HORSESHOE DRAW FLOOD CONTROL, RESTORATION AND EROSION MITIGATION STUDY AND DESIGN PROJECT

VOLUME 3

EXISTING CONDITIONS SEDIMENT TRANSPORT ANALYSIS

COCHISE COUNTY, ARIZONA

Prepared for:

Hereford Natural Resource Conservation District
2136 N. Truman Rd.
Huachuca City, AZ 85616

Prepared by:

HILGARTWILSON
2141 East Highland Avenue, Suite 250
Phoenix, AZ 85016
Phone: (602) 490-0535
Fax: (602) 368-2436

Registered Professional Engineer (Civil) CERTIFICATE NO. 40041 AUBREY J. THOMAS Date Signed 11/20/15 ARIZONA, U.S.A. Expires 12/31/17

November, 2015
HilgartWilson Project No. 1472

HILGARTWILSON
ENGINEER | PLAN | SURVEY | MANAGE

VOLUME 3
EXISTING CONDITIONS
SEDIMENT TRANSPORT ANALYSIS

TABLE OF CONTENTS

APPENDICES

FIGURES

TABLES

1. INTRODUCTION

1.1. PURPOSE

The purpose of this study is to provide a sediment transport analysis for the existing conditions of Horseshoe Draw (the Project), which is a tributary to the San Pedro River. This study analyzes the amount of sediment transport and deposition into the San Pedro for the 2-year, 25-year, 50-year, and2-year, 10-year, 25-year, and 50-year 2-year, 10-year, 25-year, and 50-year 100-year, storm event. The results of this analysis will be compared to those from a proposed conditions model which will be prepared in the near future. The proposed conditions model will evaluate what impact a proposed water impoundment structure will have on sediment deposition to the San Pedro River. The design of the water impoundment structure is discussed in further detail below. The design flow rates utilized within this study were obtained from the Horseshoe Draw Flood Control, Restoration and Mitigation Study and Design Project Volume 1 – Existing Conditions Hydrologic Study Report (Volume 1) (HILGARTWILSON 2015a) and Volume 2 – Existing Conditions Hydraulic Study Report (Volume 2) (HILGARTWILSON 2015b). Pertinent excerpts from these reports are provided in Appendix F.

The sediment transport analysis for the Project has been prepared using HEC-RAS version 4.1 with the results being compared to several empirical equations for validation. The methodology and design parameters used for these analyses are detailed below.

1.2. PROJECT LOCATION AND DESCRIPTION

The study area lies just north of the United States and Mexico border roughly 7 miles west of Naco, Arizona/Sonora within Township 24 South, Range 22 East of the Gila and Salt River Base and Meridian in Cochise County, Arizona. The Project's location is highlighted in the Vicinity Map, Figure 1, Appendix A.

This study has been prepared for the Hereford Natural Resource Conservation District (NRCD), who has identified the need for a project which will significantly reduce flooding, erosion and soil loss, as well as road and property damage in and adjacent to Horseshoe Draw. The Project also aims to improve groundwater recharge by slowing the rate of discharge to downstream waters. In order to complete such a project, the Hereford NRCD was awarded a grant from the Arizona Department of Water Resources (ADWR) through the Arizona Water Protection Fund Program. In turn, HILGARTWILSON has been contracted under the Water Protection Fund grant for professional engineering services.

This study and corresponding report make up Volume 3 in a series of reports that will be prepared under the awarded grant. This study provides existing conditions sediment transport analyses which will be used as a baseline comparison for the future sediment transport analysis that will be prepared for the proposed water impoundment structure. The proposed impoundment structure will attenuate flows and subsequently, reduce flow velocities, head cutting, and sediment transportation to the San Pedro River. The attenuation of flows also has the added benefit of improving groundwater recharge by slowing the rate of discharge to downstream waters.

2. HYDROLOGIC STUDY OVERVIEW

HEC-HMS was used for the hydrologic analysis of the Project which was detailed within Volume 1 of this report series. Horseshoe Draw conveys runoff from roughly 17 square miles of undeveloped rangeland to the San Pedro River. The watershed of the Project originates in the Sierra San Jose mountains in Mexico and extends to the confluence of Horseshoe Draw and the San Pedro River, located just south of Highway 92.

Due to the size of the watershed, both, the 100-year, 6-hour and 100-year, 24-hour storm events were modeled to compare the calculated flow rates. Based on the hydrologic modeling results, the flows determined during the 100-year, 6-hour storm exceeded those determined using the 100-year, 24-hour storm; therefore, the flowrates from the 100-year, 6-hour model have been utilized in this sediment transport analysis. Subsequently, the 2-year, 10-year, 25-year, and 50-year flow rates with the 6-hour storm duration were determined using the same methodology outlined in Volume 1. These flow rates were used in estimating the sediment transport and are provided in Appendix B.

3. HYDRAULIC STUDY OVERVIEW

Hydraulic analysis for Horseshoe Draw was performed utilizing HEC-RAS version 4.1.0 detailed in Volume 2 of this report series. Cross sections within the model were exported from a digital terrain model (DTM) from AutoCAD Civil 3D. The DTM was built based on a topographic aerial survey performed by Kenny Aerial Mapping, Inc. in October, 2014. The aerial mapping contains detailed topography at 2-foot intervals using the North American Vertical Datum of 1988 (NAVD 88).

The average slope of Horseshoe Draw within the study reach is roughly 1.0%. With this slope, many of the portions of the wash operate under a supercritical flow regime. As a result, the mixed condition flow regime was used in HEC-RAS to observe the maximum velocities within the wash to be used in this study for determining sediment transport.

The hydraulic analysis of this study focuses on the main wash of Horseshoe draw while taking into consideration the lateral inflows from the wash tributaries determined in the hydrologic study detailed in Volume 1. Flow changes have been added to cross sections directly downstream of these tributaries in order to reflect these conditions.

The mixed conditions HEC-RAS model prepared in Volume 2 was used as the baseline for this sediment transport analysis. Further description of the design parameters and methodology used in the HEC-RAS model for the sediment transport analysis are discussed in Section 5 of this report.

4. GEOTECHNICAL EVALUATION

Geotechnical analysis for the Project was prepared by Ninyo & Moore, in a report dated October 30, 2015 Geotechnical Evaluation, Horseshoe Draw Basin. The purpose of the geotechnical evaluation was to assess the subsurface conditions at the project site in order to provide geotechnical recommendations for design and construction of the impoundment structure. The geotechnical evaluation included soil borings, shallow field infiltration tests, and laboratory testing evaluating the soil properties such as; moisture content, dry density, gradation, and Atterberg limits.

The soil properties determined within the geotechnical evaluation were used in the various methods of estimating sediment transport detailed below. Pertinent excerpts from the geotechnical evaluation report have been included in Appendix D.

5. HEC-RAS SEDIMENT TRANSPORT MODEL

This section describes the methods used in the analysis of the sediment transport and related data for the study. Channel parameters were referenced from the Volume 1 HEC-RAS model and can be found in Appendix B. Other parameters required for the analysis include upstream and downstream boundary conditions, soil properties and sediment data, the specified particle fall velocity method, and the specified sediment transport function which are discussed in further detail below.

5.1. BOUNDARY CONDITIONS

A quasi-unsteady simulation is required in HEC-RAS to run the sediment transport analysis which approximates a continuous hydrograph with a series of discrete steady flow profiles. The hydrograph data is referenced from the HEC-HMS 2-year, 25-year, 50-year, and 100-year storm event models and input as the "Flow Series" quasi-unsteady upstream boundary condition at Station 165+20.00. A "Normal Depth" downstream boundary condition at Station 0+20.29 is used with the friction slope calculated to be 0.010 ft/ft. Lateral flows were added at the Stations 146+92.54, 125+56.85, and 44+62.68 where major flow changes occur within the reach. The flow input used in the sediment transport model can be found in Appendix B.

5.2. SOIL PROPERTIES AND SEDIMENT DATA

Size distributions of bed material, surface and substrate sediment samples were collected at various locations during the field geotechnical investigation performed by Ninyo & Moore (Appendix D). Based on the analysis of the various borings, soils collected from the site were generally fine grained consisting of silts and clays. Due to limited field data, the size distributions of substrate material at each boring location were averaged and used as the bed material gradation input throughout the entire reach shown in Table 1 below. To further support this assumption, inspection of the National Resource Conservation Service (NRCS) Soil Resource Map (included as Appendix E) shows that soils throughout the reach consist of very fine grained sands and silts similar to that of the collected borings.

Table 1: Boring Gradation					
Sieve Size	Percent Finer (% Passing Sieve)				
Mesh	Sample ID's				Average
	B-1	B-3	B-4	B-5	
3"	100	100	100	100	100
1.5"	100	100	100	100	100
1"	100	100	100	100	100
3/4"	100	100	100	100	100
1/2"	100	99	99	100	100
3/8"	100	99	99	99	99
No. 4	98	98	96	99	98
No. 8	96	96	90	96	95
No. 16	91	89	80	92	88
No. 30	88	82	75	90	84
No. 50	82	72	68	88	78
No. 100	72	55	55	81	66
No. 200	61	42	42	72	54

The sediment transport analysis requires input for the maximum erodible depth. Boring logs were referenced to determine an average maximum erodible layer of approximately 6 feet below ground surface based on a dense confining layer seen in most borings.

5.3. FALL VELOCITY METHOD

Two methods for calculating the fall velocity that are commonly used are the Rubey and the Report 12 methods. Rubey's method uses an analytical relationship between the fluid, sediment properties, and the fall velocity, while Report 12 method is largely based on the temperature and a wide range of the particle sizes. In addition, Rubey's method has been shown to be adequate for silt, sand, and gravel grains while Report 12 is useful for medium sands and larger (HEC-RAS 2008). Therefore, Rubey's method was chosen in the sediment transport analysis.

5.4. SEDIMENT TRANSPORT FUNCTION

To evaluate sediment transport, the analysis was run within HEC-RAS using the Laursen-Copeland equation. The HEC-RAS Hydraulic Reference Manual (HEC-RAS 2008) states that the Laursen-Copeland equation is the only function developed for grain sizes that extend into the silt range. Any sediment potentials computed for silt by other functions would compound extrapolation errors on top of the standard uncertainty associated with computing transport capacity.

6. EMPIRICAL SEDIMENT TRANSPORT CALCULATIONS

The sediment transport analysis volumes determined using HEC-RAS are based on various estimated parameters and assumptions; therefore, some comparison of results is needed. There are several methods of estimating the sediment delivered by wash erosion, typically described as bed load. In this study, bed load delivery was estimated using the Zeller-Fullerton Equation and Yang's Equation. These equations are often used in the arid southwest to define the initial sediment load to a HEC-6 sediment transport model. These methods are useful in conservatively defining the bed load resulting from a single storm event. These two equations approximate the quantity of sediment suspended in the wash at a given cross section and flow rate. As such, these equations estimate the flux of sediment passing through a cross section for a specific flow rate and duration. Calculation tables have been included in Appendix C for the empirical sediment transportation methods at various flow rates which are described below.

6.1. YANG'S EQUATION

Yang's Equation is written in two different forms:

Sand equation: median particle size less than 2.0 mm (Yang, 1973).

$$\log C_t = 5.435 - 0.286 \log (\omega D_{50}/n) - 0.457 \log(V_*/\omega) + [\, 1.799 - 0.409 \log (\omega D_{50}/n) - 0.314 \log(V_*/\omega)] \log [(VS/\omega) - (V_{cr}S/\omega)]$$

Gravel equation: median particle sizes between 2.0 mm and 10.0 mm (Yang, 1984).

$$\log C_t = 6.681 - 0.633 \log (\omega D_{50}/n) - 4.816 \log(V_*/\omega) + [2.784 - 0.305 \log (\omega D_{50}/n) - 0.282 \log(V_*/\omega)] \log [(VS/\omega) - (V_{cr}S/\omega)]$$

In the above equations, the dimensionless critical velocity is given by:

$$V_{cr}/\omega = [2.5 / (\log ((V_* D_{50})/n) - 0.06] + 0.66 \quad (\text{for } 1.2 < (V_* D_{50})/v < 70)$$

and,

$$V_{cr}/\omega = 2.05 \qquad (\text{for } (V_* D_{50})/v >= 70)$$

Where:

C_t	= Sediment concentration (parts per million)
ω	= Fall velocity of sediment particle (m/s)
v	= Kinematic viscosity (m^2/s)
V_*	= Shear velocity $(\rho RS)^{0.5}$, (m/s)
V_{cr}	= Critical velocity (m/s)
D_{50}	= Median particle size (mm)

To determine the settling velocity for a sediment particle, the following equation was used.

$$\frac{\omega \cdot d}{v} = \left(\sqrt{25+1.2d_*^2} - 5\right)^{1.5}$$

And,

$$d_* = \left(\frac{\left(\frac{\rho_s - \rho}{\rho} \right) \cdot g}{\nu^2} \right)^{1/3} \cdot d$$

Where:

d_*	= Dimensionless Particle diameter
ρ_s	= Particle density (pcf)
d	= Particle diameter (mm)

6.2. ZELLER AND FULLERTON EQUATION

The Zeller and Fullerton Equation is written as:

$$q_s = 0.0064 \frac{n^{1.77} \cdot V^{4.32} \cdot G^{0.45}}{Y_h^{0.30} \cdot D_{50}^{0.61}}$$

Where:

q_s	= Sediment transport rate (cfs/ unit width)
n	= Manning's roughness coefficient
V	= Mean velocity (ft/s)
G	= Gradation coefficient
Y_h	= Hydraulic depth (ft)
D_{50}	= Median diameter (mm)

and:

$$G = 0.5 \, (D_{84.1} / D_{50} + D_{50} / D_{15.9})$$

Both Yang's equation and the Zeller and Fullerton equation estimate the amount of sediment deposition (tons/day) for a steady flow rate. In order to more effectively estimate the sediment transport with the quasi-unsteady flow rates determined in the HEC-HMS model of Volume 1, the Zeller and Fullerton equation was modified to determine the amount of sediment transport per five minute interval with the given hydrograph flow rate. The results from Yang's and the Zeller and Fullerton Equation using steady flows as well as those estimated using quasi-unsteady flow rates with the Zeller and Fullerton equation are discussed below. The empirical calculations included in Appendix C.

7. RESULTS AND COMPARISON

Results from the HEC-RAS sediment transport model have been included in Appendix B along with the steady state model analysis. The total sediment transport and deposition from the various storm events are summarized in the table below for existing conditions.

Table 2: HEC-RAS Sediment Transport Results Summary	
Storm Event	Sediment Deposition [Tons]
2-Year	43,358
25-Year	115,038
50-Year	129,804
100-Year	144,882

Results comparing the HEC-RAS sediment transport and the empirical methods using steady flow rates are shown in Table 3 below at various flow rates. These results show the estimated sediment transportation in a given day for the uppermost cross section of the reach at the specified flow rates. The calculations assume the flow rate would be applied over an entire day which is why the quantity of sediment generated is so large.

Table 3: Steady State Flow Sediment Yield Comparison at Station 165+20 [tons/day]				
Storm Event	Flow [cfs]	Method		
		Laursen-Copeland	Yang	Zeller and Fullerton
2-Year	590	24,253	1,085	30,239
25-Year	1,641	53,407	11,483	173,704
50-Year	2,010	56,138	15,997	239,183
100-Year	2,409	61,632	25,178	315,569

Table 4 displays the comparison of results from HEC-RAS using quasi-unsteady flow rate computations and the calculations for Zeller and Fullerton method for cross section 165+20. The Zeller and Fullerton empirical analysis, similar to the HEC-RAS quasi-unsteady state analysis, approximates a continuous hydrograph referenced from the Volume 1 HEC-HMS models with a series steady state flows at discrete time steps.

Table 4: Quasi-Unsteady Flow Sediment Yield Comparison at Station 165+20 [tons/day]		
Storm Event	Method	
	Laursen-Copeland	Zeller and Fullerton
2-Year	1,682	582
25-Year	3,592	2,671
50-Year	4,170	3,655
100-Year	4,763	5,846

There is some discrepancy between the results for the steady state analysis as expected. The Zeller and Fullerton equation gives results which are comparable to the Laursen-Copeland method sediment yield at a lower flow but becomes less consistent as the flows increase. As discussed in Section 5.4, as flows increase, the extrapolation errors compound when performing the Zeller and Fullerton calculation for silts and fine grained sands. Only the Laursen-Copeland method was developed for silt sized particles and has been shown to outperform other transport functions in the silt range (HEC-RAS 2008). The Yang method is considerably lower for all flow rates compared to the Laursen-Copeland method as it was not developed to include fine grained sediment either. The quasi-unsteady state analysis yielded much more comparable results shown in Table 4. The majority of the flows at the discrete time steps are relatively low and therefore yield comparable results between the Zeller and Fullerton and the HEC-RAS Laursen-Copeland analyses.

8. CONCLUSION

This study has been prepared in order to provide an existing conditions baseline sediment transport analysis for Horseshoe Draw using HEC-RAS and will be used as a basis for future sediment transport analyses accounting for the proposed water impoundment structure.

A sediment transport model with the impoundment structure will be prepared after the mitigated flow rates leaving the proposed impoundment structure have been determined. The future model will show the beneficial impact that the structure will have on the reduced sediment transport and deposition into the San Pedro River.

9. REFERENCES

Cochise County Flood Control District, 2013. *Cochise County Floodplain Regulations.* January 2013. *Bisbee, Arizona*

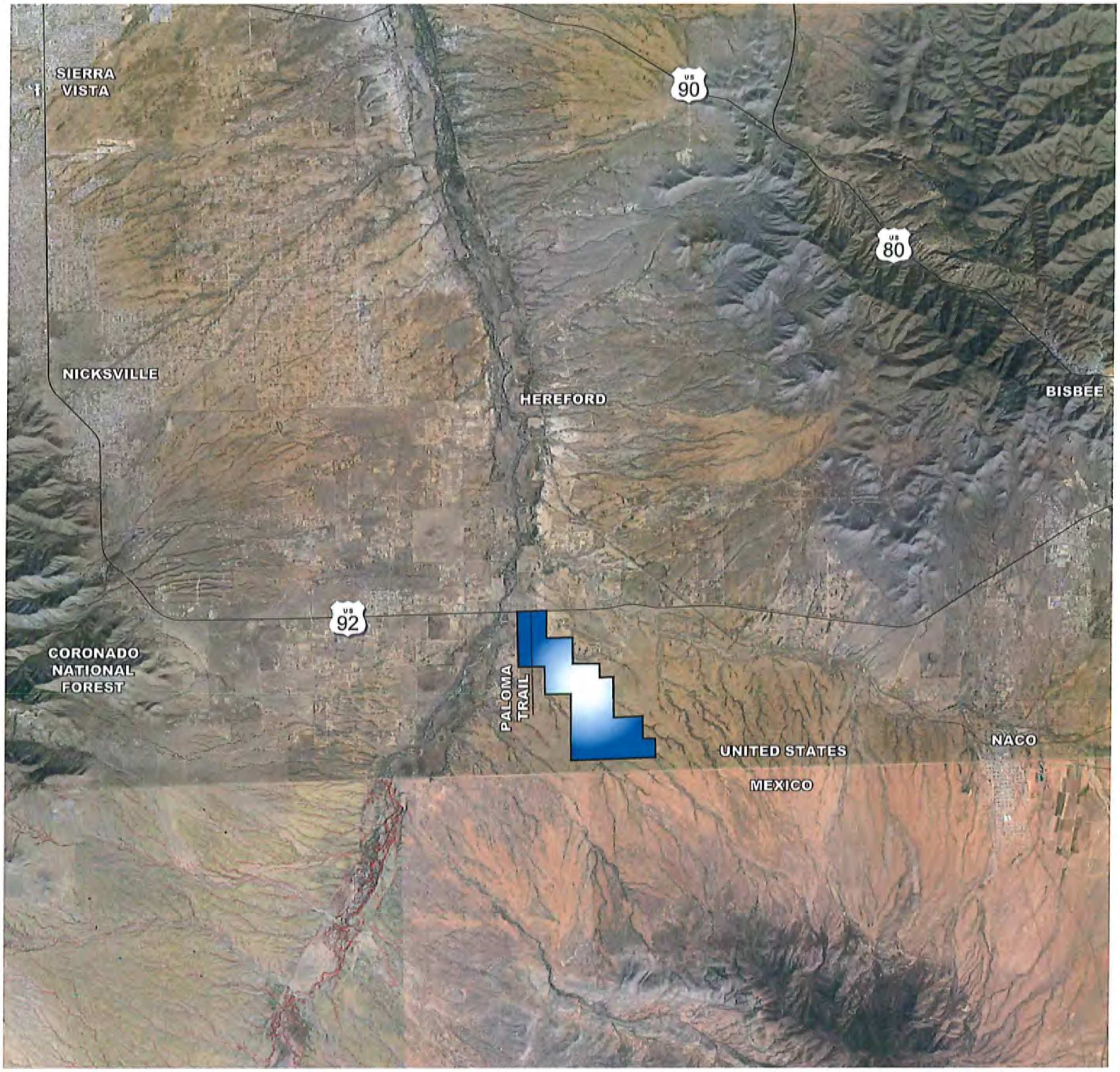
HEC-RAS 2008. *HEC-RAS River Analysis System: Hydraulic Reference Manual*. March 2008. Davis, California.

HILGARTWILSON, 2015a. *Horseshoe Draw Flood Control, Restoration and Erosion Mitigation Study and Design Project, Volume 1, Existing Conditions Hydrologic Study.* May 2015. Phoenix, Arizona.

HILGARTWILSON, 2015b. *Horseshoe Draw Flood Control, Restoration and Erosion Mitigation Study and Design Project, Volume 2, Existing Conditions Hydraulic Report.* October 2015. Phoenix, Arizona.

Ninyo & Moore 2015. *Geotechnical Evaluation Horseshoe Draw Basin*. October 2015 Phoenix, Arizona.

APPENDIX A
FIGURES



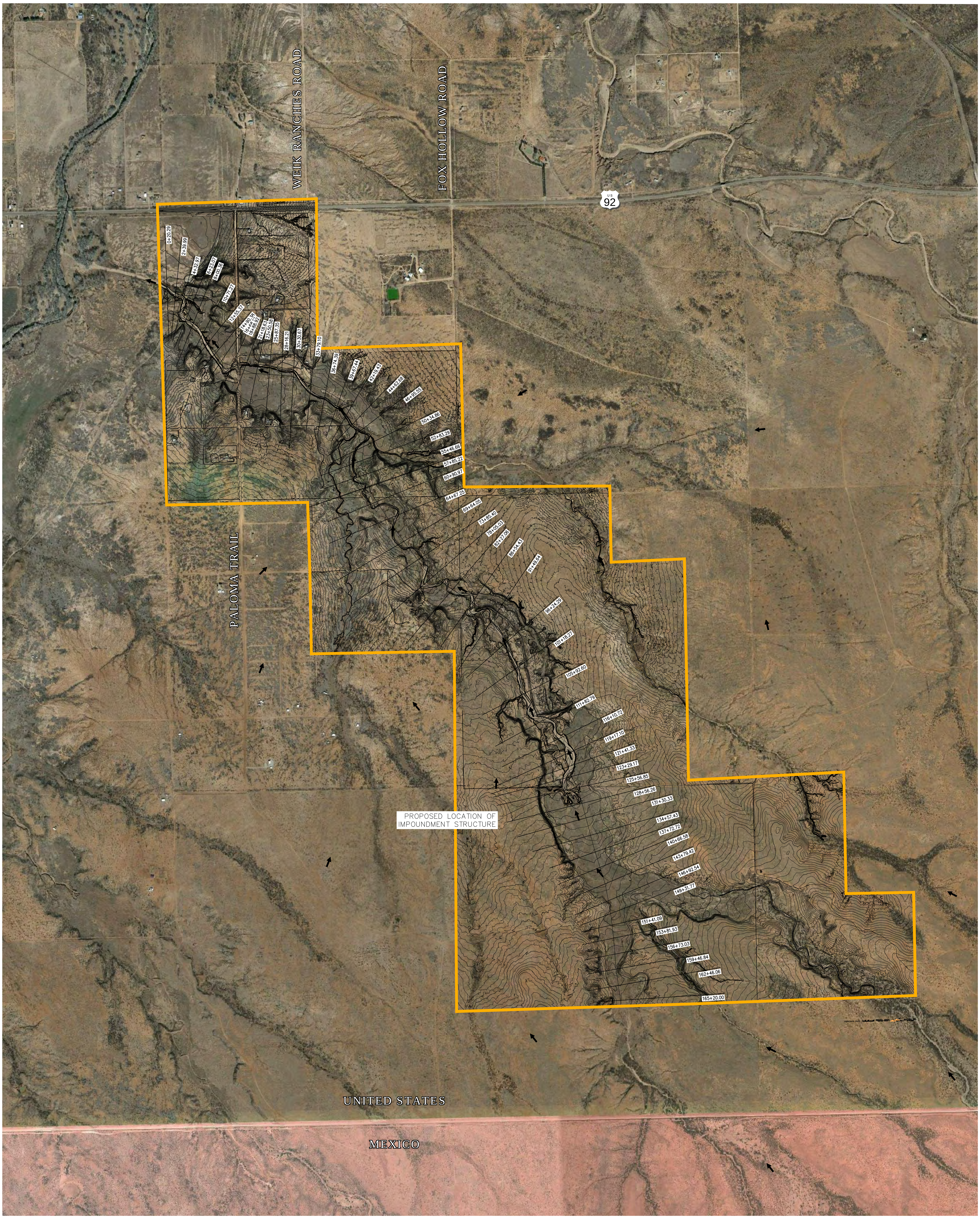
LEGEND

PROJECT LOCATION

N

PROJ.NO.:	1472	HORSESHOE DRAW	HILGARTWILSON
DATE:	NOV. 2015	COCHISE COUNTY, ARIZONA	2141 E. HIGHLAND AVE., STE. 250
SCALE:	1"=15,000'		PHOENIX, AZ 85016
DRAWN BY:	JPG	FIG 1: VICINITY MAP	P: 602.490.0535 / F: 602.368.2436
CHECKED BY:	AT		

U:\1400\1472\REPORTS\DRAINAGE\Exhibits\1472 FIG 1 – Vicinity Map 15-1002.dwg 11/17/2015 1:47 PM



LEGEND

PROJECT BOUNDARY

HEC-RAS CROSS SECTION

FLOW ARROW

N

800 400 0 800 1600

SCALE FEET

HILGARTWILSON

PROJ NO.:	1472
DATE:	NOV. 2015
SCALE:	1" = 800'
DRAWN:	JM
DESIGNED:	HW
APPROVED:	AT

HORSESHOE DRAW

COCHISE COUNTY, ARIZONA

FIG 2. EXISTING CONDITIONS SEDIMENT TRANSPORT EXHIBIT

SHT. OF

DWG. NO.

HILGARTWILSON
ENGINEER | PLAN | SURVEY | MANAGE

2141 E. HIGHLAND AVE., STE. 250
PHOENIX, AZ 85016
P: 602.490.0535 / F: 602.368.2436
www.hilgartwilson.com

REV.:

U:\1400\1472\REPORTS\DRAINAGE\Exhibits\1472 Sediment Transport.dwg 11/20/2015 10:15 AM