Date:	June 29, 2016
Prepared For:	Rosemont Copper Company
By:	Water & Earth Technologies, Inc.
Subject:	Response to Technical Memorandum dated July 27, 2015 by Dr. Mathias Kondolf and James Ashby

1.0 Introduction

WET has been contracted by Rosemont to provide this response to the technical memorandum produced by Dr. Mathias Kondolf and James Ashby for Robert Leidy of the EPA. On October 30, 2014 WET met with the EPA and their contractors (authors of the technical memorandum) on site at Sonoita Creek to walk the conceptual design in the field. The purpose of the site visit was to help the EPA and their contractors understand the principles behind the conceptual design, and to collect constructive feedback from the EPA on improving the conceptual design. After the site visit, the Kondolf-Ashby team reviewed the conceptual design (WET, 2014) pertaining to the Sonoita Creek Mitigation Project and prepared a technical memorandum dated July 27, 2015 that summarized their review.

During the October site visit, WET had discussions with the EPA and their contractors about possible negative consequences of implementing the conceptual design. Based on these discussions, discussions with the US Army Corps of Engineers (ACOE), and additional insights WET gained through the site visit, several key changes were made to the conceptual design to improve its overall functionality (Attachment 1).

Additionally, WET added Dr. Brian Bledsoe, P.E., Ph.D., to the team to complement our expertise in the areas of sediment transport and fluvial geomorphology. Dr. Bledsoe is a professor of Civil and Environment Engineering at Colorado State University who has over 25 years of experience as an engineer, hydrologist, and environmental scientist. Dr. Bledsoe has research experience in hydrology, hydraulics, fluvial geomorphology, and ecosystem restoration. Dr. Bledsoe reviewed the conceptual design and visited the site to make preliminary observations and recommendations. Following his initial site visit, Dr. Bledsoe acted in a collaborative role providing input to WET for developing and implementing a field sampling and surveying program. With Dr. Bledsoe's input, WET modified the conceptual trapezoidal channel design to incorporate terraces that better emulate the channel characteristics noted in the ecologically functional reaches of Sonoita Creek. He was present during an additional site visit and helped WET identify and conduct a sampling and survey program coupled with more robust hydrologic, and hydraulic modeling to support the design changes. Following the field sampling program, Dr. Bledsoe provided direction to WET for hydrologic, hydraulic, and sediment transport analyses that drew upon the field data to support several design revisions.

WET disagrees with several findings in the Kondolf-Ashby memo; however, WET does agree with some of the findings described in the memo and has incorporated or otherwise addressed those findings in the detailed engineering design being developed for construction. The detailed engineering design is mostly complete and the design changes will be discussed where relevant to respond to the findings presented in the Kondolf-Ashby memo. The eight findings from the Kondolf-Ashby memo and WET's responses to the findings are discussed below.

1.1 Response to Finding 1

Finding 1: The hydrologic modeling significantly overestimates the water available for Sonoita Creek and the proposed constructed channels.

Kondolf-Ashby state that WET overestimates **peak discharge** for the project by 2-3 times, but their analysis clearly illustrates that **the ratio of peak discharge to watershed area** at the project is roughly 2-3 times larger than the **ratio of peak discharge to watershed area** at the USGS Patagonia gage located about 7 miles downstream of the project, and infer that discharge increases linearly with watershed area. However, literature and hydrologic models demonstrate that discharge does not increase linearly with watershed area for medium to large watersheds (such as this project) in the arid southwest. In fact, a recent EPA technical report (Levick et al., 2008), which was co-authored by Robert Leidy of the EPA, notes this relationship and references several papers that demonstrate the non-linear relationship between discharge and watershed area. The non-linear relationship results from three factors: spatial and temporal variability of monsoonal precipitation, transmission losses, and flow attenuation. Further analysis of this can be done by considering the USGS regional regression equations for estimating discharge in ephemeral streams in Arizona (Paretti et al,. 2014). The USGS has subdivided Arizona into 5 flood districts based on their basin characteristics and rainfall-runoff response. Sonoita Creek is located in Flood Region 5. Discharge was calculated with the applicable USGS regional regression equation for the three sites used in the Kondolf-Ashby memo, and then discharge from each site was divided by watershed area to illustrate the non-linear relationship discharge has with watershed area (Table 1 & Figure 1).

Table 1 Unit Flood Discharges (cfs/mi2) From USGS Regression Equations

Return Interval (yr)	Sonoita at Patagonia Gage	Sonoita at Harshaw Cr Confluence	Sonoita at Project Design Point
100	87.8	113	231.6
50	66.5	85.3	173.3
10	29.4	37.4	74.9
5	18.2	23.2	46.1

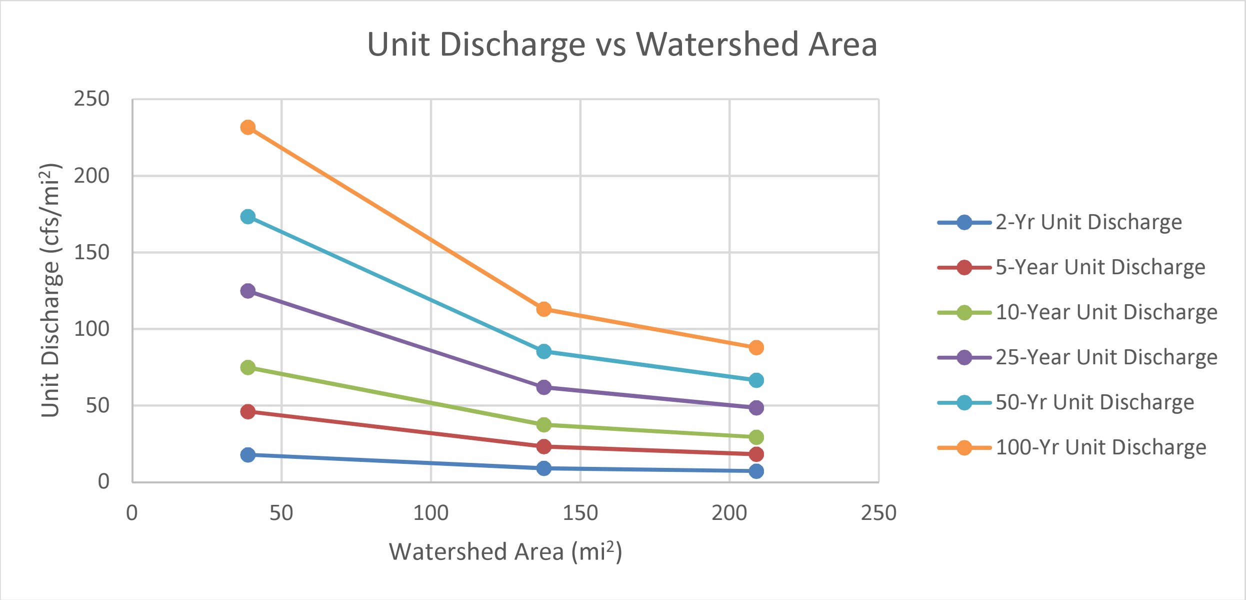

Figure 1. Unit Discharge vs Watershed Area for Sonoita Creek from USGS Regression Equations.

Unit discharges from the USGS Regression Equations also demonstrate that the ratio of discharge to watershed area at the project is roughly 2-3 times larger than the ratio of discharge to watershed area at the USGS Patagonia Gage.

For the conceptual design, WET compared peak discharges calculated using the double unit hydrograph subroutine method in SEDCAD software and the SCS dimensionless triangular unit hydrograph subroutine in the HEC-HMS software. Peak discharges predicted with the HEC-HMS software were 34% to 38% higher than discharges predicted using SEDCAD. WET believes that peak discharges calculated using SEDCAD were more representative of actual conditions during a storm event and opted to use those lower flows for design purposes. After completion of the conceptual design, WET conducted two additional hydrologic analyses to corroborate these results. The additional analyses were the Clark Time-Area Method, and the USGS regression equation method. Results of these methods are shown in Table 2.

Table 2. Calculated Peak Discharges (cfs) at the Sonoita Creek Ranch for Selected Recurrence Intervals

Return Interval	SEDCAD	Clark Time-Area Method	USGS Regression
2-Year	1463	1578	693
5-Year	2513	2648	1783
10-Year	3486	3620	2899
25-Year	4920	5041	4830
50-Year	6075	6181	6706
100-Year	7345	7428	8962

The Clark Time-Area Method considers the spatial characteristics of a watershed in its development of a synthetic unit hydrograph. The model describes the relationship between the travel time to the watershed outlet from any other location within the watershed. This relationship is based on the estimated velocity of the direct runoff. Calculated flows are routed through a linear-reservoir to account for basin storage effects. Until recently, time-area methods have been underutilized in engineering applications since the computational power needed to determine its parameters is so large. Software advances have made this type of analysis feasible.

The USGS regression equations are essentially empirical relationships of discharge vs watershed area specific to this region in Arizona. The empirical relationships were developed from gage data at 73 sites in Arizona hydrologic region 5. The SEDCAD method predicts discharges that range between the values calculated with the Clark Time-Area Method and with the USGS regression equations for the 10-year and 25-years storms, which are considered the most influential storms regarding channel forming processes and channel design for this project. Therefore, WET is confident that the values used for channel design and inundation area calculations are representative of conditions experienced during actual storm events. The values used for channel design, and for inundation area calculations are those derived from the SEDCAD double triangle unit hydrograph. While the USGS does report smaller flow values for the smaller recurrence storms (2, 5, 10 year), there is evidence that the USGS values under-represent discharge in those ranges.

Consider the following analysis at the downstream gage located on Sonoita Creek at Patagonia (Table 3). A Log-Pearson Type III (LPIII) analysis was conducted on the gage data, and discharge was computed for several recurrences and compared to the USGS regression equation applied at that point. Again, the USGS regression equation significantly under-predicts gage data for storms events up to about the 10-year storm event.

Table 3. Discharge Comparison at USGS Gage near Patagonia

Return Interval	USGS Gage Data LPIII Analysis (cfs)	USGS Regression Equation (cfs)
2-Year	2911	1513
5-Year	5861	3814
10-Year	8220	6143
25-Year	11562	10132
50-Year	14263	13900
100-Year	17094	18349

Lastly, WET conducted a rainfall-runoff analysis of the July 27, 2014 storm event that occurred in the project area (WET, 2015). A USGS rain gage located near the mouth of Big Casa Blanca Canyon (tributary to Sonoita Creek at the mitigation project site) recorded a 24-hour total of 2.76 inches on July 27, 2014. Based on rainfall data from NOAA Atlas 14, this storm was between a

2-year (2.30 inches) and a 5-year (2.86 inches) 24-hour storm event. A forensic hydraulic analysis of high water marks was conducted independent of the rainfall analysis. Peak discharges for the 2-year, 24-hour and the 5-year, 24-hour storm were estimated for the high water mark location using the SEDCAD method. Peak discharge was also estimated for the July 27, 2014 rainfall event using the measured rainfall as input. Those peak discharges were then simulated in HEC-RAS at the high water mark location. The HEC-RAS simulation showed that there is close agreement between the observed high water marks in the field and the simulated water surface elevations based on theoretical discharge computed using the SEDCAD method.

The Kondolf-Ashby memo states that WET has significantly overestimated the design flows but does not support that opinion with sound hydrological/hydraulic analyses. WET has conducted several different analyses that support the calculated discharges used for channel design, and has corroborated those results with actual data analyzed from a 2014 rainfall event that occurred on the site.

1.2 Response to Finding 2

Finding 2: Sonoita Creek is a semiarid stream that is characterized by highly dynamic geomorphic and ecological processes, however the hydraulic modeling unrealistically assumed fixed bed elevations.

The Kondolf-Ashby memo mentions that slight changes in diversion angles and elevations will have drastic negative consequences for the system, while asserting that invert elevation changes in Sonoita Creek and the development of vertical cut banks do not have adverse consequences. The memo points out that the Rail X Channel diversion point is located at the confluence of Adobe Canyon and Sonoita Creek, and would be challenging to maintain given the dynamic nature of Sonoita Creek. WET generally agrees with this opinion from the Kondolf-Ashby memo and has already modified the Rail X Channel design so that the diversion point is located approximately 250 feet downstream of the Adobe Canyon-Sonoita Creek confluence. Based on observations made during subsequent field reconnaissance, the hydraulic regime and Sonoita Creek channel bed appear to have sufficiently stabilized within 250 feet of the confluence; therefore, the diversion point in the current project design will behave in a more predictable fashion. Furthermore, all of the engineered channels divert stormwater from Sonoita Creek at a relatively slight angle that is less than 30 degrees (as opposed to a diversion oriented perpendicular to Sonoita Creek), and all diversions share the same bed elevation as Sonoita Creek (as opposed to some diversions in the conceptual design that were perched 1 foot above the Sonoita Creek channel bottom). Given the new design configuration at the diversion, and the location of three key diversion points, the current design is more predictable and less prone to adverse impacts resulting from subtle changes in channel bed elevations.

The Kondolf-Ashby memo notes that the downstream-most 6,000 feet of Sonoita Creek within the project is especially complex and dynamic. WET arrived at a similar conclusion, and detailed engineering has modified the design so that there is no diversion from the original channel in the lower 4,600 feet of Sonoita Creek. The southern-most design channel (South SCR Channel) diverts stormwater from Sonoita Creek upstream of a large cut-bank and returns flow back to Sonoita Creek upstream of the cottonwood galleries noted in the Kondolf-Ashby memo. The goal of the current design is to allow additional reaches of Sonoita Creek to behave in the more complex and dynamic way that is favorably described by Kondolf-Ashby for the southernmost project area, as opposed to the containment of flows within an incised and artificially straightened channel.

1.3 Response to Finding 3

Finding 3: The proposed constructed channels will likely not sustain flow in the specific soil types within the project reach.

The Kondolf-Ashby memo asserts that the constructed channels will probably not sustain flow due to high infiltration, which would lead to continual aggradation and eventually total abandonment of the design channels and a loss of habitat in the main stem of Sonoita Creek. The Kondolf-Ashby memo attributes the high infiltration to their determination that the majority of soils in the project area are classified as Hydrologic Soil Group (HSG) A soils. HSG A soils have the highest infiltration rates and lowest runoff potential. HSG B, C, and D soils represent the rest of the hydrologic soil group spectrum with progressively decreasing infiltration rates and higher runoff potentials, with HSG D soils having the lowest infiltration rates and highest runoff potential.

The actual disturbed soil acres for the entire project area are approximately 178.8 acres with 72 percent Pima and 28 percent Grabe-Comoro Complex. The Pima soil map unit has an HSG classification of Group C and the Grabe-Comoro complex map unit has a Group A classification. However, due to the incised nature of the existing Sonoita channel and the channel bed material, it may not be valid to directly compare Order 3 NRCS soil mapping and HSG determinations to current channel conditions.

Design channel baseline soil characterization, sampling, and laboratory analysis were designed to address the infiltration rate within the channel invert elevation after construction. Centerline soil coring was conducted in 18 locations along the designed channel centerline to depths below the channel invert elevations. Soils samples were analyzed for agronomic and engineering parameters to determine the suitability of the excavated channel invert soils to support vegetation and engineering estimates of riparian flow conditions. Laboratory analytical results for texture, organic matter, bulk density, coarse fragments, and electrical conductivity were used to populate the Soil-Plant-Air-Water (SPAW) soil water characteristics model (Saxton and Willey, 2006) to estimate the hydraulic conductivity for the soil horizon at the channel invert elevation and the horizon immediately below the invert elevation. The modeled saturated hydraulic conductivity value was used to determine the HSG from the National Engineering Handbook (Part 630, Chapter 7, Table 7.2). The HSG values for each soil core invert and sub-invert elevations are contained in Table 4 and illustrate that B and C-Group HSG soils will be evenly divided after channel construction.

Table 4. Rosemont Sonoita Channel Soil Hydrologic Group Estimates

Core #	Soil Series	Upper Depth (in)	Lower Invert Depth (in)	Texture	SPAW Saturated Hydraulic Conductivity (in/hr)	SPAW Hydrologic Subgroup
1	Pm	36	53	SL	0.59	B
2	Pm	80	87	SL	0.49	B
3	Pm	58	70	L	0.13	C
4	Pm	45	77	L	0.09	C
5	Pm	46	59	SL	0.27	C
6	GbB	45	52	SCL	0.47	C
7	GbB	23	60	SL	0.74	B
8	GbB	0	36	L	0.26	C
9	GbB	0	5	Sil	0.23	C
10	Pm	85	92	L	0.96	B
11	Pm	32	45	SL	1.22	B
12	Pm	56	86	SL	0.66	B
13	Pm	82	90	L	0.27	C
14	GbB	26	45	L	0.31	C
15	GbB	40	48	SL	1.05	B
16	GbB	56	64	SL	0.52	B
20	GbB	60	70	L	0.36	C
21	GbB	35	44	L	0.78	B

Surface water from Monkey Springs will be released into one of the design channels (SCR Channel) that flows back into Sonoita Creek. The annual volume of flow from Monkey Springs available for release has been measured and is estimated to be 192.3 million gallons. The Monkey Spring flow contribution to the design channel will provide hydration for riparian vegetation and generally increase the amount of soil moisture in the channel. Since the design channel will already have additional soil moisture, and since soil coring data indicates the soils have lower infiltration rates than suggested in the Kondolf-Ashby memo, the total transmission losses from the design channels will also be lower than suggested by Kondolf and Ashby.

An increase in infiltration isn't necessarily negative, and is in fact one of the goals of the project. The majority of channel designs are adjacent to those reaches of Sonoita Creek that have been straightened artificially. These reaches of Sonoita Creek can generally be characterized by an unnaturally low sinuosity that approaches 1.0, lack of access to floodplains, and vertical channel banks. WET believes that transmission losses in these reaches of Sonoita Creek that have been artificially straightened are unnaturally low due to those characteristics. Transmission losses from ephemeral streams are an important source of recharge for shallow groundwater, and ultimately what sustain riparian species such as Fremont cottonwood.

Regarding aggradation, as Kondolf-Ashby themselves point out, channel bed elevation variations typically depend upon the magnitude of the most recent flow event. There may be channel aggradation over some period of time, until an event large enough to redistribute the accumulated material occurs. At the present time, low-capacity reaches of the existing Sonoita Creek channel will be overtopped during higher flow events anyway. By encouraging floodplain connectivity at lower flow magnitudes, the design will prevent those reaches from becoming even more incised.

Throughout Sonoita Creek there is evidence of both aggradation and degradation that occur during each significant storm event. Relatively small, frequent storm events may result in local aggradation; however, those sediments deposited in small storms will be re-entrained into the water column and bedload during subsequent events. Channels don't normally aggrade perpetually until abandonment, but rather aggrade until a balance is reached between aggradational and degradational forces. The sporadic nature of storms in the arid southwest results in a complex channel form indicative of the recent history of flooding activity. Very large storms may widen and deepen a channel of this type, and be followed by successive smaller storms that generally aggrade and narrow the channel.

1.4 Response to Finding 4

Finding 4: The existing ecological functions of Sonoita Creek will be reduced by diverting flow from the main channel.

Finding 4 focuses on the downstream-most 6,000 feet of Sonoita Creek that both EPA and WET agree is functioning ecologically well with numerous Fremont cottonwood trees that provide valuable wildlife habitat. Again, WET's new design configuration preserves the downstream-most 4,600 feet of Sonoita Creek due to its existing resource values. The South SCR Channel essentially diverts stormwater through a 3,600-foot long design channel and then returns flow back into Sonoita Creek upstream of the Fremont cottonwood gallery.

Sonoita Creek will receive less stormwater for the reach adjacent to the SCR Channel, but it should be noted that the reach of Sonoita Creek located between the diversion point and confluence with the SCR Channel has very limited ecological functionality at present. This reach of Sonoita Creek conveys stormwater through an extremely confined channel with virtually no opportunity for floodplain development and channel meandering because it is bound by a highway on one side, and a high-pressure gas transmission line on the other. Reducing the amount of flow through this impaired reach will increase ecological function by reducing stream energy and bank erosion. The channel cross-section geometry was changed from a trapezoidal shape in the conceptual design to a more complex channel geometry with terraces. This complex, terraced channel geometry will provide new riparian habitat, and access to the floodplain during larger events.

An incipient motion threshold analysis was conducted on Sonoita Creek to consider the effect that reducing flow has on the channel bed substrate measured in the main stem of Sonoita Creek. To test for incipient motion, channel shear stress was computed, and then critical dimensionless shear stress was calculated. Shear stress is the force that flowing water imparts on channel bed particles. Critical dimensionless shear stress is a metric derived from shear stress that can be used to test for incipient motion of the bed particles. Based on field and laboratory analyses the channel bed substrate in Sonoita Creek is generally composed of sand-sized particles with some gravels and cobbles. The average D16, D50, and D84 particle sizes for the reference reach samples are 0.5 mm, 2.3 mm, and 11.9 mm, respectively, as determined with laboratory sieve analysis (Table 5).

Table 5. Reference Reach Channel Substrate Gradations

Sample ID	D16 (mm)	D50 (mm)	D84 (mm)
2	0.4	2	9.9
6 Composite	0.5	2.3	13.2
6.5	0.7	3.5	17.7
8	0.3	1.3	5.3
Sample Average	0.5	2.3	11.9

WET analyzed Sonoita Creek and the three design channels for incipient motion of the channel bed material that would occur during small, frequent storms. Shear stress in the channel was calculated for the discharge assuming a flow split as determined by HEC-RAS resulting from the 2-year design storm. Shear stress was calculated for the main channel (ignoring shear stress for the over bank areas) using HEC-RAS. The equation to calculate shear stress is shown below:

$$\tau = \gamma * d * s$$

Where: τ= shear stress
γ = unit weight of water
d = channel hydraulic depth
s = channel slope

Critical dimensionless shear stress was then calculated using shear stress calculations derived from the previous equation. Critical dimensionless shear stress was calculated for the average D50 and D84 fractions of the channel bed material using the equations below:

$$\tau^*_{D50} = \frac{\tau}{1.65 * \gamma * D50}$$

$$\tau^*_{D84} = \frac{\tau}{1.65 * \gamma * D84}$$

Where: τ_{D50}*= critical dimensionless shear stress for the channel bed D50 particle size

τ_{D84}*= critical dimensionless shear stress for the channel bed D84 particle size

γ = unit weight of water

D50 = particle size that is larger than 50 percent of all particles in the sample

D84 = particle size larger than 84 percent of all particles in the sample.

To test for incipient motion, critical dimensionless shear stress was calculated at cross-sections spaced 400 feet apart in both Sonoita Creek and at cross-sections located in the design channels. If critical dimensionless shear stress is equal to or greater than 0.03 (Parker, 2008) then mobilization is expected. In all cases, critical dimensionless shear stress is 0.03 or greater during the 2-year storm for both Sonoita Creek (utilizing the post-design flow split discharge) and for the three design channels (RX Channel, SCR Channel, South SCR Channel). Despite the significant reduction in flow for the three reaches of Sonoita Creek adjacent to the design channels resulting from the three diversions, there is still sufficient flow to mobilize bed particles during a 2-year storm. The larger storms generally responsible for channel shaping in the arid southwest (10-year, 25-year) will also result in discharge with sufficient energy to drive channel-forming processes.

Additionally, the Kondolf-Ashby memo points out in Finding 4 that “a minimum 32-acre section of existing, regionally rare, native big sacaton (*Sporobolus wrightii*) grasslands would be impacted by the proposed channel construction.” However, since the conceptual design has been modified to exclude channel construction adjacent to the lower 4,600 feet of Sonoita Creek, the big sacaton grass communities that will be impacted have been reduced from 32 acres down to about 20 acres. Furthermore, the agriculture field, through which the SCR Channel will be constructed, will be reclaimed and big sacaton will be transplanted. The current design includes 1,090 big sacaton transplants that will be salvaged from the areas where they are disturbed and used to establish new big sacaton communities in areas that have lost much of their native vegetation and ecological function due to previous agricultural activities. The design will result in a net increase of big sacaton grasslands.

1.5 Response to Finding 5

Finding 5: There are no comparable reference sites shown or provided for the constructed channel design.

The Kondolf-Ashby memo notes that there are no reference sites provided for the constructed channel design and criticizes WET for using Vermejo Park Ranch (VPR) as a reference project similar to the Sonoita Creek Mitigation Project. WET acknowledges that VPR is in a different ecosystem than Sonoita Creek. However, VPR is similar to Sonoita Creek in that they are both located in the arid southwest with similar channel forming characteristics and similar annual rainfall. Both projects include ephemeral channel designs whose annual peaks usually result from the North American Monsoon. WET's entire purpose in including photographs of restored stream reaches at VPR was to demonstrate that natural channel forming processes redistribute material in constructed channels in ways that increase aesthetics and complexity and improve ecological function.

However, WET does agree with Kondolf-Ashby in that reference sites can provide a good analog for channel design. WET has subsequently conducted a field survey at the Sonoita Creek project area and surveyed multiple cross sections in seven reference reaches for guidance on refining the design channel cross-sectional geometry. The reference reaches span the entire project and were selected because they were the least disturbed sites and represented the highest ecological function within the project area. At each reference reach, three channel cross-sections were surveyed. The cross sections traversed the channel, floodplain, and upland areas adjacent to the channel. Vegetation surveys and soil core samples were collected along these cross sections to characterize changes in vegetation community and soil types with an emphasis on identifying and characterizing biological benchmarks observed at the reference sites. In addition to the channel cross-section survey, samples of the channel bed were collected for use in sediment transport analysis. The reference reach survey coupled with hydrologic and hydraulic analyses were used to develop the design channel cross-section used in the current design.

The two reference reaches deemed most applicable to use as a reference for channel design are Site 6 and Site 8, both located in the main stem of Sonoita Creek. Site 6 is located near the ranch headquarters and is roughly 2,000 feet upstream from where Sonoita Creek was straightened to flow adjacent to the highway. Site 8 is located near the southern end of the project in a complex and highly functional reach littered with secondary channels and Fremont cottonwood trees. The Kondolf-Ashby memo describes this reach as "especially dynamic and complex" and recommends that it be preserved. WET agrees that it should be preserved, and that is reflected in a current design configuration that excludes channel restoration designs for that reach while providing a net increase in restored channel acreage. These two sites in Sonoita Creek are characterized by relatively large channel widths, floodplain access, and relative channel stability. These two sites were noted as having the highest ecological function of all the reference sites, and were used to inform the current channel design. Channel bottom widths ranged from approximately 40 feet up to 70 feet with an average bottom width slightly greater than 50 feet. Typically, at least one, and usually both sides of the channel have terrace features that are perched 1 to 3 feet above the active channel bottom with riparian vegetation species. Secondary channels were also observed at both of these sites. The combined right and left terrace widths ranged from approximately 28 feet up to 175 feet.

To develop a discharge scaled design cross-section that emulates the reference reaches, downstream hydraulic geometry relationships were determined for the reference reaches and then applied to the design channels. Downstream hydraulic geometry is basically a site-specific mathematical relationship between discharge and channel width. WET developed the relationship from the reference reaches in Sonoita Creek, and then applied that relationship to the proportioned flow in the design channels. This technique allowed the engineering used for the design channels to better emulate the reference reach than the conceptual design.

The surveyed channel cross-sections were modeled with HEC-RAS, and downstream hydraulic geometry relationships were determined. Hydraulic geometry relationships can be expressed mathematically as:

$$W = a * Q^b$$

Where: W = width (ft)
a = constant
Q = discharge
b = exponent (typically 0.5)

Discharge and width are known variables, the b-exponent was set to 0.5, and the equation was solved for a. The hydraulic geometry a-value is greater for relatively wide channels, and smaller for relatively narrow channels. Factors that affect the hydraulic geometry a-value include vegetation, soils, sediment load, and historical storm events. The average hydraulic geometry a-value for our two reference reaches ranged from 3.1 to 3.8 for the 5- and 10 - year storm events. Hydraulic geometry relationships were determined for the design channels based upon a flow split as determined with HEC-RAS for the 5- and 10-year storm events. The hydraulic geometry a-values ranged from 3.4 to 4.6 for the three design channels: Rail X Channel, SCR Channel, and South SCR Channel (Table 6).

Table 6. Hydraulic Geometry a-Values for Selected Channels (English Units)

Channel	5-Year Storm	10-Year Storm
Sonoita Creek Reference Site 6	3.7	3.8
Sonoita Creek Reference Site 8	3.6	3.1
Rail X Channel	3.9	3.7
SCR Channel	4.6	4.1
South SCR Channel	4.1	3.4

The design channel cross-sections were developed to emulate the reference reaches and be practical to construct. The design channel cross-sections include an active channel with a bottom width that ranges from 35 to 55 feet, and terraces perched 2 feet above the channel bottom consistent with the reference reaches surveyed at Sonoita Creek. The terrace features range from 50 feet wide to 60 feet wide for a typical channel cross section. The design channel width, relative to the downstream hydraulic geometry for split flow, is slightly greater than the reference reaches. The greater width is warranted due to the lack of vegetation that will initially be present following channel construction, and provides for greater channel capacity should the design channel receive a greater proportion of the stormwater flow due to subtle changes in channel geometry at the diversion points. The design channel geometry will change over time, and the magnitude and direction of change (channel size increasing or decreasing) is highly dependent on the actual storm events that occur following channel construction. A series of frequent, small storms events will likely lead to aggradation and a net decrease in channel capacity, while moderate to large storms will likely maintain or increase channel size.

In short, we agree with the Kondolf-Ashby memo statement that reference reaches should be used to help inform channel design, and we have used reference reaches in developing the current detailed engineering design.

1.6 Response to Finding 6

Finding 6: The proposed channel design is not self-maintaining or sustainable and will require continual maintenance.

The Kondolf-Ashby memo asserts that while the design channels may function during small flood events, they are likely to fail during larger floods without specifying why or how the design channels may fail. Recall that during larger floods there are low-capacity reaches of Sonoita Creek that will be overtopped with the current channel configuration, as well as reaches that are likely to experience further incision and/or bank failure. The Kondolf-Ashby memo suggests that since there have been unstable channel restoration designs implemented in Maryland, California, and North Carolina, the Sonoita Creek Mitigation Project probably would not be stable either. The Kondolf-Ashby memo fails to explain why those channels failed, or discuss the specific similarities between those projects and Sonoita Creek Mitigation Project, which is located within a much different ecosystem. Additionally, in Finding 6, the Kondolf-Ashby memo criticizes the use of buried riprap as a bank protection method and the sheer size of the soil repositories and their potential for erosion. Lastly, the Kondolf-Ashby memo argues that spreading 0.8 feet of fill over the agricultural field has the potential to impact existing resources.

Regarding the buried riprap, the new channel designs do not include any riprap in the three main channels, Rail X Channel, SCR Channel, and South SCR Channel. The buried riprap specified in the conceptual design was to prevent bank erosion and subsequent channel migration towards the high pressure gas transmission pipeline and towards the highway. The current design has modified the channel alignments to provide ample room for channel migration without threatening the high pressure gas transmission pipeline or the highway.

To reduce the impact of the geomorphic soil repositories, the current design produces considerably less material excavated from the channels. The conceptual design had approximately 1,000,000 CY of material excavated from the channels to be placed as fill in the geomorphic landforms, and spread over the agricultural fields, whereas the current design has reduced that volume to approximately 530,000 CY of material. Furthermore, instead of only two very large landforms created from the excavated material, there are now 12 small soil repositories. The conceptual design included two large repositories with a combined footprint of approximately 43.2 acres and an average repository hillslope gradient of 12.0%, and included fill to be spread throughout the 70 acres of the agricultural field. The large reduction in excavated material and increase in combined footprint area to 86.7 acres for the 11 upland repositories has resulted in a lower average hillslope gradient of 6.0%. The twelfth repository consists of 38.1acres of the agricultural field that will be covered with fill material and have an average gradient that approximates the valley slope of 1 percent.

To summarize, the detailed design requires about half as much soil to be excavated from the design channels (compared to the conceptual design), which is placed in multiple soil repositories that occupy roughly the same total footprint area as the conceptual design. This results in substantially flatter slopes that are less prone to erosion. WET acknowledges that the soil repositories will be created from somewhat unconsolidated alluvium. However, the soil repositories have significantly flatter slopes than the surrounding native hillslopes, which generally range from 30 to 50 percent.

Regarding the impact to existing resources from spreading material over the agricultural field, WET ascertains that this is one of the non-channelized areas that will receive the greatest ecological benefit from reclamation. The agricultural field has been highly manipulated by man, with the primary vegetation species being non-native grasses such as Johnsongrass. The native big sacaton communities are non-existent within the agricultural field. Restoration work in the agricultural field will include big sacaton transplants as well as seeding of other native species.

Erosion potential of the fill material placed in the agricultural field is quite low due to the flat gradient (approximately 1 percent).

1.7 Response to Finding 7

The proposed constructed channels do not provide equal ecological value or the same level of functions as the original Sonoita Creek Channel.

Sonoita Creek is currently operating at less than its true ecological potential due to artificial straightening and channel incision. The reach of Sonoita Creek that flows parallel to the highway, and adjacent to the agriculture field is providing very little ecological function at present. Currently, this reach of Sonoita Creek is characterized by high, steep or vertical channel banks prone to instability, limited floodplain access, and minimal complexity. The channel is highly incised and located 6 to 10 feet below the ground surface of the agriculture field. Stormwater currently flows through this zone at relatively high velocities due to its narrow, incised cross-section. Furthermore, a distinct riparian zone is largely absent simply because the transition between the channel bottom and the agriculture field is a short, steep or vertical slope.

The construction of design channels will reduce specific stream energy, and provide additional basin recharge. Additionally, the design channels will increase the amount of riparian habitat, and are designed to accommodate further channel evolution and complexity. Furthermore, the spring flow from Monkey Springs will provide a substantial amount of water for plant growth and basin recharge near the upper end of the SCR Channel. Quantifying the length of channel that will be continuously hydrated from this water source is a challenging exercise in modeling that is not well understood by researchers, and thus was not completed. Nonetheless, the design channel and additional flow contribution from Monkey Springs will provide significant ecological benefit for this highly manipulated and impaired section of Sonoita Creek. Furthermore, the design incorporates other improvements including more appropriate diversion locations that have departure angles less than 30 degrees. At the diversions, the design channel inverts match Sonoita Creek instead of being perched 1 foot above Sonoita Creek in the conceptual design. Also, the channel geometry is based upon reference reaches surveyed in the project area instead of an arbitrary trapezoidal shape, and better emulates the most ecologically functional reaches of Sonoita Creek that are within the project area.

WET acknowledges that the diversion points may reflect some design uncertainty with respect to flow. However, the number of diversions has been reduced from six down to three in the current detailed engineering design. Additionally, the diversion offsets of 1 foot in the conceptual design were modified to match the elevation of existing Sonoita Creek for the engineered design, and the diversion angles are less than 30 degrees. The detailed engineering design includes fewer diversions with a more favorable hydraulic configuration, thereby reducing uncertainty and increasing stability. Many reaches of Sonoita Creek provide little ecological function. The newly design channels are highly functional and will provide far more ecological value than the parallel reaches of Sonoita Creek.

1.8 Response to Finding 8

There is no ecological benefit to controlling bank erosion at Sonoita Creek.

The Kondolf-Ashby memo states that no information was presented that indicates Sonoita Creek is experiencing unusual or artificially-elevated bank erosion rates. Ephemeral streams in the arid southwest are known for their high sediment loads during storms, and Sonoita Creek is no exception.

WET has observed that Sonoita Creek has a plentiful supply of sediment, which is consistent with the Kondolf-Ashby memo. Despite the fact that Sonoita Creek is expected to have high sediment loads, sediment is still considered a significant pollutant in most surface water bodies, and there is merit to controlling bank erosion along Sonoita Creek. The soils composing the channel banks were observed to be significantly finer textured than the channel bed material. During the field reconnaissance, bed samples were collected and analyzed for particle size, as well as soil core samples collected along the channel banks and throughout the valley floor where the design channel would be constructed. The average D50 of channel bed material was 2.3 mm while the average D50 from the soil cores taken from areas adjacent to the channel was 0.16 mm. The finer grained particles are largely absent in the channel bed, which indicates that when channel banks slough and erode, these sediments are entrained in runoff and are generally staying in the water column and passing through the system. The most likely place for deposition of these fines is downstream at Lake Patagonia. Because the finely textured soils located in the channel banks are largely absent within the channel, these soils are not likely necessary to drive future channel complexity and are not necessary for proper ecological function.

Thus, controlling bank erosion has a two-fold ecological benefit. First, even a small reduction in bank erosion would benefit the system downstream by reducing the amount of fine soils (silts and clays) that are likely deposited in Lake Patagonia. Second, bank erosion will be controlled by diverting a fraction of the stormwater runoff into the three design channels which represent new riparian habitat. Bank erosion will also be reduced by constructing a channel terrace feature on the east bank of Sonoita Creek downstream from its confluence with the SCR Channel. The terrace construction ultimately widens the channel and decreases specific stream energy, resulting in less erosion of bank materials while increasing ecological function.

The impaired, artificially manipulated sections of Sonoita Creek contain many reaches with high, steep or vertical banks that are showing obvious signs of erosion. These reaches contrast with the southern-most reach of Sonoita Creek that shows the least amount of artificial disturbance. The southern reaches of Sonoita Creek are highly complex, with broad floodplains, secondary channels, and an abundance of riparian vegetation including the Fremont cottonwood. High, steep or vertical banks are not a predominant feature in the southern-most reaches of Sonoita Creek with the highest ecological function. WET does not agree that controlling bank erosion will provide no ecological benefit. The engineering design will reduce the amount of fine sediments transported to Lake Patagonia, and will provide more ecological function where the steep banks in Sonoita Creek are modified.

2.0 Conclusion

The goal of the Sonoita Creek Mitigation Project is to allow additional reaches of Sonoita Creek to behave in the more complex and dynamic way that is favorably described by Kondolf-Ashby for the southernmost project area, as opposed to the containment of flows within an incised and artificially straightened channel that is characteristic of the current system. WET does not agree with the Kondolf-Ashby assessment that the design flows were significantly overestimated. Subsequent hydrologic modeling corroborates results presented in the conceptual design. However, the Kondolf-Ashby memo includes some good comments concerning the project's conceptual design. In many cases, these comments have been considered during subsequent field visits made to Sonoita Creek, and have been incorporated into the detailed engineering design for the project.

The Sonoita Creek Mitigation Project provides a tremendous opportunity to restore a highly manipulated section of Sonoita Creek. WET strongly believes that this project will provide substantial system-level ecological benefits. Within the project area, there have been significant man-made alterations and ecological constraints imposed on Sonoita Creek and the adjoining agricultural land. While preserving the most manipulated and impaired reaches of Sonoita is one option, WET believes it is a worthwhile endeavor to restore and enhance these areas as well as preserve the reaches of Sonoita Creek where high ecological functionality continues to exist.

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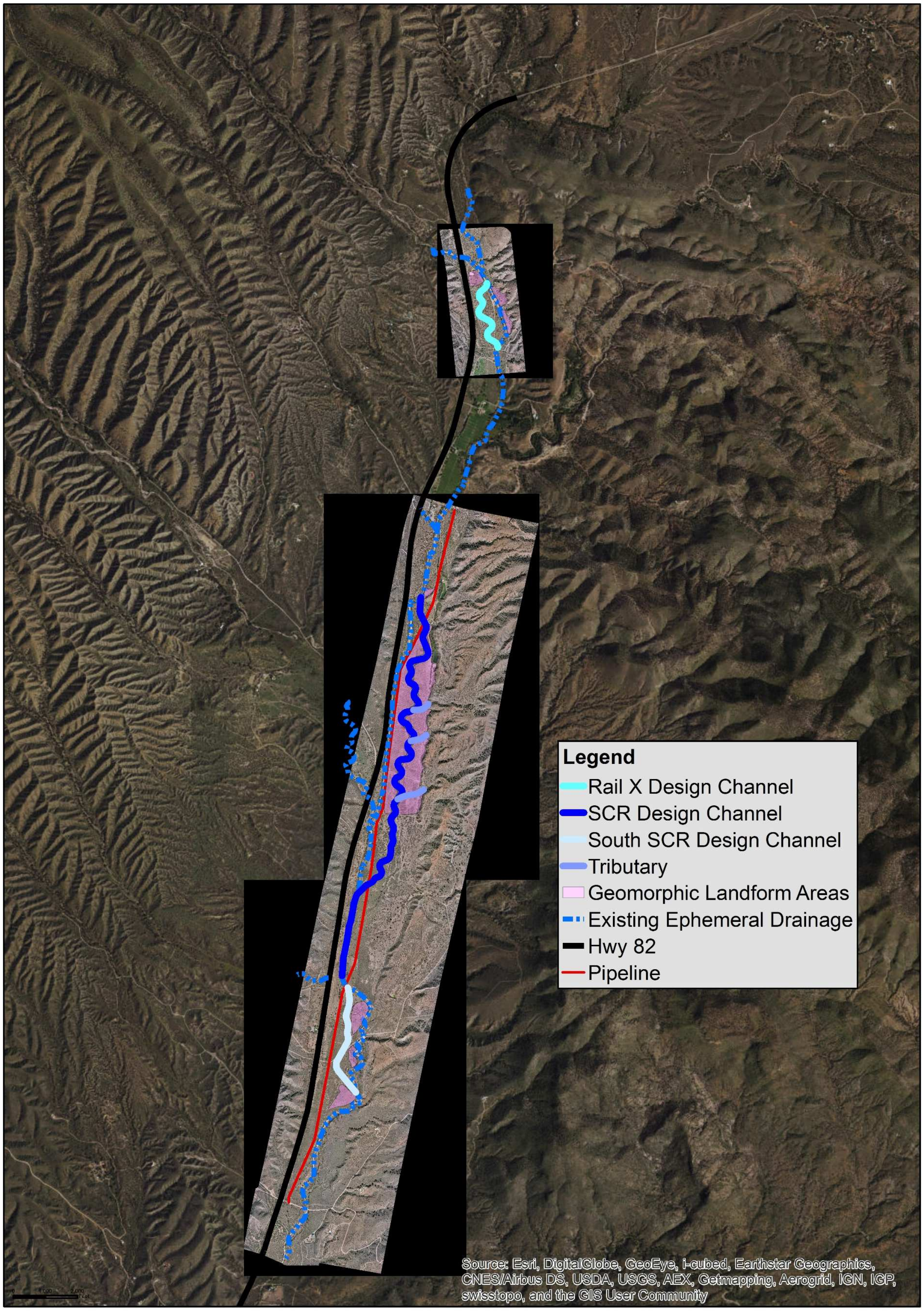
Attachment 1 – Detailed Engineering Design Channel Layout



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