are conceptual and the locations and elevations shown are approximate. Final designs are pending further analyses to be conducted at a later date.

Job No. :	60504989	UPSTREAM ENGINEERED RIFFLE DIVERSION
Prepared By :	BAT	
Date :	1/6/2017	Page 43 of 46

DRAWING PATH: C:\0-Documents\AECOMM Drive\60504989_NMCAP_30\900-Work\910-CAD\20-SHEETS\09_EXHIBITS\ENGINEERED RIFFLE OP1.dwg

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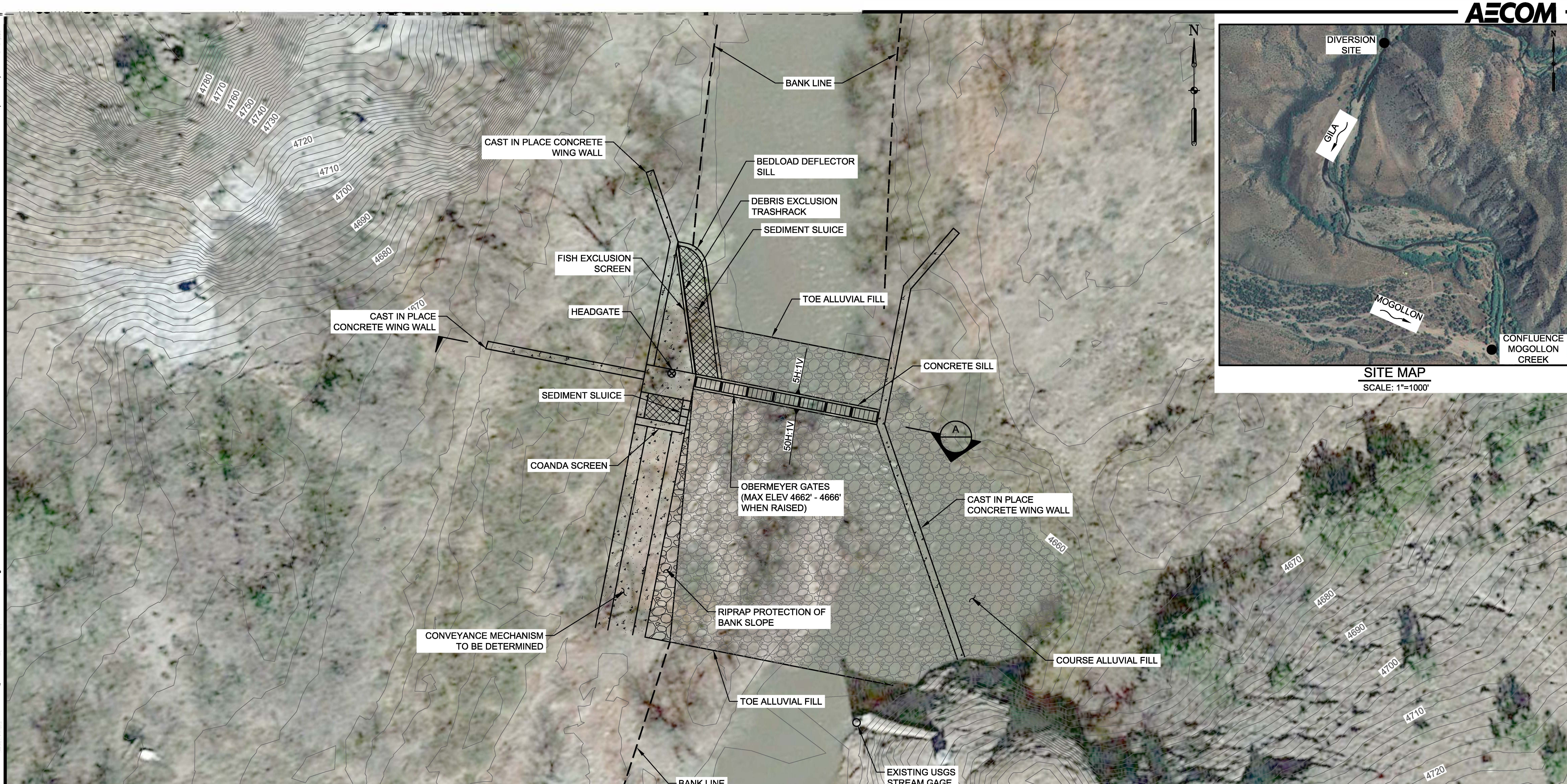

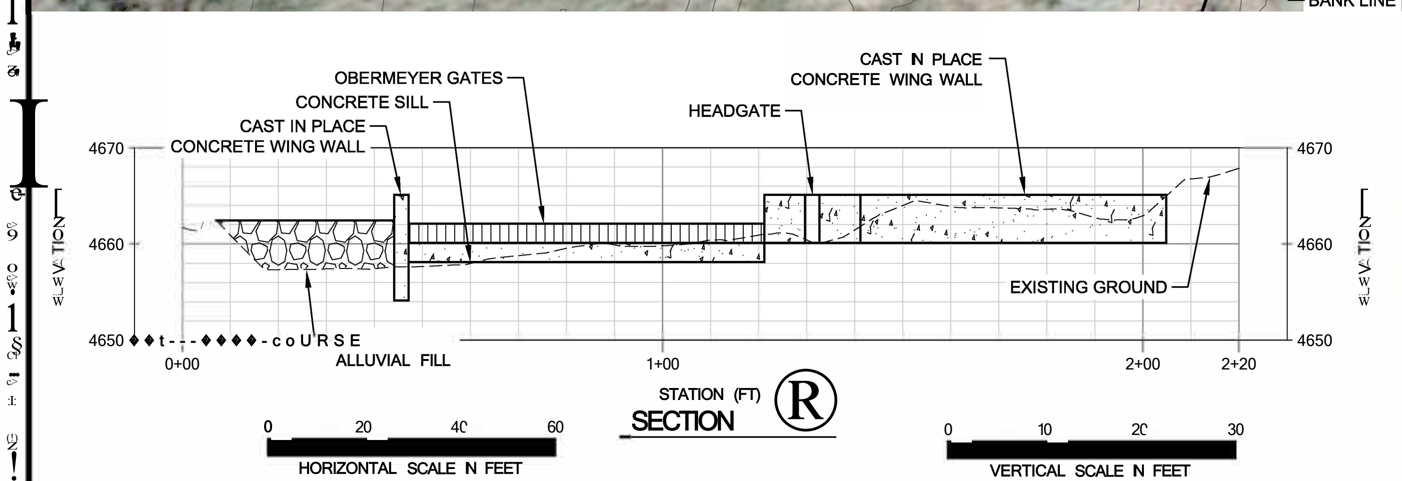

Job No.:	60504989	UPSTREAM OBERMEYER PNEUMATIC GATE DIVERSION
Prepared By :	BAT	
Date:	1/6/2017	Page 44 of 46

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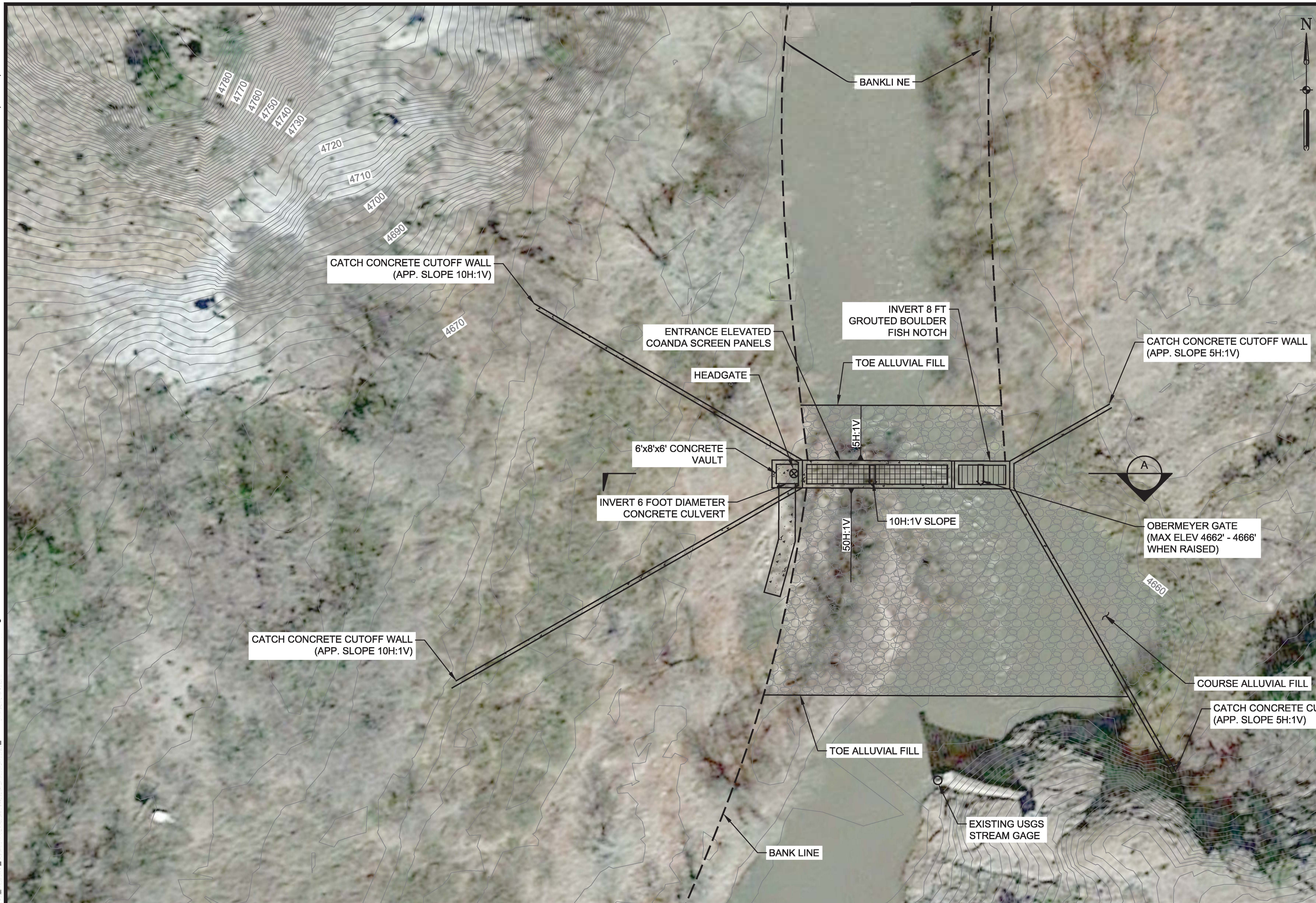


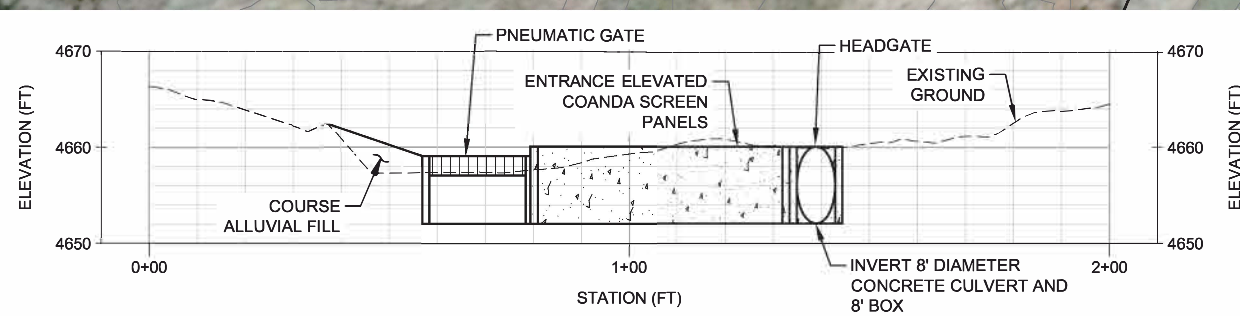
SITE MAP

SCALE: 1"=1000'

PLAN

0 20 40 60

HORIZONTAL SCALE IN FEET



0 20 40 60

HORIZONTAL SCALE IN FEET

SECTION (A)

0 10 20 30

VERTICAL SCALE IN FEET

Note: All designs are conceptual and the locations and elevations shown are approximate.
Final designs are pending further analyses to be conducted at a later date.

Job No. :	60504989	UPSTREAM COANDA SCREEN DIVERSION
Prepared By :	BAT	
Date :	1/6/2017	Page 45 of 46

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